CHAPTER 6†: CRITICALITY EVALUATION

This chapter documents the criticality evaluation of the HI-STORM 100 System for the storage of spent nuclear fuel in accordance with 10CFR72.124. The results of this evaluation demonstrate that the HI-STORM 100 System is consistent with the Standard Review Plan for Dry Cask Storage Systems, NUREG-1536, and thus, fulfills the following acceptance criteria:

1. The multiplication factor (k_{eff}), including all biases and uncertainties at a 95-percent confidence level, should not exceed 0.95 under all credible normal, off-normal, and accident conditions.

2. At least two unlikely, independent, and concurrent or sequential changes to the conditions essential to criticality safety, under normal, off-normal, and accident conditions, should occur before an accidental criticality is deemed to be possible.

3. When practicable, criticality safety of the design should be established on the basis of favorable geometry, permanent fixed neutron-absorbing materials (poisons), or both.

4. Criticality safety of the cask system should not rely on use of the following credits:

    a. burnup of the fuel
    b. fuel-related burnable neutron absorbers
    c. more than 75 percent for fixed neutron absorbers when subject to standard acceptance test††.

In addition to demonstrating that the criticality safety acceptance criteria are satisfied, this chapter describes the HI-STORM 100 System design structures and components important to criticality safety and defines the limiting fuel characteristics in sufficient detail to identify the package accurately and provide a sufficient basis for the evaluation of the package. Analyses for the HI-STAR 100 System, which are applicable to the HI-STORM 100 System, have been previously submitted to the USNRC under Docket Numbers 72-1008 and 71-9261.

† This chapter has been prepared in the format and section organization set forth in Regulatory Guide 3.61. However, the material content of this chapter also fulfills the requirements of NUREG-1536. Pagination and numbering of sections, figures, and tables are consistent with the convention set down in *Chapter 1,* Section 1.0, herein. Finally, all terms-of-art used in this chapter are consistent with the terminology of the glossary (Table 1.0.1) and component nomenclature of the Bill-of-Materials (Section 1.5).

†† For greater credit allowance, fabrication tests capable of verifying the presence and uniformity of the neutron absorber are needed.

6.1 DISCUSSION AND RESULTS

In conformance with the principles established in NUREG-1536 [6.1.1], 10CFR72.124 [6.1.2], and NUREG-0800 Section 9.1.2 [6.1.3], the results in this chapter demonstrate that the effective multiplication factor (k_{eff}) of the HI-STORM 100 System, including all biases and uncertainties evaluated with a 95% probability at the 95% confidence level, does not exceed 0.95 under all credible normal, off-normal, and accident conditions. Moreover, these results demonstrate that the HI-STORM 100 System is designed and maintained such that at least two unlikely, independent, and concurrent or sequential changes must occur to the conditions essential to criticality safety before a nuclear criticality accident is possible. These criteria provide a large subcritical margin, sufficient to assure the criticality safety of the HI-STORM 100 System when fully loaded with fuel of the highest permissible reactivity.

Criticality safety of the HI-STORM 100 System depends on the following four principal design parameters:

1. The inherent geometry of the fuel basket designs within the MPC (and the flux-trap water gaps in the MPC-24, MPC-24E and MPC-24EF);

2. The incorporation of permanent fixed neutron-absorbing panels in the fuel basket structure;

3. An administrative limit on the maximum enrichment for PWR fuel and maximum planar-average enrichment for BWR fuel; and

4. An administrative limit on the minimum soluble boron concentration in the water for loading/unloading fuel with higher enrichments in the MPC-24, MPC-24E and MPC-24EF, and for loading/unloading fuel in the MPC-32 and MPC-32F.

The off-normal and accident conditions defined in Chapter 2 and considered in Chapter 11 have no adverse effect on the design parameters important to criticality safety, and thus, the off-normal and accident conditions are identical to those for normal conditions.

The HI-STORM 100 System is designed such that the fixed neutron absorber will remain effective for a storage period greater than 20 years, and there are no credible means to lose it. Therefore, in accordance with 10CFR72.124(b), there is no need to provide a surveillance or monitoring program to verify the continued efficacy of the neutron absorber.

Criticality safety of the HI-STORM 100 System does not rely on the use of any of the following credits:

- burnup of fuel

- fuel-related burnable neutron absorbers

- more than 75 percent of the B-10 content for the Boral fixed neutron absorber

- more than 90 percent of the B-10 content for the Metamic fixed neutron absorber, with comprehensive fabrication tests as described in Section 9.1.5.3.2.

The following four interchangeable basket designs are available for use in the HI-STORM 100 System:

- a 24-cell basket (MPC-24), designed for intact PWR fuel assemblies with a specified maximum enrichment and, for higher enrichments, a minimum soluble boron concentration in the pool water for loading/unloading operations,

- a 24-cell basket (MPC-24E) for intact and damaged PWR fuel assemblies. This is a variation of the MPC-24, with an optimized cell arrangement, increased ^{10}B content in the fixed neutron absorber and with four cells capable of accommodating either intact fuel or a damaged fuel container (DFC). Additionally, a variation in the MPC-24E, designated MPC-24EF, is designed for intact and damaged PWR fuel assemblies and PWR fuel debris. The MPC-24E and MPC-24EF are designed for fuel assemblies with a specified maximum enrichment and, for higher enrichments, a minimum soluble boron concentration in the pool water for loading/unloading operations,

- a 32-cell basket (MPC-32), designed for intact and damaged PWR fuel assemblies of a specified maximum enrichment and minimum soluble boron concentration for loading/unloading. Additionally, a variation in the MPC-32, designated MPC-32F, is designed for intact and damaged PWR fuel assemblies and PWR fuel debris. And

- a 68-cell basket (MPC-68), designed for both intact and damaged BWR fuel assemblies with a specified maximum planar-average enrichment. Additionally, variations in the MPC-68, designated MPC-68F and MPC-68FF, are designed for intact and damaged BWR fuel assemblies and BWR fuel debris with a specified maximum planar-average enrichment.

Two interchangeable neutron absorber materials are used in these baskets, Boral and Metamic. For Boral, 75 percent of the minimum B-10 content is credited in the criticality analysis, while for Metamic, 90 percent of the minimum B-10 content is credited, based on the neutron absorber tests specified in Section 9.1.5.3. However, the B-10 content in Metamic is chosen to be lower than the B-10 content in Boral, and is chosen so that the absolute B-10 content credited in the criticality analysis is the same for the two materials. This makes the two materials identical from a criticality perspective. This is confirmed by comparing results for a selected number of cases that were performed with both materials (see Section 6.4.11). Calculations in this chapter are therefore only performed for the Boral neutron absorber, with results directly applicable to Metamic.

The HI-STORM 100 System includes the HI-TRAC transfer cask and the HI-STORM storage cask. The HI-TRAC transfer cask is required for loading and unloading fuel into the MPC and for transfer of the MPC into the HI-STORM storage cask. HI-TRAC uses a lead shield for gamma radiation and a water-filled jacket for neutron shielding. The HI-STORM storage cask uses concrete as a shield for both gamma and neutron radiation. Both the HI-TRAC transfer cask and the HI-STORM storage cask, as well as the HI-STAR System†, accommodate the interchangeable MPC designs. The three cask designs (HI-STAR, HI-STORM, and HI-TRAC) differ only in the overpack reflector materials (steel for HI-STAR, concrete for HI-STORM, and lead for HI-TRAC), which do not significantly affect the reactivity. Consequently, analyses for the HI-STAR System are directly applicable to the HI-STORM 100 system and vice versa. Therefore, the majority of criticality calculations to support both the HI-STAR and the HI-STORM System have been performed for only one of the two systems, namely the HI-STAR System. Only a selected number of analyses has been performed for both systems to demonstrate that this approach is valid. Therefore, unless specifically noted otherwise, all analyses documented throughout this chapter have been performed for the HI-STAR System. For the cases where analyses were performed for both the HI-STORM and HI-STAR System, this is clearly indicated.

The HI-STORM 100 System for storage (concrete overpack) is dry (no moderator), and thus, the reactivity is very low (k_{eff} <0.52). However, the HI-STORM 100 System for cask transfer (HI-TRAC, lead overpack) is flooded for loading and unloading operations, and thus, represents the limiting case in terms of reactivity.

The MPC-24EF, MPC-32F and MPC-68FF contain the same basket as the MPC-24E, MPC-32 and MPC-68, respectively. More specifically, all dimensions relevant to the criticality analyses are identical between the MPC-24E and MPC-24EF, the MPC-32 and MPC-32F, and the MPC-68 and MPC-68FF. Therefore, all criticality results obtained for the MPC-24E, MPC-32 and MPC-68 are valid for the MPC-24EF, MPC-32F and MPC-68FF, respectively, and no separate analyses for the MPC-24EF, MPC-32F and MPC-68FF are necessary. Therefore, throughout this chapter and unless otherwise noted, 'MPC-68' refers to 'MPC-68 and/or MPC-68FF', 'MPC-

† Analyses for the HI-STAR System have previously been submitted to the USNRC under Docket Numbers 72-1008 and 71-9261.

24E' or 'MPC-24E/EF' refers to 'MPC-24E and/or MPC-24EF', and 'MPC-32' or 'MPC-32/32F' refers to 'MPC-32 and/or MPC-32F'.

Confirmation of the criticality safety of the HI-STORM 100 System was accomplished with the three-dimensional Monte Carlo code MCNP4a [6.1.4]. Independent confirmatory calculations were made with NITAWL-KENO5a from the SCALE-4.3 package [6.4.1]. KENO5a [6.1.5] calculations used the 238-group SCALE cross-section library in association with the NITAWL-II program [6.1.6], which adjusts the uranium-238 cross sections to compensate for resonance self-shielding effects. The Dancoff factors required by NITAWL-II were calculated with the CELLDAN code [6.1.13], which includes the SUPERDAN code [6.1.7] as a subroutine. K-factors for one-sided statistical tolerance limits with 95% probability at the 95% confidence level were obtained from the National Bureau of Standards (now NIST) Handbook 91 [6.1.8].

To assess the incremental reactivity effects due to manufacturing tolerances, CASMO-3, a two-dimensional transport theory code [6.1.9-6.1.12] for fuel assemblies, and MCNP4a [6.1.4] were used. The CASMO-3 and MCNP4a calculations identify those tolerances that cause a positive reactivity effect, enabling the subsequent Monte Carlo code input to define the worst case (most conservative) conditions. CASMO-3 was not used for quantitative information, but only to qualitatively indicate the direction and approximate magnitude of the reactivity effects of the manufacturing tolerances.

Benchmark calculations were made to compare the primary code packages (MCNP4a and KENO5a) with experimental data, using critical experiments selected to encompass, insofar as practical, the design parameters of the HI-STORM 100 System. The most important parameters are (1) the enrichment, (2) the water-gap size (MPC-24, MPC-24E and MPC-24EF) or cell spacing (MPC-32, MPC-32F, MPC-68, MPC-68F and MPC-68FF), (3) the ^{10}B loading of the neutron absorber panels, and (4) the soluble boron concentration in the water. The critical experiment benchmarking is presented in Appendix 6.A.

Applicable codes, standards, and regulations, or pertinent sections thereof, include the following:

- NUREG-1536, Standard Review Plan for Dry Cask Storage Systems, USNRC, Washington D.C., January 1997.

- 10CFR72.124, Criteria For Nuclear Criticality Safety.

- Code of Federal Regulations, Title 10, Part 50, Appendix A, General Design Criterion 62, Prevention of Criticality in Fuel Storage and Handling.

- USNRC Standard Review Plan, NUREG-0800, Section 9.1.2, Spent Fuel Storage, Rev. 3, July 1981.

To assure the true reactivity will always be less than the calculated reactivity, the following conservative design criteria and assumptions were made:

- The MPCs are assumed to contain the most reactive fresh fuel authorized to be loaded into a specific basket design.

- Consistent with NUREG-1536, no credit for fuel burnup is assumed, either in depleting the quantity of fissile nuclides or in producing fission product poisons.

- Consistent with NUREG-1536, the criticality analyses assume 75% of the manufacturer's minimum Boron-10 content for the Boral neutron absorber and 90% of the manufacturer's minimum Boron-10 content for the Metamic neutron absorber.

- The fuel stack density is conservatively assumed to be at least 96% of theoretical (10.522 g/cm^3) for all criticality analyses. Fuel stack density is approximately equal to 98% of the pellet density. Therefore, while the pellet density of some fuels may be slightly greater than 96% of theoretical, the actual stack density will be less.

- No credit is taken for the ^{234}U and ^{236}U in the fuel.

- When flooded, the moderator is assumed to be water, with or without soluble boron, at a temperature and density corresponding to the highest reactivity within the expected operating range.

- When credit is taken for soluble boron, a ^{10}B content of 18.0 wt% in boron is assumed.

- Neutron absorption in minor structural members and optional heat conduction elements is neglected, i.e., spacer grids, basket supports, and optional aluminum heat conduction elements are replaced by water.

- Consistent with NUREG-1536, the worst hypothetical combination of tolerances (most conservative values within the range of acceptable values), as identified in Section 6.3, is assumed.

- When flooded, the fuel rod pellet-to-clad gap regions are assumed to be flooded with pure unborated water.

- Planar-averaged enrichments are assumed for BWR fuel. (Consistent with NUREG-1536, analysis is presented in Appendix 6.B to demonstrate that the use of planar-average enrichments produces conservative results.)

- Consistent with NUREG-1536, fuel-related burnable neutron absorbers, such as the Gadolinia normally used in BWR fuel and IFBA normally used in PWR fuel, are neglected.

- For evaluation of the bias, all benchmark calculations that result in a k_{eff} greater than 1.0 are conservatively truncated to 1.0000, consistent with NUREG-1536.

- The water reflector above and below the fuel is assumed to be unborated water, even if borated water is used in the fuel region.

- For fuel assemblies that contain low-enriched axial blankets, the governing enrichment is that of the highest planar average, and the blankets are not included in determining the average enrichment.

- Regarding the position of assemblies in the basket, configurations with centered and eccentric positioning of assemblies in the fuel storage locations are considered. For further discussions see Section 6.3.3.

- For intact fuel assemblies, as defined in Table 1.0.1, missing fuel rods must be replaced with dummy rods that displace a volume of water that is equal to, or larger than, that displaced by the original rods.

Results of the design basis criticality safety calculations for single internally flooded HI-TRAC transfer casks with full water reflection on all sides (limiting cases for the HI-STORM 100 System), and for single unreflected, internally flooded HI-STAR casks (limiting cases for the HI-STAR 100 System), loaded with intact fuel assemblies are listed in Tables 6.1.1 through 6.1.8, conservatively evaluated for the worst combination of manufacturing tolerances (as identified in Section 6.3), and including the calculational bias, uncertainties, and calculational statistics. Comparing corresponding results for the HI-TRAC and HI-STAR demonstrates that the overpack material does not significantly affect the reactivity. Consequently, analyses for the HI-STAR System are directly applicable to the HI-STORM 100 System and vice versa. In addition, a few results for single internally dry (no moderator) HI-STORM storage casks with full water reflection on all external surfaces of the overpack, including the annulus region between the MPC and overpack, are listed to confirm the low reactivity of the HI-STORM 100 System in storage.

For each of the MPC designs, minimum soluble boron concentration (if applicable) and fuel assembly classes[††], Tables 6.1.1 through 6.1.8 list the bounding maximum k_{eff} value, and the associated maximum allowable enrichment. The maximum allowed enrichments and the minimum soluble boron concentrations are also listed in Section 2.1.9. The candidate fuel assemblies, that are bounded by those listed in Tables 6.1.1 through 6.1.8, are given in Section 6.2.

Results of the design basis criticality safety calculations for single unreflected, internally flooded casks (limiting cases) loaded with damaged fuel assemblies or a combination of intact and damaged fuel assemblies are listed in Tables 6.1.9 through 6.1.12. The results include the calculational bias, uncertainties, and calculational statistics. For each of the MPC designs qualified for damaged fuel and/or fuel debris (MPC-24E, MPC-24EF, MPC-68, MPC-68F, MPC-68FF, MPC-32 and MPC-32F), Tables 6.1.9 through 6.1.12 indicate the maximum number of DFCs and list the fuel assembly classes, the bounding maximum k_{eff} value, the associated maximum allowable enrichment, and if applicable the minimum soluble boron concentration. For the permissible location of DFCs see Subsection 6.4.4.2. The maximum allowed enrichments are also listed in Section 2.1.9.

A table listing the maximum k_{eff} (including bias, uncertainties, and calculational statistics), calculated k_{eff}, standard deviation, and energy of the average lethargy causing fission (EALF) for each of the candidate fuel assemblies and basket configurations is provided in Appendix 6.C. These results confirm that the maximum k_{eff} values for the HI-STORM 100 System are below the limiting design criteria ($k_{eff} < 0.95$) when fully flooded and loaded with any of the candidate fuel assemblies and basket configurations. Analyses for the various conditions of flooding that support the conclusion that the fully flooded condition corresponds to the highest reactivity, and thus is most limiting, are presented in Section 6.4. The capability of the HI-STORM 100 System to safely accommodate damaged fuel and fuel debris is demonstrated in Subsection 6.4.4.

Accident conditions have also been considered and no credible accident has been identified that would result in exceeding the design criteria limit on reactivity. After the MPC is loaded with spent fuel, it is seal-welded and cannot be internally flooded. The HI-STORM 100 System for storage is dry (no moderator) and the reactivity is very low. For arrays of HI-STORM storage casks, the radiation shielding and the physical separation between overpacks due to the large diameter and cask pitch preclude any significant neutronic coupling between the casks.

[††] For each array size (e.g., 6x6, 7x7, 14x14, etc.), the fuel assemblies have been subdivided into a number of assembly classes, where an assembly class is defined in terms of the (1) number of fuel rods; (2) pitch; (3) number and location of guide tubes (PWR) or water rods (BWR); and (4) cladding material. The assembly classes for BWR and PWR fuel are defined in Section 6.2.

Table 6.1.1

BOUNDING MAXIMUM k_{eff} VALUES FOR EACH ASSEMBLY CLASS IN THE MPC-24
(no soluble boron)

Fuel Assembly Class	Maximum Allowable Enrichment (wt% ^{235}U)	Maximum† k_{eff}		
		HI-STORM	HI-TRAC	HI-STAR
14x14A	4.6	0.3080	0.9283	0.9296
14x14B	4.6	---	0.9237	0.9228
14x14C	4.6	---	0.9274	0.9287
14x14D	4.0	---	0.8531	0.8507
14x14E	5.0‡	---	0.7627	0.7627
15x15A	4.1	---	0.9205	0.9204
15x15B	4.1	---	0.9387	0.9388
15x15C	4.1	---	0.9362	0.9361
15x15D	4.1	---	0.9354	0.9367
15x15E	4.1	---	0.9392	0.9368
15x15F	4.1	0.3648	0.9393††	0.9395†††
15x15G	4.0	---	0.8878	0.8876
15x15H	3.8	---	0.9333	0.9337
16x16A	4.6	0.3447	0.9273	0.9287
17x17A	4.0	0.3243	0.9378	0.9368
17x17B	4.0	---	0.9318	0.9324
17x17C	4.0	---	0.9319	0.9336

Note: The HI-STORM results are for internally dry (no moderator) HI-STORM storage casks with full water reflection on all sides, the HI-TRAC results are for internally fully flooded HI-TRAC transfer casks (which are part of the HI-STORM 100 System) with full water reflection on all sides, and the HI-STAR results are for unreflected, internally fully flooded HI-STAR casks.

† The term "maximum k_{eff} " as used here, and elsewhere in this document, means the highest possible k-effective, including bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

‡ For Assembly Class 14x14E, the maximum enrichment is limited to 4.5 wt% in Section 2.1.9.

†† KENO5a verification calculation resulted in a maximum k_{eff} of 0.9383.

††† KENO5a verification calculation resulted in a maximum k_{eff} of 0.9378.

Table 6.1.2

BOUNDING MAXIMUM k_{eff} VALUES FOR EACH ASSEMBLY CLASS IN THE MPC-24 WITH 400 PPM SOLUBLE BORON

Fuel Assembly Class	Maximum Allowable Enrichment (wt% ^{235}U)	Maximum† k_{eff}		
		HI-STORM	HI-TRAC	HI-STAR
14x14A	5.0	---	---	0.8884
14x14B	5.0	---	---	0.8900
14x14C	5.0	---	---	0.8950
14x14D	5.0	---	---	0.8518
14x14E	5.0‡	---	---	0.7132
15x15A	5.0	---	---	0.9119
15x15B	5.0	---	---	0.9284
15x15C	5.0	---	---	0.9236
15x15D	5.0	---	---	0.9261
15x15E	5.0	---	---	0.9265
15x15F	5.0	0.4013	0.9301	0.9314
15x15G	5.0	---	---	0.8939
15x15H	5.0	---	0.9345	0.9366
16x16A	5.0	---	---	0.8955
17x17A	5.0	---	---	0.9264
17x17B	5.0	---	---	0.9284
17x17C	5.0	---	0.9296	0.9294

Note: The HI-STORM results are for internally dry (no moderator) HI-STORM storage casks with full water reflection on all sides, the HI-TRAC results are for internally fully flooded HI-TRAC transfer casks (which are part of the HI-STORM 100 System) with full water reflection on all sides, and the HI-STAR results are for unreflected, internally fully flooded HI-STAR casks.

† The term "maximum k_{eff}" as used here, and elsewhere in this document, means the highest possible k-effective, including bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

‡ For Assembly Class 14x14E, the maximum enrichment is limited to 4.5 wt% in Section 2.1.9.

Table 6.1.3

BOUNDING MAXIMUM k_{eff} VALUES FOR EACH ASSEMBLY CLASS IN THE MPC-24E AND MPC-24EF (no soluble boron)

Fuel Assembly Class	Maximum Allowable Enrichment (wt% ^{235}U)	Maximum[†] k_{eff}		
		HI-STORM	HI-TRAC	HI-STAR
14x14A	5.0	---	---	0.9380
14x14B	5.0	---	---	0.9312
14x14C	5.0	---	---	0.9356
14x14D	5.0	---	---	0.8875
14x14E	5.0[‡]	---	---	0.7651
15x15A	4.5	---	---	0.9336
15x15B	4.5	---	---	0.9465
15x15C	4.5	---	---	0.9462
15x15D	4.5	---	---	0.9440
15x15E	4.5	---	---	0.9455
15x15F	4.5	0.3699	0.9465	0.9468
15x15G	4.5	---	---	0.9054
15x15H	4.2	---	---	0.9423
16x16A	5.0	---	---	0.9341
17x17A	4.4	---	0.9467	0.9447
17x17B	4.4	---	---	0.9421
17x17C	4.4	---	---	0.9433

Note: The HI-STORM results are for internally dry (no moderator) HI-STORM storage casks with full water reflection on all sides, the HI-TRAC results are for internally fully flooded HI-TRAC transfer casks (which are part of the HI-STORM 100 System) with full water reflection on all sides, and the HI-STAR results are for unreflected, internally fully flooded HI-STAR casks.

† The term "maximum k_{eff} " as used here, and elsewhere in this document, means the highest possible k-effective, including bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

‡ For Assembly Class 14x14E, the maximum enrichment is limited to 4.5 wt% in Section 2.1.9.

Table 6.1.4

BOUNDING MAXIMUM k_{eff} VALUES FOR EACH ASSEMBLY CLASS IN THE MPC-24E AND MPC-24EF WITH 300 PPM SOLUBLE BORON

Fuel Assembly Class	Maximum Allowable Enrichment (wt% ^{235}U)	Maximum† k_{eff}		
		HI-STORM	HI-TRAC	HI-STAR
14x14A	5.0	---	---	0.8963
14x14B	5.0	---	---	0.8974
14x14C	5.0	---	---	0.9031
14x14D	5.0	---	---	0.8588
14x14E	5.0‡	---	---	0.7249
15x15A	5.0	---	---	0.9161
15x15B	5.0	---	---	0.9321
15x15C	5.0	---	---	0.9271
15x15D	5.0	---	---	0.9290
15x15E	5.0	---	---	0.9309
15x15F	5.0	0.3897	0.9333	0.9332
15x15G	5.0	---	---	0.8972
15x15H	5.0	---	0.9399	0.9399
16x16A	5.0	---	---	0.9021
17x17A	5.0	---	0.9320	0.9332
17x17B	5.0	---	---	0.9316
17x17C	5.0	---	---	0.9312

Note: The HI-STORM results are for internally dry (no moderator) HI-STORM storage casks with full water reflection on all sides, the HI-TRAC results are for internally fully flooded HI-TRAC transfer casks (which are part of the HI-STORM 100 System) with full water reflection on all sides, and the HI-STAR results are for unreflected, internally fully flooded HI-STAR casks.

† The term "maximum k_{eff}" as used here, and elsewhere in this document, means the highest possible k-effective, including bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

‡ For Assembly Class 14x14E, the maximum enrichment is limited to 4.5 wt% in Section 2.1.9.

Table 6.1.5

BOUNDING MAXIMUM k_{eff} VALUES FOR EACH ASSEMBLY CLASS IN THE MPC-32 AND MPC-32F FOR 4.1% ENRICHMENT

Fuel Assembly Class	**Maximum Allowable Enrichment (wt% ^{235}U)**	**Minimum Soluble Boron Concentration (ppm)***	**Maximum† k_{eff}**		
			HI-STORM	**HI-TRAC**	**HI-STAR**
14x14A	4.1	1300	---	---	0.9041
14x14B	4.1	1300	---	---	0.9257
14x14C	4.1	1300	---	---	0.9423
14x14D	4.1	1300	---	---	0.8970
14x14E††	n/a	n/a	n/a	n/a	n/a
15x15A	4.1	1800	---	---	0.9206
15x15B	4.1	1800	---	---	0.9397
15x15C	4.1	1800	---	---	0.9266
15x15D	4.1	1900	---	---	0.9384
15x15E	4.1	1900	---	---	0.9365
15x15F	4.1	1900	0.4691	0.9403	0.9411
15x15G	4.1	1800	---	---	0.9147
15x15H	4.1	1900	---	---	0.9276
16x16A	4.1	1300	---	---	0.9468
17x17A	4.1	1900	---	---	0.9111
17x17B	4.1	1900	---	---	0.9309
17x17C	4.1	1900	---	0.9365	0.9355

Note: The HI-STORM results are for internally dry (no moderator) HI-STORM storage casks with full water reflection on all sides, the HI-TRAC results are for internally fully flooded HI-TRAC transfer casks (which are part of the HI-STORM 100 System) with full water reflection on all sides, and the HI-STAR results are for unreflected, internally fully flooded HI-STAR casks.

* For maximum allowable enrichments between 4.1 wt% ^{235}U and 5.0 wt% ^{235}U, the minimum soluble boron concentration may be calculated by linear interpolation between the minimum soluble boron concentrations specified in Table 6.1.5 and Table 6.1.6 for each assembly class.

† The term "maximum k_{eff}" as used here, and elsewhere in this document, means the highest possible k-effective, including bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

†† The 14x14E class in the MPC-32 is analyzed in Supplement 6.II

Table 6.1.6
BOUNDING MAXIMUM k_{eff} VALUES FOR EACH ASSEMBLY CLASS IN THE MPC-32 AND MPC-32F FOR 5.0% ENRICHMENT

Fuel Assembly Class	**Maximum Allowable Enrichment (wt% ^{235}U)**	**Minimum Soluble Boron Concentration (ppm)** *	**Maximum† k_{eff}**		
			HI-STORM	**HI-TRAC**	**HI-STAR**
14x14A	5.0	1900	---	---	0.9000
14x14B	5.0	1900	---	---	0.9214
14x14C	5.0	1900	---	---	0.9480
14x14D	5.0	1900	---	---	0.9050
14x14E††	n/a	n/a	n/a	n/a	n/a
15x15A	5.0	2500	---	---	0.9230
15x15B	5.0	2500	---	---	0.9429
15x15C	5.0	2500	---	---	0.9307
15x15D	5.0	2600	---	---	0.9466
15x15E	5.0	2600	---	---	0.9434
15x15F	5.0	2600	0.5142	0.9470	0.9483
15x15G	5.0	2500	---	---	0.9251
15x15H	5.0	2600	---	---	0.9333
16x16A	5.0	1900	---	---	0.9474
17x17A	5.0	2600	---	---	0.9161
17x17B	5.0	2600	---	---	0.9371
17x17C	5.0	2600	---	0.9436	0.9437

Note: The HI-STORM results are for internally dry (no moderator) HI-STORM storage casks with full water reflection on all sides, the HI-TRAC results are for internally fully flooded HI-TRAC transfer casks (which are part of the HI-STORM 100 System) with full water reflection on all sides, and the HI-STAR results are for unreflected, internally fully flooded HI-STAR casks.

* For maximum allowable enrichments between 4.1 wt% ^{235}U and 5.0 wt% ^{235}U, the minimum soluble boron concentration may be calculated by linear interpolation between the minimum soluble boron concentrations specified in Table 6.1.5 and Table 6.1.6 for each assembly class.

† The term "maximum k_{eff} " as used here, and elsewhere in this document, means the highest possible k-effective, including bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

†† The 14x14E class in the MPC-32 is analyzed in Supplement 6.II

Table 6.1.7

BOUNDING MAXIMUM k_{eff} VALUES FOR EACH ASSEMBLY CLASS IN THE MPC-68 AND MPC-68FF

Fuel Assembly Class	**Maximum Allowable Planar-Average Enrichment (wt% ^{235}U)**	**Maximum† k_{eff}**		
		HI-STORM	**HI-TRAC**	**HI-STAR**
6x6A	2.7††	---	0.7886	0.7888†††
6x6B‡	2.7††	---	0.7833	0.7824†††
6x6C	2.7††	0.2759	0.8024	0.8021†††
7x7A	2.7††	---	0.7963	0.7974†††
7x7B	4.2	0.4061	0.9385	0.9386
8x8A	2.7††	---	0.7690	0.7697†††
8x8B	4.2	0.3934	0.9427	0.9416
8x8C	4.2	0.3714	0.9429	0.9425
8x8D	4.2	---	0.9408	0.9403
8x8E	4.2	---	0.9309	0.9312
8x8F	4.0	---	0.9396	0.9411

Note: The HI-STORM results are for internally dry (no moderator) HI-STORM storage casks with full water reflection on all sides, the HI-TRAC results are for internally fully flooded HI-TRAC transfer casks (which are part of the HI-STORM 100 System) with full water reflection on all sides, and the HI-STAR results are for unreflected, internally fully flooded HI-STAR casks.

† The term "maximum k_{eff}" as used here, and elsewhere in this document, means the highest possible k-effective, including bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

†† This calculation was performed for 3.0% planar-average enrichment, however, the authorized contents are limited to a maximum planar-average enrichment of 2.7%. Therefore, the listed maximum k_{eff} value is conservative.

††† This calculation was performed for a ^{10}B loading of 0.0067 g/cm^2, which is 75% of a minimum ^{10}B loading of 0.0089 g/cm^2. The minimum ^{10}B loading in the MPC-68 is at least 0.0310 g/cm^2. Therefore, the listed maximum k_{eff} value is conservative.

‡ Assemblies in this class contain both MOX and UO_2 pins. The composition of the MOX fuel pins is given in Table 6.3.4. The maximum allowable planar-average enrichment for the MOX pins is given in the specification of authorized contents in Section 2.1.9.

Table 6.1.7 (continued)

BOUNDING MAXIMUM k_{eff} VALUES FOR EACH ASSEMBLY CLASS IN THE MPC-68 AND MPC-68FF

Fuel Assembly Class	**Maximum Allowable Planar-Average Enrichment (wt% ^{235}U)**	**Maximum† k_{eff}**		
		HI-STORM	**HI-TRAC**	**HI-STAR**
9x9A	4.2	0.3365	0.9434	0.9417
9x9B	4.2	---	0.9417	0.9436
9x9C	4.2	---	0.9377	0.9395
9x9D	4.2	---	0.9387	0.9394
9x9E	4.0		0.9402	0.9401
9x9F	4.0	---	0.9402	0.9401
9x9G	4.2	---	0.9307	0.9309
10x10A	4.2	0.3379	0.9448‡‡	0.9457*
10x10B	4.2	---	0.9443	0.9436
10x10C	4.2	---	0.9430	0.9433
10x10D	4.0	---	0.9383	0.9376
10x10E	4.0	---	0.9157	0.9185

Note: The HI-STORM results are for internally dry (no moderator) HI-STORM storage casks with full water reflection on all sides, the HI-TRAC results are for internally fully flooded HI-TRAC transfer casks (which are part of the HI-STORM 100 System) with full water reflection on all sides, and the HI-STAR results are for unreflected, internally fully flooded HI-STAR casks.

† The term "maximum k_{eff} " as used here, and elsewhere in this document, means the highest possible k-effective, including bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

‡‡ KENO5a verification calculation resulted in a maximum k_{eff} of 0.9451.

* KENO5a verification calculation resulted in a maximum k_{eff} of 0.9453.

Table 6.1.8

BOUNDING MAXIMUM k_{eff} VALUES FOR EACH ASSEMBLY CLASS IN THE MPC-68F

Fuel Assembly Class	Maximum Allowable Planar-Average Enrichment (wt% ^{235}U)	Maximum† k_{eff}		
		HI-STORM	HI-TRAC	HI-STAR
6x6A	2.7††	---	0.7886	0.7888
6x6B†††	2.7	---	0.7833	0.7824
6x6C	2.7	0.2759	0.8024	0.8021
7x7A	2.7	---	0.7963	0.7974
8x8A	2.7	---	0.7690	0.7697

Notes:

1. The HI-STORM results are for internally dry (no moderator) HI-STORM storage casks with full water reflection on all sides, the HI-TRAC results are for internally fully flooded HI-TRAC transfer casks (which are part of the HI-STORM 100 System) with full water reflection on all sides, and the HI-STAR results are for unreflected, internally fully flooded HI-STAR casks.

2. These calculations were performed for a ^{10}B loading of 0.0067 g/cm^2, which is 75% of a minimum ^{10}B loading of 0.0089 g/cm^2. The minimum ^{10}B loading in the MPC-68F is 0.010 g/cm^2. Therefore, the listed maximum k_{eff} values are conservative.

† The term "maximum k_{eff} " as used here, and elsewhere in this document, means the highest possible k-effective, including bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

†† These calculations were performed for 3.0% planar-average enrichment, however, the authorized contents are limited to a maximum planar-average enrichment of 2.7%. Therefore, the listed maximum k_{eff} values are conservative.

††† Assemblies in this class contain both MOX and UO_2 pins. The composition of the MOX fuel pins is given in Table 6.3.4. The maximum allowable planar-average enrichment for the MOX pins is specified in the specification of authorized contents in Section 2.1.9.

Table 6.1.9

BOUNDING MAXIMUM k_{eff} VALUES FOR THE MPC-24E AND MPC-24EF WITH UP TO 4 DFCs

Fuel Assembly Class	**Maximum Allowable Enrichment (wt% ^{235}U)**		**Minimum Soluble Boron Concentration (ppm)**	**Maximum k_{eff}**	
	Intact Fuel	**Damaged Fuel and Fuel Debris**		**HI-TRAC**	**HI-STAR**
All PWR Classes	4.0	4.0	0	0.9486	0.9480
All PWR Classes‡	5.0	5.0	600	0.9177	0.9185

Table 6.1.10

BOUNDING MAXIMUM k_{eff} VALUES FOR THE MPC-68, MPC-68F AND MPC-68FF WITH UP TO 68 DFCs

Fuel Assembly Class	**Maximum Allowable Planar-Average Enrichment (wt% ^{235}U)**		**Maximum k_{eff}**	
	Intact Fuel	**Damaged Fuel and Fuel Debris**	**HI-TRAC**	**HI-STAR**
6x6A, 6x6B, 6x6C, 7x7A, 8x8A	2.7	2.7	0.8024	0.8021

Table 6.1.11

BOUNDING MAXIMUM k_{eff} VALUES FOR THE MPC-68 AND MPC-68FF WITH UP TO 16 DFCs

Fuel Assembly Class	**Maximum Allowable Planar-Average Enrichment (wt% ^{235}U)**		**Maximum k_{eff}**	
	Intact Fuel	**Damaged Fuel and Fuel Debris**	**HI-TRAC**	**HI-STAR**
All BWR Classes	3.7	4.0	0.9328	0.9328

‡ For Assembly Class 14x14E, the maximum enrichment is limited to 4.5 wt% in Section 2.1.9.

Table 6.1.12

BOUNDING MAXIMUM k_{eff} VALUES FOR THE MPC-32 AND MPC-32F WITH UP TO 8 DFCs

Fuel Assembly Class of Intact Fuel	Maximum Allowable Enrichment for Intact Fuel and Damaged Fuel/Fuel Debris (wt% ^{235}U)	Minimum Soluble Boron Content (ppm) †	Maximum k_{eff}	
			HI-TRAC	HI-STAR
14x14A, B, C, D	4.1	1500	---	0.9336
	5.0	2300	---	0.9269
15x15A, B, C, G	4.1	1900	0.9349	0.9350
	5.0	2700	---	0.9365
15x15D, E, F, H	4.1	2100	---	0.9340
	5.0	2900	0.9382	0.9397
16x16A	4.1	1500	---	0.9335
	5.0	2300	---	0.9289
17x17A, B, C	4.1	2100	---	0.9294
	5.0	2900	---	0.9367

† For maximum allowable enrichments between 4.1 wt% ^{235}U and 5.0 wt% ^{235}U, the minimum soluble boron concentration may be calculated by linear interpolation between the minimum soluble boron concentrations specified for each assembly class.

6.2 SPENT FUEL LOADING

Specifications for the BWR and PWR fuel assemblies that were analyzed are given in Tables 6.2.1 and 6.2.2, respectively. For the BWR fuel characteristics, the number and dimensions for the water rods are the actual number and dimensions. For the PWR fuel characteristics, the actual number and dimensions of the control rod guide tubes and thimbles are used. Table 6.2.1 lists 72 unique BWR assemblies while Table 6.2.2 lists 46 unique PWR assemblies, all of which were explicitly analyzed for this evaluation. Examination of Tables 6.2.1 and 6.2.2 reveals that there are a large number of minor variations in fuel assembly dimensions.

Due to the large number of minor variations in the fuel assembly dimensions, the use of explicit dimensions in defining the authorized contents could limit the applicability of the HI-STORM 100 System. To resolve this limitation, bounding criticality analyses are presented in this section for a number of defined fuel assembly classes for both fuel types (PWR and BWR). The results of the bounding criticality analyses justify using bounding fuel dimensions for defining the authorized contents.

6.2.1 Definition of Assembly Classes

For each array size (e.g., 6x6, 7x7, 15x15, etc.), the fuel assemblies have been subdivided into a number of defined classes, where a class is defined in terms of (1) the number of fuel rods; (2) pitch; (3) number and locations of guide tubes (PWR) or water rods (BWR); and (4) cladding material. The assembly classes for BWR and PWR fuel are defined in Tables 6.2.1 and 6.2.2, respectively. It should be noted that these assembly classes are unique to this evaluation and are not known to be consistent with any class designations in the open literature.

For each assembly class, calculations have been performed for all of the dimensional variations for which data is available (i.e., all data in Tables 6.2.1 and 6.2.2). These calculations demonstrate that the maximum reactivity corresponds to:

- maximum active fuel length,
- maximum fuel pellet diameter,
- minimum cladding outside diameter (OD),
- maximum cladding inside diameter (ID),
- minimum guide tube/water rod thickness, and
- maximum channel thickness (for BWR assemblies only).

Therefore, for each assembly class, a bounding assembly was defined based on the above characteristics and a calculation for the bounding assembly was performed to demonstrate compliance with the regulatory requirement of $k_{eff} < 0.95$. In some assembly classes this bounding assembly corresponds directly to one of the actual (real) assemblies; while in most assembly classes, the bounding assembly is artificial (i.e., based on bounding dimensions from more than one of the actual assemblies). In classes where the bounding assembly is artificial, the reactivity of the actual (real) assemblies is typically much less than that of the bounding assembly; thereby providing additional conservatism. As a result of these analyses, the authorized contents in Section 2.1.9 are defined in terms of the bounding assembly parameters for each class.

To demonstrate that the aforementioned characteristics are bounding, a parametric study was performed for a reference BWR assembly, designated herein as 8x8C04 (identified generally as a GE8x8R). Additionally, parametric studies were performed for a PWR assembly (the 15x15F assembly class) in the MPC-24 and MPC-32 with soluble boron in the water flooding the MPC. The results of these studies are shown in Table 6.2.3 through 6.2.5, and verify the positive reactivity effect associated with (1) increasing the pellet diameter, (2) maximizing the cladding ID (while maintaining a constant cladding OD), (3) minimizing the cladding OD (while maintaining a constant cladding ID), (4) decreasing the water rod/guide tube thickness, (5) artificially replacing the Zircaloy water rod tubes/guide tubes with water, (6) maximizing the channel thickness (for BWR Assemblies), and (7) increasing the active length. These results, and the many that follow, justify the approach for using bounding dimensions for defining the authorized contents. Where margins permit, the Zircaloy water rod tubes (BWR assemblies) are artificially replaced by water in the bounding cases to remove the requirement for water rod thickness from the specification of the authorized contents. As these studies were performed with and without soluble boron, they also demonstrate that the bounding dimensions are valid independent of the soluble boron concentration.

As mentioned, the bounding approach used in these analyses often results in a maximum k_{eff} value for a given class of assemblies that is much greater than the reactivity of any of the actual (real) assemblies within the class, and yet, is still below the 0.95 regulatory limit.

6.2.2 Intact PWR Fuel Assemblies

6.2.2.1 Intact PWR Fuel Assemblies in the MPC-24 without Soluble Boron

For PWR fuel assemblies (specifications listed in Table 6.2.2) the 15x15F01 fuel assembly at 4.1% enrichment has the highest reactivity (maximum k_{eff} of 0.9395). The 17x17A01 assembly (otherwise known as a Westinghouse 17x17 OFA) has a similar reactivity (see Table 6.2.20) and was used throughout this criticality evaluation as a reference PWR assembly. The 17x17A01 assembly is a representative PWR fuel assembly in terms of design and reactivity and is useful for the reactivity studies presented in Sections 6.3 and 6.4. Calculations for the various PWR fuel assemblies in the MPC-24 are summarized in Tables 6.2.6 through 6.2.22 for the fully flooded condition without soluble boron in the water.

Tables 6.2.6 through 6.2.22 show the maximum k_{eff} values for the assembly classes that are acceptable for storage in the MPC-24. All maximum k_{eff} values include the bias, uncertainties, and calculational statistics, evaluated for the worst combination of manufacturing tolerances. All calculations for the MPC-24 were performed for a ^{10}B loading of 0.020 g/cm^2, which is 75% of the minimum loadingof 0.0267 g/cm^2 for Boral, or 90% of the minimum loading of 0.0223 g/cm^2 for Metamic. The maximum allowable enrichment in the MPC-24 varies from 3.8 to 5.0 wt% ^{235}U, depending on the assembly class, and is defined in Tables 6.2.6 through 6.2.22. It should be noted that the maximum allowable enrichment does not vary within an assembly class. Table 6.1.1 summarizes the maximum allowable enrichments for each of the assembly classes that are acceptable for storage in the MPC-24.

Tables 6.2.6 through 6.2.22 are formatted with the assembly class information in the top row, the unique assembly designations, dimensions, and k_{eff} values in the following rows above the bold double lines, and the bounding dimensions selected to define the authorized contents and corresponding bounding k_{eff} values in the final rows. Where the bounding assembly corresponds directly to one of the actual assemblies, the fuel assembly designation is listed in the bottom row in parentheses (e.g., Table 6.2.6). Otherwise, the bounding assembly is given a unique designation. For an assembly class that contains only a single assembly (e.g., 14x14D, see Table 6.2.9), the authorized contents dimensions are based on the assembly dimensions from that single assembly. All of the maximum k_{eff} values corresponding to the selected bounding dimensions are greater than or equal to those for the actual assembly dimensions and are below the 0.95 regulatory limit.

The results of the analyses for the MPC-24, which were performed for all assemblies in each class (see Tables 6.2.6 through 6.2.22), further confirm the validity of the bounding dimensions established in Section 6.2.1. Thus, for all following calculations, namely analyses of the MPC-24E, MPC-32, and MPC-24 with soluble boron present in the water, only the bounding assembly in each class is analyzed.

6.2.2.2 Intact PWR Fuel Assemblies in the MPC-24 with Soluble Boron

Additionally, the HI-STAR 100 system is designed to allow credit for the soluble boron typically present in the water of PWR spent fuel pools. For a minimum soluble boron concentration of 400ppm, the maximum allowable fuel enrichment is 5.0 wt% ^{235}U for all assembly classes identified in Tables 6.2.6 through 6.2.22. Table 6.1.2 shows the maximum k_{eff} for the bounding assembly in each assembly class. All maximum k_{eff} values are below the 0.95 regulatory limit. The 15x15H assembly class has the highest reactivity (maximum k_{eff} of 0.9366). The calculated k_{eff} and calculational uncertainty for each class is listed in Appendix 6.C.

6.2.2.3 Intact PWR Assemblies in the MPC-24E and MPC-24EF with and without Soluble Boron

The MPC-24E and MPC-24EF are variations of the MPC-24, which provide for storage of higher enriched fuel than the MPC-24 through optimization of the storage cell layout. The MPC-24E and MPC-24EF also allow for the loading of up to 4 PWR Damaged Fuel Containers (DFC) with damaged PWR fuel (MPC-24E and MPC–24EF) and PWR fuel debris (MPC-24EF only). The requirements for damaged fuel and fuel debris in the MPC-24E and MPC-24EF are discussed in Section 6.2.4.3.

Without credit for soluble boron, the maximum allowable fuel enrichment varies between 4.2 and 5.0 wt% ^{235}U, depending on the assembly classes as identified in Tables 6.2.6 through 6.2.22. The maximum allowable enrichment for each assembly class is listed in Table 6.1.3, together with the maximum k_{eff} for the bounding assembly in the assembly class. All maximum k_{eff} values are below the 0.95 regulatory limit The 15x15F assembly class at 4.5% enrichment has the highest reactivity (maximum k_{eff} of 0.9468). The calculated k_{eff} and calculational uncertainty for each class is listed in Appendix 6.C.

For a minimum soluble boron concentration of 300ppm, the maximum allowable fuel enrichment is 5.0 wt% ^{235}U for all assembly classes identified in Tables 6.2.6 through 6.2.22. Table 6.1.4 shows the maximum k_{eff} for the bounding assembly in each assembly class. All maximum k_{eff} values are below the 0.95 regulatory limit. The 15x15H assembly class has the highest reactivity (maximum k_{eff} of 0.9399). The calculated k_{eff} and calculational uncertainty for each class is listed in Appendix 6.C.

6.2.2.4 Intact PWR Assemblies in the MPC-32 and MPC-32F

When loading any PWR fuel assembly in the MPC-32 or MPC-32F, a minimum soluble boron concentration is required.

For a maximum allowable fuel enrichment of 4.1 wt% ^{235}U for all assembly classes identified in Tables 6.2.6 through 6.2.22, a minimum soluble boron concentration between 1300ppm and 1900ppm is required, depending on the assembly class. Table 6.1.5 shows the maximum k_{eff} for the bounding assembly in each assembly class. All maximum k_{eff} values are below the 0.95 regulatory limit. The 16x16A assembly class has the highest reactivity (maximum k_{eff} of 0.9468). The calculated k_{eff} and calculational uncertainty for each class is listed in Appendix 6.C.

For a maximum allowable fuel enrichment of 5.0 wt% ^{235}U for all assembly classes identified in Tables 6.2.6 through 6.2.22, a minimum soluble boron concentration between 1900ppm and 2600ppm is required, depending on the assembly class. Table 6.1.6 shows the maximum k_{eff} for the bounding assembly in each assembly class. All maximum k_{eff} values are below the 0.95

regulatory limit. The 15x15F assembly class has the highest reactivity (maximum k_{eff} of 0.9483). The calculated k_{eff} and calculational uncertainty for each class is listed in Appendix 6.C.

It is desirable to limit the soluble boron concentration to a level appropriate for the maximum enrichment in a basket, since this prevents adding soluble boron unnecessarily to the spent fuel pool during loading and unloading operations. This approach requires a minimum soluble boron level as a function of the maximum allowable enrichment, which can be directly derived by linear interpolation from the calculations at 4.1 wt% ^{235}U and 5.0 wt% ^{235}U shown in Tables 6.1.5 and 6.1.6. Since the maximum k_{eff} is a near linear function of both enrichment and soluble boron concentration, linear interpolation is both appropriate and sufficient. Further, studies have shown that this approach results in maximum k_{eff} values for enrichments between 4.1 wt% ^{235}U and 5.0 wt% ^{235}U that are lower than those maximum k_{eff} values calculated at 4.1 wt% and 5.0 wt% ^{235}U in Tables 6.1.5 and 6.1.6.

6.2.3 Intact BWR Fuel Assemblies in the MPC-68 and MPC-68FF

For BWR fuel assemblies (specifications listed in Table 6.2.1) the artificial bounding assembly for the 10x10A assembly class at 4.2% enrichment has the highest reactivity (maximum k_{eff} of 0.9457). Calculations for the various BWR fuel assemblies in the MPC-68 and MPC-68FF are summarized in Tables 6.2.23 through 6.2.40 for the fully flooded condition. In all cases, the gadolinia (Gd_2O_3) normally incorporated in BWR fuel was conservatively neglected.

For calculations involving BWR assemblies, the use of a uniform (planar-average) enrichment, as opposed to the distributed enrichments normally used in BWR fuel, produces conservative results. Calculations confirming this statement are presented in Appendix 6.B for several representative BWR fuel assembly designs. These calculations justify the specification of planar-average enrichments to define acceptability of BWR fuel for loading into the MPC-68.

Tables 6.2.23 through 6.2.40 show the maximum k_{eff} values for assembly classes that are acceptable for storage in the MPC-68 and MPC-68FF. All maximum k_{eff} values include the bias, uncertainties, and calculational statistics, evaluated for the worst combination of manufacturing tolerances. With the exception of assembly classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A, which will be discussed in Section 6.2.4, all calculations for the MPC-68 and MPC-68FF were performed with a ^{10}B loading of 0.0279 g/cm^2, which is 75% of the minimum loading of 0.0372 g/cm^2 for Boral, or 90% of the minimum loading of 0.031 g/cm^2 for Metamic. Calculations for assembly classes 6x6A, 6x6B, 6x6C, 7x7A, and 8x8A were conservatively performed with a ^{10}B loading of 0.0067 g/cm^2. The maximum allowable enrichment in the MPC-68 and MPC-68FF varies from 2.7 to 4.2 wt% ^{235}U, depending on the assembly class. It should be noted that the maximum allowable enrichment does not vary within an assembly class. Table 6.1.7 summarizes the maximum allowable enrichments for all assembly classes that are acceptable for storage in the MPC-68 and MPC-68FF.

Tables 6.2.23 through 6.2.40 are formatted with the assembly class information in the top row, the unique assembly designations, dimensions, and k_{eff} values in the following rows above the bold double lines, and the bounding dimensions selected to define the authorized contents and corresponding bounding k_{eff} values in the final rows. Where an assembly class contains only a single assembly (e.g., 8x8E, see Table 6.2.27), the authorized contents dimensions are based on the assembly dimensions from that single assembly. For assembly classes that are suspected to contain assemblies with thicker channels (e.g., 120 mils), bounding calculations are also performed to qualify the thicker channels (e.g. 7x7B, see Table 6.2.23). All of the maximum k_{eff} values corresponding to the selected bounding dimensions are shown to be greater than or equal to those for the actual assembly dimensions and are below the 0.95 regulatory limit.

For assembly classes that contain partial length rods (i.e., 9x9A, 10x10A, and 10x10B), calculations were performed for the actual (real) assembly configuration and for the axial segments (assumed to be full length) with and without the partial length rods. In all cases, the axial segment with only the full length rods present (where the partial length rods are absent) is bounding. Therefore, the bounding maximum k_{eff} values reported for assembly classes that contain partial length rods bound the reactivity regardless of the active fuel length of the partial length rods. As a result, the specification of the authorized contents has no minimum requirement for the active fuel length of the partial length rods.

For BWR fuel assembly classes where margins permit, the Zircaloy water rod tubes are artificially replaced by water in the bounding cases to remove the requirement for water rod thickness from the specification of the authorized contents. For these cases, the bounding water rod thickness is listed as zero.

As mentioned, the highest observed maximum k_{eff} value is 0.9457, corresponding to the artificial bounding assembly in the 10x10A assembly class. This assembly has the following bounding characteristics: (1) the partial length rods are assumed to be zero length (most reactive configuration); (2) the channel is assumed to be 120 mils thick; and (3) the active fuel length of the full length rods is 155 inches. Therefore, the maximum reactivity value is bounding compared to any of the real BWR assemblies listed.

6.2.4 BWR and PWR Damaged Fuel Assemblies and Fuel Debris

In addition to storing intact PWR and BWR fuel assemblies, the HI-STORM 100 System is designed to store BWR and PWR damaged fuel assemblies and fuel debris. Damaged fuel assemblies and fuel debris are defined in Table 1.0.1. Both damaged fuel assemblies and fuel debris are required to be loaded into Damaged Fuel Containers (DFCs) prior to being loaded into the MPC. Five different DFC types with different cross sections are considered; three types for BWR fuel and two for PWR fuel. DFCs containing fuel debris must be stored in the MPC-68F, MPC-68FF, MPC-24EF or MPC-32F. DFCs containing BWR damaged fuel assemblies may be stored in the MPC-68, MPC-68F or MPC-68FF. DFCs containing PWR damaged fuel may be stored in the MPC-24E, MPC-24EF, MPC-32 or MPC-32F. The criticality evaluation of various possible damaged conditions of the fuel is presented in Subsection 6.4.4.

6.2.4.1 Damaged BWR Fuel Assemblies and BWR Fuel Debris in Assembly Classes 6x6A, 6x6B, 6x6C, 7x7A and 8x8A

Tables 6.2.41 through 6.2.45 show the maximum k_{eff} values for the five assembly classes 6x6A, 6x6B, 6x6C, 7x7A and 8x8A. All maximum k_{eff} values include the bias, uncertainties, and calculational statistics, evaluated for the worst combination of manufacturing tolerances. All calculations were performed for a ^{10}B loading of 0.0067 g/cm^2, which is 75% of a minimum loading, 0.0089 g/cm^2. However, because the practical manufacturing lower limit for minimum ^{10}B loading is 0.01 g/cm^2, the minimum ^{10}B loading of 0.01 g/cm^2 is specified on the drawing in Section 1.5, for the MPC-68F. As an additional level of conservatism in the analyses, the calculations were performed for an enrichment of 3.0 wt% ^{235}U, while the maximum allowable enrichment for these assembly classes is limited to 2.7 wt% ^{235}U in the specification of the authorized contents. Therefore, the maximum k_{eff} values for damaged BWR fuel assemblies and fuel debris are conservative. Calculations for the various BWR fuel assemblies in the MPC-68F are summarized in Tables 6.2.41 through 6.2.45 for the fully flooded condition.

For the assemblies that may be stored as damaged fuel or fuel debris, the 6x6C01 assembly at 3.0 wt% ^{235}U enrichment has the highest reactivity (maximum k_{eff} of 0.8021). Considering all of the conservatism built into this analysis (e.g., higher than allowed enrichment and lower than actual ^{10}B loading), the actual reactivity will be lower.

Because the analysis for the damaged BWR fuel assemblies and fuel debris was performed for a ^{10}B loading of 0.0089 g/cm^2, which conservatively bounds the analysis of damaged BWR fuel assemblies in an MPC-68 or MPC-68FF with a minimum ^{10}B loading of 0.0372 g/cm^2, damaged BWR fuel assemblies may also be stored in the MPC-68 or MPC-68FF. However, fuel debris is limited to the MPC-68F and MPC-68FF by the specification of the authorized contents.

Tables 6.2.41 through 6.2.45 are formatted with the assembly class information in the top row, the unique assembly designations, dimensions, and k_{eff} values in the following rows above the bold double lines, and the bounding dimensions selected to define the authorized contents and corresponding bounding k_{eff} values in the final rows. Where an assembly class contains only a single assembly (e.g., 6x6C, see Table 6.2.43), the authorized contents dimensions are based on the assembly dimensions from that single assembly. All of the maximum k_{eff} values corresponding to the selected bounding dimensions are greater than or equal to those for the actual assembly dimensions and are well below the 0.95 regulatory limit.

6.2.4.2 Damaged BWR Fuel Assemblies and Fuel Debris in the MPC-68 and MPC-68FF

Damaged BWR fuel assemblies and fuel debris from all BWR classes may be loaded into the MPC-68 and MPC-68FF by restricting the locations of the DFCs to 16 specific cells on the periphery of the fuel basket. The MPC-68 may be loaded with up to 16 DFCs containing damaged fuel assemblies. The MPC-68FF may also be loaded with up to 16 DFCs, with up to 8 DFCs containing fuel debris.

For all assembly classes, the enrichment of the damaged fuel or fuel debris is limited to a maximum of 4.0 wt% ^{235}U, while the enrichment of the intact assemblies stored together with the damaged fuel is limited to a maximum of 3.7 wt% ^{235}U. The maximum k_{eff} is 0.9328. The criticality evaluation of the damaged fuel assemblies and fuel debris in the MPC-68 and MPC-68FF is presented in Section 6.4.4.2.

6.2.4.3 Damaged PWR Fuel Assemblies and Fuel Debris

In addition to storing intact PWR fuel assemblies, the HI-STORM 100 System is designed to store damaged PWR fuel assemblies (MPC-24E, MPC-24EF, MPC-32 and MPC-32F) and fuel debris (MPC-24EF and MPC-32F only). Damaged fuel assemblies and fuel debris are defined in Table 1.0.1. Damaged PWR fuel assemblies and fuel debris are required to be loaded into PWR Damaged Fuel Containers (DFCs).

6.2.4.3.1 Damaged PWR Fuel Assemblies and Fuel Debris in the MPC-24E and MPC-24EF

Up to four DFCs may be stored in the MPC-24E or MPC-24EF. When loaded with damaged fuel and/or fuel debris, the maximum enrichment for intact and damaged fuel is 4.0 wt% ^{235}U for all assembly classes listed in Table 6.2.6 through 6.2.22 without credit for soluble boron. The maximum k_{eff} for these classes is 0.9486. For a minimum soluble boron concentration of 600ppm, the maximum enrichment for intact and damaged fuel is 5.0 wt% ^{235}U for all assembly classes listed in Table 6.2.6 through 6.2.22. The criticality evaluation of the damaged fuel is presented in Subsection 6.4.4.2.

6.2.4.3.2 Damaged PWR Fuel Assemblies and Fuel Debris in the MPC-32 and MPC-32F

Up to eight DFCs may be stored in the MPC-32 or MPC-32F. For a maximum allowable fuel enrichment of 4.1 wt% ^{235}U for intact fuel, damaged fuel and fuel debris for all assembly classes identified in Tables 6.2.6 through 6.2.22, a minimum soluble boron concentration between 1500ppm and 2100ppm is required, depending on the assembly class of the intact assembly. For a maximum allowable fuel enrichment of 5.0 wt% ^{235}U for intact fuel, damaged fuel and fuel debris, a minimum soluble boron concentration between 2300ppm and 2900ppm is required, depending on the assembly class of the intact assembly. Table 6.1.12 shows the maximum k_{eff} by assembly class. All maximum k_{eff} values are below the 0.95 regulatory limit.

As discussed in Section 6.2.2.4, it is desirable to limit the soluble boron concentration to a level appropriate for the maximum enrichment in a basket. The discussion presented in Section 6.2.2.4 is also applicable for the MPC-32 with damaged fuel or fuel debris. Further, studies with damaged fuel have shown that this approach also results in maximum k_{eff} values that are lower than those k_{eff} values calculated for 4.1 wt% and 5.0 wt% ^{235}U in Table 6.1.12.

6.2.5 Thoria Rod Canister

Additionally, the HI-STORM 100 System is designed to store a Thoria Rod Canister in the MPC-68, MPC-68F or MPC-68FF. The canister is similar to a DFC and contains 18 intact Thoria Rods placed in a separator assembly. The reactivity of the canister in the MPC is very low compared to the approved fuel assemblies (The ^{235}U content of these rods correspond to UO_2 rods with an initial enrichment of approximately 1.7 wt% ^{235}U). It is therefore permissible to the Thoria Rod Canister together with any approved content in a MPC-68 or MPC-68F. Specifications of the canister and the Thoria Rods that are used in the criticality evaluation are given in Table 6.2.46. The criticality evaluation are presented in Subsection 6.4.6.

Table 6.2.1 (page 1 of 7)
BWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Water Rods	Water Rod OD	Water Rod ID	Channel Thickness	Channel ID
6x6A Assembly Class												
6x6A01	Zr	0.694	36	0.5645	0.0350	0.4940	110.0	0	n/a	n/a	0.060	4.290
6x6A02	Zr	0.694	36	0.5645	0.0360	0.4820	110.0	0	n/a	n/a	0.060	4.290
6x6A03	Zr	0.694	36	0.5645	0.0350	0.4820	110.0	0	n/a	n/a	0.060	4.290
6x6A04	Zr	0.694	36	0.5550	0.0350	0.4820	110.0	0	n/a	n/a	0.060	4.290
6x6A05	Zr	0.696	36	0.5625	0.0350	0.4820	110.0	0	n/a	n/a	0.060	4.290
6x6A06	Zr	0.696	35	0.5625	0.0350	0.4820	110.0	1	0.0	0.0	0.060	4.290
6x6A07	Zr	0.700	36	0.5555	0.03525	0.4780	110.0	0	n/a	n/a	0.060	4.290
6x6A08	Zr	0.710	36	0.5625	0.0260	0.4980	110.0	0	n/a	n/a	0.060	4.290
6x6B (MOX) Assembly Class												
6x6B01	Zr	0.694	36	0.5645	0.0350	0.4820	110.0	0	n/a	n/a	0.060	4.290
6x6B02	Zr	0.694	36	0.5625	0.0350	0.4820	110.0	0	n/a	n/a	0.060	4.290
6x6B03	Zr	0.696	36	0.5625	0.0350	0.4820	110.0	0	n/a	n/a	0.060	4.290
6x6B04	Zr	0.696	35	0.5625	0.0350	0.4820	110.0	1	0.0	0.0	0.060	4.290
6x6B05	Zr	0.710	35	0.5625	0.0350	0.4820	110.0	1	0.0	0.0	0.060	4.290
6x6C Assembly Class												
6x6C01	Zr	0.740	36	0.5630	0.0320	0.4880	77.5	0	n/a	n/a	0.060	4.542
7x7A Assembly Class												
7x7A01	Zr	0.631	49	0.4860	0.0328	0.4110	80	0	n/a	n/a	0.060	4.542

Table 6.2.1 (page 2 of 7)
BWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Water Rods	Water Rod OD	Water Rod ID	Channel Thickness	Channel ID
7x7B Assembly Class												
7x7B01	Zr	0.738	49	0.5630	0.0320	0.4870	150	0	n/a	n/a	0.080	5.278
7x7B02	Zr	0.738	49	0.5630	0.0370	0.4770	150	0	n/a	n/a	0.102	5.291
7x7B03	Zr	0.738	49	0.5630	0.0370	0.4770	150	0	n/a	n/a	0.080	5.278
7x7B04	Zr	0.738	49	0.5700	0.0355	0.4880	150	0	n/a	n/a	0.080	5.278
7x7B05	Zr	0.738	49	0.5630	0.0340	0.4775	150	0	n/a	n/a	0.080	5.278
7x7B06	Zr	0.738	49	0.5700	0.0355	0.4910	150	0	n/a	n/a	0.080	5.278
8x8A Assembly Class												
8x8A01	Zr	0.523	64	0.4120	0.0250	0.3580	110	0	n/a	n/a	0.100	4.290
8x8A02	Zr	0.523	63	0.4120	0.0250	0.3580	120	0	n/a	n/a	0.100	4.290

Table 6.2.1 (page 3 of 7)
BWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Water Rods	Water Rod OD	Water Rod ID	Channel Thickness	Channel ID
8x8B Assembly Class												
8x8B01	Zr	0.641	63	0.4840	0.0350	0.4050	150	1	0.484	0.414	0.100	5.278
8x8B02	Zr	0.636	63	0.4840	0.0350	0.4050	150	1	0.484	0.414	0.100	5.278
8x8B03	Zr	0.640	63	0.4930	0.0340	0.4160	150	1	0.493	0.425	0.100	5.278
8x8B04	Zr	0.642	64	0.5015	0.0360	0.4195	150	0	n/a	n/a	0.100	5.278
8x8C Assembly Class												
8x8C01	Zr	0.641	62	0.4840	0.0350	0.4050	150	2	0.484	0.414	0.100	5.278
8x8C02	Zr	0.640	62	0.4830	0.0320	0.4100	150	2	0.591	0.531	0.000	no channel
8x8C03	Zr	0.640	62	0.4830	0.0320	0.4100	150	2	0.591	0.531	0.080	5.278
8x8C04	Zr	0.640	62	0.4830	0.0320	0.4100	150	2	0.591	0.531	0.100	5.278
8x8C05	Zr	0.640	62	0.4830	0.0320	0.4100	150	2	0.591	0.531	0.120	5.278
8x8C06	Zr	0.640	62	0.4830	0.0320	0.4110	150	2	0.591	0.531	0.100	5.278
8x8C07	Zr	0.640	62	0.4830	0.0340	0.4100	150	2	0.591	0.531	0.100	5.278
8x8C08	Zr	0.640	62	0.4830	0.0320	0.4100	150	2	0.493	0.425	0.100	5.278
8x8C09	Zr	0.640	62	0.4930	0.0340	0.4160	150	2	0.493	0.425	0.100	5.278
8x8C10	Zr	0.640	62	0.4830	0.0340	0.4100	150	2	0.591	0.531	0.120	5.278
8x8C11	Zr	0.640	62	0.4830	0.0340	0.4100	150	2	0.591	0.531	0.120	5.215
8x8C12	Zr	0.636	62	0.4830	0.0320	0.4110	150	2	0.591	0.531	0.120	5.215

Table 6.2.1 (page 4 of 7)
BWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Water Rods	Water Rod OD	Water Rod ID	Channel Thickness	Channel ID
8x8D Assembly Class												
8x8D01	Zr	0.640	60	0.4830	0.0320	0.4110	150	2 large/ 2 small	0.591/ 0.483	0.531/ 0.433	0.100	5.278
8x8D02	Zr	0.640	60	0.4830	0.0320	0.4110	150	4	0.591	0.531	0.100	5.278
8x8D03	Zr	0.640	60	0.4830	0.0320	0.4110	150	4	0.483	0.433	0.100	5.278
8x8D04	Zr	0.640	60	0.4830	0.0320	0.4110	150	1	1.34	1.26	0.100	5.278
8x8D05	Zr	0.640	60	0.4830	0.0320	0.4100	150	1	1.34	1.26	0.100	5.278
8x8D06	Zr	0.640	60	0.4830	0.0320	0.4110	150	1	1.34	1.26	0.120	5.278
8x8D07	Zr	0.640	60	0.4830	0.0320	0.4110	150	1	1.34	1.26	0.080	5.278
8x8D08	Zr	0.640	61	0.4830	0.0300	0.4140	150	3	0.591	0.531	0.080	5.278
8x8E Assembly Class												
8x8E01	Zr	0.640	59	0.4930	0.0340	0.4160	150	5	0.493	0.425	0.100	5.278
8x8F Assembly Class												
8x8F01	Zr	0.609	64	0.4576	0.0290	0.3913	150	4†	0.291†	0.228†	0.055	5.390
9x9A Assembly Class												
9x9A01	Zr	0.566	74	0.4400	0.0280	0.3760	150	2	0.98	0.92	0.100	5.278
9x9A02	Zr	0.566	66	0.4400	0.0280	0.3760	150	2	0.98	0.92	0.100	5.278
9x9A03	Zr	0.566	74/66	0.4400	0.0280	0.3760	150/90	2	0.98	0.92	0.100	5.278
9x9A04	Zr	0.566	66	0.4400	0.0280	0.3760	150	2	0.98	0.92	0.120	5.278

† Four rectangular water cross segments dividing the assembly into four quadrants

Table 6.2.1 (page 5 of 7)
BWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Water Rods	Water Rod OD	Water Rod ID	Channel Thickness	Channel ID
9x9B Assembly Class												
9x9B01	Zr	0.569	72	0.4330	0.0262	0.3737	150	1	1.516	1.459	0.100	5.278
9x9B02	Zr	0.569	72	0.4330	0.0260	0.3737	150	1	1.516	1.459	0.100	5.278
9x9B03	Zr	0.572	72	0.4330	0.0260	0.3737	150	1	1.516	1.459	0.100	5.278
9x9C Assembly Class												
9x9C01	Zr	0.572	80	0.4230	0.0295	0.3565	150	1	0.512	0.472	0.100	5.278
9x9D Assembly Class												
9x9D01	Zr	0.572	79	0.4240	0.0300	0.3565	150	2	0.424	0.364	0.100	5.278
9x9E Assembly Class†												
9x9E01	Zr	0.572	76	0.4170	0.0265	0.3530	150	5	0.546	0.522	0.120	5.215
9x9E02	Zr	0.572	48 28	0.4170 0.4430	0.0265 0.0285	0.3530 0.3745	150	5	0.546	0.522	0.120	5.215

† The 9x9E and 9x9F fuel assembly classes represent a single fuel type containing fuel rods with different dimensions (SPC 9x9-5). In addition to the actual configuration (9x9E02 and 9x9F02), the 9x9E class contains a hypothetical assembly with only small fuel rods (9x9E01), and the 9x9F class contains a hypothetical assembly with only large rods (9x9F01). This was done in order to simplify the specification of this assembly in Section 2.1.9.

Table 6.2.1 (page 6 of 7)
BWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Water Rods	Water Rod OD	Water Rod ID	Channel Thickness	Channel ID
9x9F Assembly Class*												
9x9F01	Zr	0.572	76	0.4430	0.0285	0.3745	150	5	0.546	0.522	0.120	5.215
9x9F02	Zr	0.572	48 28	0.4170 0.4430	0.0265 0.0285	0.3530 0.3745	150	5	0.546	0.522	0.120	5.215
9x9G Assembly Class												
9x9G01	Zr	0.572	72	0.4240	0.0300	0.3565	150	1	1.668	1.604	0.120	5.278
10x10A Assembly Class												
10x10A01	Zr	0.510	92	0.4040	0.0260	0.3450	155	2	0.980	0.920	0.100	5.278
10x10A02	Zr	0.510	78	0.4040	0.0260	0.3450	155	2	0.980	0.920	0.100	5.278
10x10A03	Zr	0.510	92/78	0.4040	0.0260	0.3450	155/90	2	0.980	0.920	0.100	5.278
10x10B Assembly Class												
10x10B01	Zr	0.510	91	0.3957	0.0239	0.3413	155	1	1.378	1.321	0.100	5.278
10x10B02	Zr	0.510	83	0.3957	0.0239	0.3413	155	1	1.378	1.321	0.100	5.278
10x10B03	Zr	0.510	91/83	0.3957	0.0239	0.3413	155/90	1	1.378	1.321	0.100	5.278

* The 9x9E and 9x9F fuel assembly classes represent a single fuel type containing fuel rods with different dimensions (SPC 9x9-5). In addition to the actual configuration (9x9E02 and 9x9F02), the 9x9E class contains a hypothetical assembly with only small fuel rods (9x9E01), and the 9x9F class contains a hypothetical assembly with only large rods (9x9F01). This was done in order to simplify the specification of this assembly in Section 2.1.9.

Table 6.2.1 (page 7 of 7)
BWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Water Rods	Water Rod OD	Water Rod ID	Channel Thickness	Channel ID
10x10C Assembly Class												
10x10C01	Zr	0.488	96	0.3780	0.0243	0.3224	150	5	1.227	1.165	0.055	5.347
10x10D Assembly Class												
10x10D01	SS	0.565	100	0.3960	0.0200	0.3500	83	0	n/a	n/a	0.08	5.663
10x10E Assembly Class												
10x10E01	SS	0.557	96	0.3940	0.0220	0.3430	83	4	0.3940	0.3500	0.08	5.663

Table 6.2.2 (page 1 of 4)
PWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Guide Tubes	Guide Tube OD	Guide Tube ID	Guide Tube Thickness
14x14A Assembly Class											
14x14A01	Zr	0.556	179	0.400	0.0243	0.3444	150	17	0.527	0.493	0.0170
14x14A02	Zr	0.556	179	0.400	0.0243	0.3444	150	17	0.528	0.490	0.0190
14x14A03	Zr	0.556	179	0.400	0.0243	0.3444	150	17	0.526	0.492	0.0170
14x14B Assembly Class											
14x14B01	Zr	0.556	179	0.422	0.0243	0.3659	150	17	0.539	0.505	0.0170
14x14B02	Zr	0.556	179	0.417	0.0295	0.3505	150	17	0.541	0.507	0.0170
14x14B03	Zr	0.556	179	0.424	0.0300	0.3565	150	17	0.541	0.507	0.0170
14x14B04	Zr	0.556	179	0.426	0.0310	0.3565	150	17	0.541	0.507	0.0170
14x14C Assembly Class											
14x14C01	Zr	0.580	176	0.440	0.0280	0.3765	150	5	1.115	1.035	0.0400
14x14C02	Zr	0.580	176	0.440	0.0280	0.3770	150	5	1.115	1.035	0.0400
14x14C03	Zr	0.580	176	0.440	0.0260	0.3805	150	5	1.111	1.035	0.0380
14x14D Assembly Class											
14x14D01	SS	0.556	180	0.422	0.0165	0.3835	144	16	0.543	0.514	0.0145

Table 6.2.2 (page 2 of 4)
PWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Guide Tubes	Guide Tube OD	Guide Tube ID	Guide Tube Thickness
14x14E Assembly Class											
14x14E01†	SS	0.453 and 0.441	162 3 8	0.3415 0.3415 0.3415	0.0120 0.0285 0.0200	0.313 0.280 0.297	102	0	n/a	n/a	n/a
14x14E02†	SS	0.453 and 0.441	173	0.3415	0.0120	0.313	102	0	n/a	n/a	n/a
14x14E03†	SS	0.453 and 0.441	173	0.3415	0.0285	0.0280	102	0	n/a	n/a	n/a
15x15A Assembly Class											
15x15A01	Zr	0.550	204	0.418	0.0260	0.3580	150	21	0.533	0.500	0.0165

† This is the fuel assembly used at Indian Point 1 (IP-1). This assembly is a 14x14 assembly with 23 fuel rods omitted to allow passage of control rods between assemblies. It has a different pitch in different sections of the assembly, and different fuel rod dimensions in some rods.

```
si13  -47.7139 -34.7091
si14  -31.2293 -18.2245
si15  -14.7447 -1.7399
si16   1.7399   14.7447
si17   18.2245  31.2293
si18   34.7091  47.7139
si19   51.1937  64.1985
si20   67.6783  80.6831
c
si21  -80.6831 -67.6783
si22  -64.1985 -51.1937
si23  -47.7139 -34.7091
si24  -31.2293 -18.2245
si25  -14.7447 -1.7399
si26   1.7399   14.7447
si27   18.2245  31.2293
si28   34.7091  47.7139
si29   51.1937  64.1985
si30   67.6783  80.6831
sp11  0 1
sp12  0 1
sp13  0 1
sp14  0 1
sp15  0 1
sp16  0 1
sp17  0 1
sp18  0 1
sp19  0 1
sp20  0 1
sp21  0 1
sp22  0 1
sp23  0 1
sp24  0 1
sp25  0 1
sp26  0 1
sp27  0 1
sp28  0 1
sp29  0 1
sp30  0 1
c
m1            92235.50c   -0.03702  $ 4.20% E Fuel
              92238.50c   -0.84448
              8016.50c    -0.1185
m3            40000.56c   1.           $ Zr Clad
m4            1001.50c    0.6667       $ Water
              8016.50c    0.3333
m5            24000.50c   0.01761      $ Steel
              25055.50c   0.001761
              26000.55c   0.05977
              28000.50c   0.008239
m6            5010.50c    8.0707E-03   $ Boral
              5011.50c    3.2553E-02
              6000.50c    1.0146E-02
              13027.50c   3.8054E-02
m7            13027.50c    1.            $ Al Clad
m8            82000.50c   1.0      $ Lead
m9             6000.50c  -27.660   $ Neutron Shield Holtite-A (NS-4-FR)
               1001.50c   -5.920
              13027.50c  -21.285
               7014.50c   -1.98
               8016.50c  -42.372
               5010.50c   -0.141
```

```
            5011.50c    -0.642
mt4         lwtr.01t
prdmp     j    -120    j    2
fm4       1000    1    -6
f4:n    1
sd4       1000
e4      1.000E-11   1.000E-10   5.000E-10   7.500E-10   1.000E-09   1.200E-09
        1.500E-09   2.000E-09   2.500E-09   3.000E-09
        4.700E-09   5.000E-09   7.500E-09   1.000E-08   2.530E-08
        3.000E-08   4.000E-08   5.000E-08   6.000E-08   7.000E-08
        8.000E-08   9.000E-08   1.000E-07   1.250E-07   1.500E-07
        1.750E-07   2.000E-07   2.250E-07   2.500E-07   2.750E-07
        3.000E-07   3.250E-07   3.500E-07   3.750E-07   4.000E-07
        4.500E-07   5.000E-07   5.500E-07   6.000E-07   6.250E-07
        6.500E-07   7.000E-07   7.500E-07   8.000E-07   8.500E-07
        9.000E-07   9.250E-07   9.500E-07   9.750E-07   1.000E-06
        1.010E-06   1.020E-06   1.030E-06   1.040E-06   1.050E-06
        1.060E-06   1.070E-06   1.080E-06   1.090E-06   1.100E-06
        1.110E-06   1.120E-06   1.130E-06   1.140E-06   1.150E-06
        1.175E-06   1.200E-06   1.225E-06   1.250E-06   1.300E-06
        1.350E-06   1.400E-06   1.450E-06   1.500E-06   1.590E-06
        1.680E-06   1.770E-06   1.860E-06   1.940E-06   2.000E-06
        2.120E-06   2.210E-06   2.300E-06   2.380E-06   2.470E-06
        2.570E-06   2.670E-06   2.770E-06   2.870E-06   2.970E-06
        3.000E-06   3.050E-06   3.150E-06   3.500E-06   3.730E-06
        4.000E-06   4.750E-06   5.000E-06   5.400E-06   6.000E-06
        6.250E-06   6.500E-06   6.750E-06   7.000E-06   7.150E-06
        8.100E-06   9.100E-06   1.000E-05   1.150E-05   1.190E-05
        1.290E-05   1.375E-05   1.440E-05   1.510E-05   1.600E-05
        1.700E-05   1.850E-05   1.900E-05   2.000E-05   2.100E-05
        2.250E-05   2.500E-05   2.750E-05   3.000E-05   3.125E-05
        3.175E-05   3.325E-05   3.375E-05   3.460E-05   3.550E-05
        3.700E-05   3.800E-05   3.910E-05   3.960E-05   4.100E-05
        4.240E-05   4.400E-05   4.520E-05   4.700E-05   4.830E-05
        4.920E-05   5.060E-05   5.200E-05   5.340E-05   5.900E-05
        6.100E-05   6.500E-05   6.750E-05   7.200E-05   7.600E-05
        8.000E-05   8.200E-05   9.000E-05   1.000E-04   1.080E-04
        1.150E-04   1.190E-04   1.220E-04   1.860E-04   1.925E-04
        2.075E-04   2.100E-04   2.400E-04   2.850E-04   3.050E-04
        5.500E-04   6.700E-04   6.830E-04   9.500E-04   1.150E-03
        1.500E-03   1.550E-03   1.800E-03   2.200E-03   2.290E-03
        2.580E-03   3.000E-03   3.740E-03   3.900E-03   6.000E-03
        8.030E-03   9.500E-03   1.300E-02   1.700E-02   2.500E-02
        3.000E-02   4.500E-02   5.000E-02   5.200E-02   6.000E-02
        7.300E-02   7.500E-02   8.200E-02   8.500E-02   1.000E-01
        1.283E-01   1.500E-01   2.000E-01   2.700E-01   3.300E-01
        4.000E-01   4.200E-01   4.400E-01   4.700E-01   4.995E-01
        5.500E-01   5.730E-01   6.000E-01   6.700E-01   6.790E-01
        7.500E-01   8.200E-01   8.611E-01   8.750E-01   9.000E-01
        9.200E-01   1.010E+00   1.100E+00   1.200E+00   1.250E+00
        1.317E+00   1.356E+00   1.400E+00   1.500E+00   1.850E+00
        2.354E+00   2.479E+00   3.000E+00   4.304E+00   4.800E+00
        6.434E+00   8.187E+00   1.000E+01   1.284E+01   1.384E+01
        1.455E+01   1.568E+01   1.733E+01   2.000E+01
```

```
HI-STORM Storage Cask containing MPC24, 17x17 assembly @ 4.0 wt% Enrich.
c
c
c
c MPC-24/24E cell configuration
c
c HI-STORM with active length 150 inch
c
c
c Cask Input Preprocessor
c cskinp 17a 17a mpc24n mpc24n historm historm 4.0 4sf7a45 empty
c ------      cpp\17a.bat
c   added 17a.ce
c   added 17a.su
c   added 17a.sp
c ------      cpp\mpc24n.bat
c   added mpc24n.co
c   added mpc24n.ce
c   added mpc24n.su
c   added mpc24n.sp
c ------      cpp\historm.bat
c   added historm.co
c   added historm.ce
c   added historm.su
c   added historm.sp
c end of comments
c
c start of cells
c
c 17x17a
c
c number of cells: 6
c cell numbers:      1 to 7
c univers numbers:   1 to 3
c surface numbers:   1 to 9
c
c number of cells: 1
1     1 -10.522     -1  u=2         $ fuel
2     4 -1.0     1  -2  u=2         $ gap
3     3 -6.55    2  -3  u=2         $ Zr Clad
4     2 -0.0002         3  u=2        $ water in fuel region
5     2 -0.0002  -4:5     u=3        $ water in guide tubes
6     3 -6.55   4 -5    u=3         $ guide tubes
7     2 -0.0002  -6   +7   -8   +9   u=1  lat=1
      fill= -9:9    -9:9   0:0
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 2 2 2 2 2 3 2 2 3 2 2 3 2 2 2 2 2 1
      1 2 2 2 3 2 2 2 2 2 2 2 2 2 3 2 2 2 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 2 2 3 2 2 3 2 2 3 2 2 3 2 2 3 2 2 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 2 2 3 2 2 3 2 2 3 2 2 3 2 2 3 2 2 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 2 2 3 2 2 3 2 2 3 2 2 3 2 2 3 2 2 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 2 2 2 3 2 2 2 2 2 2 2 2 2 3 2 2 2 1
      1 2 2 2 2 2 3 2 2 3 2 2 3 2 2 2 2 2 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
```

```
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
c
c     MPC-24
c
c number of cells: 102
c cell numbers :       400   to  699
c universe numbers :     4   to    9
c surface numbers :    400   to  699
c
c     Right Side
c
408      0           -410   411  -412   413    u=4 fill=1 (1)
409      5  -7.84     410  -424   413  -426    u=4
410     2 -0.0002      424  -428   448  -445    u=4
411     7   -2.7     428  -528  448  -445    u=4
412     6  -2.66   528  -532  448  -445    u=4
413     7   -2.7    532  -432   448  -445    u=4
414     2 -0.0002      432  -436   448  -445    u=4
415     5   -7.84    436  -440   448  -445    u=4
416     2 -0.0002      440         413          u=4
417     2 -0.0002      424  -440   413  -447    u=4
418     2 -0.0002      424  -440   446           u=4
419     5   -7.84    424  -440   447  -448    u=4
420     5   -7.84    424  -440   445  -446    u=4
c
c    Left Side
c
421     5   -7.84    425  -411   413           u=4
422     2 -0.0002      429  -425   448  -445    u=4
423     7   -2.7    529  -429   448  -445    u=4
424     6   -2.66   533 -529   448  -445    u=4
425     7   -2.7     433 -533   448  -445    u=4
426     2 -0.0002      437  -433   448  -445    u=4
427     5   -7.84    441  -437   448  -445    u=4
428     2 -0.0002          -441   413          u=4
429     2 -0.0002      441  -425   413  -447    u=4
430     2 -0.0002      441  -425   446           u=4
431     5   -7.84    441  -425   447  -448    u=4
432     5   -7.84    441  -425   445  -446    u=4
c
c     Top
c
433     5   -7.84    411  -410   412  -426    u=4
434     2 -0.0002      451  -452   426  -430    u=4
435     7   -2.7     451  -452   430 -530    u=4
436     6   -2.66    451  -452  530 -534    u=4
437     7   -2.7     451  -452  534  -434    u=4
438     2 -0.0002      451  -452   434  -438    u=4
439     5   -7.84    451  -452   438  -442    u=4
440     2 -0.0002      411  -424   442           u=4
441     2 -0.0002      411  -450   426  -442    u=4
442     2 -0.0002      453  -424   426  -442    u=4
443     5   -7.84    450  -451   426  -442    u=4
444     5   -7.84    452  -453   426  -442    u=4
c
c     Bottom
c
445     5  -7.84     427              -413    u=4
446     2 -0.0002      451  -452   431  -427    u=4
447     7   -2.7     451  -452  531  -431    u=4
448     6   -2.66    451  -452  535 -531    u=4
```

```
449    7  -2.7      451  -452   435 -535    u=4
450    2 -0.0002      451  -452   439  -435    u=4
451    5  -7.84     451  -452   443  -439    u=4
452    2 -0.0002      411              -443    u=4
453    2 -0.0002      411  -450   443  -427    u=4
454    2 -0.0002      453         443  -427    u=4
455    5  -7.84     450  -451   443  -427    u=4
456    5  -7.84     452  -453   443  -427    u=4
457    5  -7.84     425  -411        -427    u=4
458    2 -0.0002          -425         -427    u=4
c
c     TYPE B CELL  -  Short Boral on top and right
c
c     Right Side
c
459    0           -410   411  -412   413    u=5 fill=1 (1)
460    5  -7.84     410  -424   413  -426    u=5
470    2 -0.0002      424  -428   548 -545    u=5
471    7  -2.7      428  -528 548 -545    u=5
472    6  -2.66    528  -532 548 -545    u=5
473    7  -2.7     532  -432  548 -545    u=5
474    2 -0.0002      432  -436  548 -545    u=5
475    5  -7.84     436  -440  548 -545    u=5
476    2 -0.0002      440         413        u=5
477    2 -0.0002      424  -440   413 -547    u=5
478    2 -0.0002      424  -440  546          u=5
479    5  -7.84     424  -440  547 -548    u=5
480    5  -7.84     424  -440  545 -546    u=5
c
c    Left Side
c
481    5  -7.84     425  -411   413          u=5
482    2 -0.0002      429  -425   448  -445    u=5
483    7  -2.7     529  -429   448  -445    u=5
484    6  -2.66    533 -529   448  -445    u=5
485    7  -2.7      433 -533   448  -445    u=5
486    2 -0.0002      437  -433   448  -445    u=5
487    5  -7.84     441  -437   448  -445    u=5
488    2 -0.0002          -441   413        u=5
489    2 -0.0002      441  -425   413  -447    u=5
490    2 -0.0002      441  -425   446          u=5
491    5  -7.84     441  -425   447  -448    u=5
492    5  -7.84     441  -425   445  -446    u=5
c
c     Top
c
493    5  -7.84     411  -410   412  -426    u=5
494    2 -0.0002     551 -552   426  -430    u=5
495    7  -2.7     551 -552   430 -530    u=5
496    6  -2.66    551 -552  530 -534    u=5
497    7  -2.7     551 -552  534  -434    u=5
498    2 -0.0002     551 -552   434  -438    u=5
499    5  -7.84    551 -552   438  -442    u=5
500   2 -0.0002     411  -424   442          u=5
501   2 -0.0002     411 -550   426  -442    u=5
502   2 -0.0002    553  -424   426  -442    u=5
503   5  -7.84   550 -551   426  -442    u=5
504   5  -7.84   552 -553   426  -442    u=5
c
c     Bottom
c
505   5  -7.84    427            -413    u=5
```

```
506   2 -0.0002     451  -452   431  -427    u=5
507   7  -2.7      451  -452  531  -431    u=5
508   6  -2.66     451  -452  535 -531    u=5
509   7  -2.7      451  -452   435 -535    u=5
510   2 -0.0002     451  -452   439  -435    u=5
511   5  -7.84     451  -452   443  -439    u=5
512   2 -0.0002     411              -443    u=5
513   2 -0.0002     411  -450   443  -427    u=5
514   2 -0.0002     453           443  -427    u=5
515   5  -7.84     450  -451   443  -427    u=5
516   5  -7.84     452  -453   443  -427    u=5
517   5  -7.84     425  -411        -427    u=5
518   2 -0.0002         -425        -427    u=5
c
c
c
c     TYPE D CELL  -  Short Boral on left and bottom, different cell ID
c
c number of cells: 51
c
c     Right Side
c
1570   0           -1410   1411  -1412   1413    u=17 fill=1 (1)
1571   5  -7.84     1410  -1424   1413  -1426    u=17
1572   2 -0.0002     1424  -1428   1448  -1445    u=17
1573   7  -2.7      1428  -1528  1448  -1445    u=17
1574   6  -2.66    1528  -1532  1448  -1445    u=17
1575   7  -2.7     1532  -1432   1448  -1445    u=17
1576   2 -0.0002     1432  -1436   1448  -1445    u=17
1577   5  -7.84     1436  -1440   1448  -1445    u=17
1578   2 -0.0002     1440          1413         u=17
1579   2 -0.0002     1424  -1440   1413  -1447    u=17
1580   2 -0.0002     1424  -1440   1446          u=17
1581   5  -7.84     1424  -1440   1447  -1448    u=17
1582   5  -7.84     1424  -1440   1445  -1446    u=17
c
c    Left Side
c
1583   5  -7.84     1425  -1411   1413         u=17
1584   2 -0.0002     1429  -1425  1548 -1545    u=17
1585   7  -2.7     1529  -1429  1548 -1545    u=17
1586   6  -2.66    1533 -1529  1548 -1545    u=17
1587   7  -2.7      1433 -1533  1548 -1545    u=17
1588   2 -0.0002     1437  -1433  1548 -1545    u=17
1589   5  -7.84     1441  -1437  1548 -1545    u=17
1590   2 -0.0002          -1441   1413         u=17
1591   2 -0.0002     1441  -1425   1413 -1547    u=17
1592   2 -0.0002     1441  -1425  1546         u=17
1593   5  -7.84     1441  -1425  1547 -1548    u=17
1594   5  -7.84     1441  -1425  1545 -1546    u=17
c
c     Top
c
1595   5  -7.84     1411  -1410   1412  -1426    u=17
1596   2 -0.0002     1451  -1452   1426  -1430    u=17
1597   7  -2.7      1451  -1452   1430 -1530    u=17
1598   6  -2.66     1451  -1452  1530 -1534    u=17
1599   7  -2.7      1451  -1452  1534  -1434    u=17
1600   2 -0.0002     1451  -1452   1434  -1438    u=17
1601   5  -7.84     1451  -1452   1438  -1442    u=17
1602   2 -0.0002     1411  -1424   1442         u=17
1603   2 -0.0002     1411  -1450   1426  -1442    u=17
```

```
1604   2 -0.0002     1453  -1424   1426  -1442    u=17
1605   5  -7.84    1450  -1451   1426  -1442    u=17
1606   5  -7.84    1452  -1453   1426  -1442    u=17
c
c     Bottom
c
1607   5  -7.84    1427             -1413    u=17
1608   2 -0.0002    1551 -1552   1431  -1427    u=17
1609   7  -2.7    1551 -1552  1531  -1431    u=17
1610   6  -2.66   1551 -1552  1535 -1531    u=17
1611   7  -2.7    1551 -1552   1435 -1535    u=17
1612   2 -0.0002    1551 -1552   1439  -1435    u=17
1613   5  -7.84   1551 -1552   1443  -1439    u=17
1614   2 -0.0002     1411            -1443    u=17
1615   2 -0.0002     1411 -1550   1443  -1427    u=17
1616   2 -0.0002    1553         1443  -1427    u=17
1617   5  -7.84   1550 -1551   1443  -1427    u=17
1618   5  -7.84   1552 -1553   1443  -1427    u=17
1619   5  -7.84    1425  -1411        -1427    u=17
1620   2 -0.0002         -1425        -1427    u=17
c
c number of cells: 29
c
c empty cell no boral, no top
c
c
751     2 -0.0002   -410   411  -412   413    u=14
752     5  -7.84    410  -424   413  -426    u=14
753    5  -7.84    425  -411   413          u=14
754    2 -0.0002     411  -410   412  -426    u=14
755    5  -7.84    427          -413    u=14
756    5  -7.84    425  -411      -427    u=14
757    2 -0.0002     411   426              u=14
758    2 -0.0002     411  -427              u=14
759    2 -0.0002    -425   413              u=14
760    2 -0.0002     424   413   -426       u=14
761    2 -0.0002    -425  -427              u=14
c
c
701    5   -7.84   701 -702 711 -713     u=9   $ steel post
702    5   -7.84   702 -703 711 -712     u=9   $ steel post
c
711    0           701 -705 711 -715 (702:713) (703:712)
                   fill=4 (13.8506 13.8506 0) u=9
712    0           704 (-706:-716) (705:715) -717 -710
                   fill=4 (17.9489 41.5518 0  0 1 0  -1 0 0   0 0 1) u=9
713    0           (705:715) -707 714 (-706:-716)  710
                   fill=4 (41.5518 17.9489 0  0 -1 0  1 0 0   0 0 1) u=9
714    0           701 -705 717 -719
                   fill=5 (13.8506 69.253 0) u=9
715    0           707 -709 711 -715
                   fill=5 (69.253 13.8506 0) u=9
716    0           706 -708 716 -718
                   fill=17 (45.6501 45.6501 0  -1 0 0  0 -1 0  0 0 1) u=9
717    0           705 -706 717 -719
                   fill=14 (41.5518 69.253 0) u=9
718    0           707 -709 715 -716
                   fill=14 (69.253 41.5518 0 0 1 0   1 0 0   0 0 1) u=9
719    0           701 -704 715 -717
                   fill=14 (-9.75233 41.5518 0  -1 0 0  0 1 0   0 0 1) u=9
720    0           705 -707 711 -714
                   fill=14 (41.5518 -9.75233 0   0 -1 0  1 0 0   0 0 1) u=9
```

```
721   2 -0.0002     (706:719) (708:718) (709:716) u=9
c
c
c
731   2 -0.0002      720  721   fill=9 (0 0 0) u=19
732   2 -0.0002     -720  721   fill=9 (0 0 0
                              -1 0 0  0  1 0  0 0 1) u=19
733   2 -0.0002      720 -721   fill=9 (0 0 0
                               1 0 0  0 -1 0  0 0 1) u=19
734   2 -0.0002     -720 -721   fill=9 (0 0 0
                              -1 0 0  0 -1 0  0 0 1) u=19
c
673   0           -41              39  -40  fill=19
c
c number of cells: 19
374   2  -0.0002 -41      330  -39              $ Void below Fuel (4 in.)
375   5  -7.84   -309     332  -330             $ MPC Steel below Fuel (2.5 in.)
376   5  -7.84   -304     310  -332             $ Cask Steel (5.0 in.)
377   8  -2.35   -304     311  -310             $ Cask Concrete (17.0 in.)
378   5  -7.84   -304     312  -311             $ Cask Steel (2.0 in.)
c
379   2  -0.0002 -41      40  -331          $ Void above Fuel (6 in.)
380   5  -7.84   -309    331  -333          $ MPC Steel above Fuel (9.5 - 0.06 in)
381   4  -1.0    -309    333  -320          $ Water (1.0 in.)
382   5  -7.84   -304     320  -321         $ Cask Steel (1.25 in.)
383   8  -2.35   -304     321  -322         $ Cask Concrete (10.5 in.)
384   5  -7.84   -304     322  -323         $ Cask Steel (4.0 in.)
c
390   5  -7.84     41 -309  330  -331         $ Radial Steel - MPC shell
391   4  -1.00    309 -300  332  -320         $ Radial Water
392   5  -7.84    300 -301  332  -320         $ Radial Steel - overpack inner shell
394   5  -7.84    301 -302  332  -320         $ Radial Steel -
395   8  -2.35    302 -303  332  -320         $ Radial Shield - Concrete Overpack
396   5  -7.84    303 -304  332  -320         $ Radial Steel - overpack outer shell
c
300   4  -1.00    340 -341 -345        (304 :-312:  323)    $ outer water reflector
301   0           345 :-340: 341      $ outside world
c end of cells
c --- empty line

c --- empty line
c start of surfaces
1     cz          0.3922    $ fuel
2     cz          0.4001    $ clad ID
3     cz          0.4572    $ clad OD
4     cz          0.5613    $ guide ID
5     cz          0.6020    $ guide OD
6     px          0.6299    $ pin pitch
7     px         -0.6299
8     py          0.6299
9     py         -0.6299
c
c
c cell-id      8.98
c cell-pitch   10.906
c wall-thkns   5/16
c angle-thkns  5/16
c boral-gap    0.0035
c boral-gap-o  0.0035
c boral-thkns  0.075
c boral-clad   0.01
c sheathing    0.0235
```

```
c boral-wide   7.5
c boral-narrow 6.25
c
c gap size     1.09
c basket-od    67.335
c
410    px         11.40460 $x 8.98/2
411    px        -11.40460 $x {410} *-1
412    py         11.40460 $x {410}
413    py        -11.40460 $x {411}
416    px         13.85062 $x (10.906 + 5/16 - 5/16) /2
417    px        -13.85062 $x -10.906 + {416}
418    py         13.85062 $x {416}
419    py        -13.85062 $x {417}
424    px         12.19835 $x {410} + 5/16     $ angle
425    px        -12.19835 $x {411} - 5/16     $ box wall
426    py         12.19835 $x {412} + 5/16
427    py        -12.19835 $x {413} - 5/16
428    px         12.20724 $x {424} + 0.0035   $ wall to boral gap
429    px        -12.20724 $x {425} - 0.0035
430    py         12.20724 $x {426} + 0.0035
431    py        -12.20724 $x {427} - 0.0035
432    px         12.39774 $x {428} + 0.075    $ boral
433    px        -12.39774 $x {429} - 0.075
434    py         12.39774 $x {430} + 0.075
435    py        -12.39774 $x {431} - 0.075
436    px         12.40663 $x {432} + 0.0035   $ boral to sheathing gap
437    px        -12.40663 $x {433} - 0.0035
438    py         12.40663 $x {434} + 0.0035
439    py        -12.40663 $x {435} - 0.0035
440    px         12.46632 $x {436} + 0.0235   $ sheathing
441    px        -12.46632 $x {437} - 0.0235
442    py         12.46632 $x {438} + 0.0235
443    py        -12.46632 $x {439} - 0.0235
445    py          9.52500 $x 7.5/2
446    py          9.58469 $x {445} + 0.0235   $ sheathing
447    py         -9.58469 $x {446} *-1
448    py         -9.52500 $x {445} *-1
450    px         -9.58469 $x {447}
451    px         -9.52500 $x {448}
452    px          9.52500 $x {445}
453    px          9.58469 $x {446}
528   px         12.23264 $x {428} + 0.01  $ Aluminum on the outside of boral
529   px        -12.23264 $x {429} - 0.01
530   py         12.23264 $x {430} + 0.01
531   py        -12.23264 $x {431} - 0.01
532   px         12.37234 $x {432} - 0.01
533   px        -12.37234 $x {433} + 0.01
534   py         12.37234 $x {434} - 0.01
535   py        -12.37234 $x {435} + 0.01
545   py          7.93750 $x 6.25/2
546   py          7.99719 $x {545} + 0.0235   $ sheathing
547   py         -7.99719 $x {546} *-1
548   py         -7.93750 $x {545} *-1
550   px         -7.99719 $x {547}
551   px         -7.93750 $x {548}
552   px          7.93750 $x {545}
553   px          7.99719 $x {546}
c
c cell-id-2 8.98
c gap-o     1.09
c
```

```
701   px        -5.0
702   px        1.90627 $x (10.906 - 8.98)/2 - 5/16 + 0.1
703   px        3.45694 $x 2.722/2
704   px        4.09829 $x 10.906 - 8.98 - 5/16
705   px        27.70124 $x 10.906
706   px        31.79953 $x 2 * 10.906 - (8.98+8.98)/2 - 5/16
707   px        55.40248 $x 2 * 10.906
708   px        59.50077 $x {707} + {704}
709   px        83.10372 $x 3 * 10.906
710   p     1  -1  0  0.1 $ diagonal x=y, offset by 0.1 to avoid intersecting corners
711   py        -4.99999 $x {701}
712   py        1.90627 $x {702}
713   py        3.45694 $x {703}
714   py        4.09829 $x {704}
715   py        27.70124 $x {705}
716   py        31.79953 $x {706}
717   py        55.40248 $x {707}
718   py        59.50077 $x {708}
719   py        83.10372 $x {709}
720   px        0.0
721   py        0.0
1410    px         11.40460 $x 8.98/2
1411    px        -11.40460 $x {1410} *-1
1412    py         11.40460 $x {1410}
1413    py        -11.40460 $x {1411}
1424    px         12.19835 $x {1410} + 5/16      $ angle
1425    px        -12.19835 $x {1411} - 5/16      $ box wall
1426    py         12.19835 $x {1412} + 5/16
1427    py        -12.19835 $x {1413} - 5/16
1428    px         12.20724 $x {1424} + 0.0035    $ wall to boral gap
1429    px        -12.20724 $x {1425} - 0.0035
1430    py         12.20724 $x {1426} + 0.0035
1431    py        -12.20724 $x {1427} - 0.0035
1432    px         12.39774 $x {1428} + 0.075     $ boral
1433    px        -12.39774 $x {1429} - 0.075
1434    py         12.39774 $x {1430} + 0.075
1435    py        -12.39774 $x {1431} - 0.075
1436    px         12.40663 $x {1432} + 0.0035    $ boral to sheathing gap
1437    px        -12.40663 $x {1433} - 0.0035
1438    py         12.40663 $x {1434} + 0.0035
1439    py        -12.40663 $x {1435} - 0.0035
1440    px         12.46632 $x {1436} + 0.0235    $ sheathing
1441    px        -12.46632 $x {1437} - 0.0235
1442    py         12.46632 $x {1438} + 0.0235
1443    py        -12.46632 $x {1439} - 0.0235
1445    py          9.52500 $x 7.5/2
1446    py          9.58469 $x {1445} + 0.0235    $ sheathing
1447    py         -9.58469 $x {1446} *-1
1448    py         -9.52500 $x {1445} *-1
1450    px         -9.58469 $x {1447}
1451    px         -9.52500 $x {1448}
1452    px          9.52500 $x {1445}
1453    px          9.58469 $x {1446}
1528   px        12.23264 $x {1428} + 0.01  $ Aluminum on the outside of boral
1529   px       -12.23264 $x {1429} - 0.01
1530   py        12.23264 $x {1430} + 0.01
1531   py       -12.23264 $x {1431} - 0.01
1532   px        12.37234 $x {1432} - 0.01
1533   px       -12.37234 $x {1433} + 0.01
1534   py        12.37234 $x {1434} - 0.01
1535   py       -12.37234 $x {1435} + 0.01
1545   py         7.93750 $x 6.25/2
```

```
1546   py        7.99719 $x {1545} + 0.0235   $ sheathing
1547   py       -7.99719 $x {1546} *-1
1548   py       -7.93750 $x {1545} *-1
1550   px       -7.99719 $x {1547}
1551   px       -7.93750 $x {1548}
1552   px        7.93750 $x {1545}
1553   px        7.99719 $x {1546}
39    pz        0.
40    pz       381.0       $  150 inch active fuel length
330    pz        -10.16   $ lower water thkness = 4 in.
331    pz        396.24  $ upper water thkness = 6 in.
332    pz        -16.51   $ thkness of MPC baseplate = 2.5 in.
333    pz        420.02  $ thkness of MPC lid = 9.5 -0.06 in.
41    cz        85.57    $ I.D. = 67.37 in
309    cz        86.84    $ I.D. = 68.375 in.
300   cz        93.35    $ I.D. = 73.50 in.
301   cz        96.52    $ I.D. = 76.00 in.
302   cz        98.43    $ I.D. = 77.50 in.
303   cz       166.37    $ I.D. = 131.00 in.
304   cz       168.28    $ I.D. = 132.50 in.
310   pz       -29.21    $ thkness steel - 5.0 in.
311   pz       -72.39    $ thkness concrete - 17.0 in.
312   pz       -77.47    $ thkness steel - 2.0 in.
320   pz       422.76    $ thkness water - 1.0 in.
321   pz       425.94    $ thkness steel - 1.25 in.
322   pz       452.61    $ thkness concrete - 10.5 in.
323   pz       462.765   $ thkness steel - 4.0 in.
c
*340  pz -107.47   $ lower boundary
*341  pz  492.765  $ upper boundary
*345  cz  198.28   $ outer radial boundary
c end of surfaces
c --- empty line

c --- empty line
tr1 0 0 0
kcode    10000  .94  20  120
sdef  par=1  erg=d1 axs=0 0 1 x=d4 y=fx d5 z=d3
c
sp1  -2 1.2895
c
sp3  0 1
c
si4  s         13 14
            12 13 14 15
         11 12 13 14 15 16
         11 12 13 14 15 16
            12 13 14 15
               13 14
sp4  1 23r
c
ds5  s               26 26
                  25 25 25 25
               24 24 24 24 24 24
               23 23 23 23 23 23
                  22 22 22 22
                     21 21
c
si11  -79.25435 -57.61355
si12  -51.88077 -30.23997
si13  -24.50719 -2.86639
si14   2.86639   24.50719
```

```
si15   30.23997  51.88077
si16   57.61355  79.25435
c
si21  -79.25435 -57.61355
si22  -51.88077 -30.23997
si23  -24.50719 -2.86639
si24   2.86639   24.50719
si25   30.23997  51.88077
si26   57.61355  79.25435
c
sp11  0 1
sp12  0 1
sp13  0 1
sp14  0 1
sp15  0 1
sp16  0 1
sp21  0 1
sp22  0 1
sp23  0 1
sp24  0 1
sp25  0 1
sp26  0 1
c
m3          40000.56c   1.           $ Zr Clad
m4          1001.50c    0.6667       $ Water
            8016.50c    0.3333
m5          24000.50c   0.01761      $ Steel
            25055.50c   0.001761
            26000.55c   0.05977
            28000.50c   0.008239
m6          5010.50c   -0.054427     $ Boral Central Section @ 0.02 g/cmsq
            5011.50c   -0.241373
            13027.50c  -0.6222
            6000.50c   -0.0821
m7          13027.50c   1.0
mt4        lwtr.01t
prdmp    j   -120    j    2
fm4      1000    1    -6
f4:n   1
sd4      1000
e4    1.000E-11   1.000E-10   5.000E-10   7.500E-10   1.000E-09   1.200E-09
      1.500E-09   2.000E-09   2.500E-09   3.000E-09
      4.700E-09   5.000E-09   7.500E-09   1.000E-08   2.530E-08
      3.000E-08   4.000E-08   5.000E-08   6.000E-08   7.000E-08
      8.000E-08   9.000E-08   1.000E-07   1.250E-07   1.500E-07
      1.750E-07   2.000E-07   2.250E-07   2.500E-07   2.750E-07
      3.000E-07   3.250E-07   3.500E-07   3.750E-07   4.000E-07
      4.500E-07   5.000E-07   5.500E-07   6.000E-07   6.250E-07
      6.500E-07   7.000E-07   7.500E-07   8.000E-07   8.500E-07
      9.000E-07   9.250E-07   9.500E-07   9.750E-07   1.000E-06
      1.010E-06   1.020E-06   1.030E-06   1.040E-06   1.050E-06
      1.060E-06   1.070E-06   1.080E-06   1.090E-06   1.100E-06
      1.110E-06   1.120E-06   1.130E-06   1.140E-06   1.150E-06
      1.175E-06   1.200E-06   1.225E-06   1.250E-06   1.300E-06
      1.350E-06   1.400E-06   1.450E-06   1.500E-06   1.590E-06
      1.680E-06   1.770E-06   1.860E-06   1.940E-06   2.000E-06
      2.120E-06   2.210E-06   2.300E-06   2.380E-06   2.470E-06
      2.570E-06   2.670E-06   2.770E-06   2.870E-06   2.970E-06
      3.000E-06   3.050E-06   3.150E-06   3.500E-06   3.730E-06
      4.000E-06   4.750E-06   5.000E-06   5.400E-06   6.000E-06
      6.250E-06   6.500E-06   6.750E-06   7.000E-06   7.150E-06
      8.100E-06   9.100E-06   1.000E-05   1.150E-05   1.190E-05
```

```
        1.290E-05   1.375E-05   1.440E-05   1.510E-05   1.600E-05
        1.700E-05   1.850E-05   1.900E-05   2.000E-05   2.100E-05
        2.250E-05   2.500E-05   2.750E-05   3.000E-05   3.125E-05
        3.175E-05   3.325E-05   3.375E-05   3.460E-05   3.550E-05
        3.700E-05   3.800E-05   3.910E-05   3.960E-05   4.100E-05
        4.240E-05   4.400E-05   4.520E-05   4.700E-05   4.830E-05
        4.920E-05   5.060E-05   5.200E-05   5.340E-05   5.900E-05
        6.100E-05   6.500E-05   6.750E-05   7.200E-05   7.600E-05
        8.000E-05   8.200E-05   9.000E-05   1.000E-04   1.080E-04
        1.150E-04   1.190E-04   1.220E-04   1.860E-04   1.925E-04
        2.075E-04   2.100E-04   2.400E-04   2.850E-04   3.050E-04
        5.500E-04   6.700E-04   6.830E-04   9.500E-04   1.150E-03
        1.500E-03   1.550E-03   1.800E-03   2.200E-03   2.290E-03
        2.580E-03   3.000E-03   3.740E-03   3.900E-03   6.000E-03
        8.030E-03   9.500E-03   1.300E-02   1.700E-02   2.500E-02
        3.000E-02   4.500E-02   5.000E-02   5.200E-02   6.000E-02
        7.300E-02   7.500E-02   8.200E-02   8.500E-02   1.000E-01
        1.283E-01   1.500E-01   2.000E-01   2.700E-01   3.300E-01
        4.000E-01   4.200E-01   4.400E-01   4.700E-01   4.995E-01
        5.500E-01   5.730E-01   6.000E-01   6.700E-01   6.790E-01
        7.500E-01   8.200E-01   8.611E-01   8.750E-01   9.000E-01
        9.200E-01   1.010E+00   1.100E+00   1.200E+00   1.250E+00
        1.317E+00   1.356E+00   1.400E+00   1.500E+00   1.850E+00
        2.354E+00   2.479E+00   3.000E+00   4.304E+00   4.800E+00
        6.434E+00   8.187E+00   1.000E+01   1.284E+01   1.384E+01
        1.455E+01   1.568E+01   1.733E+01   2.000E+01
si3  h 0 381.00
m2            8016.50c  -1.0
m8           13027.50c  -0.048        $ Concrete
             14000.50c  -0.315
              8016.50c  -0.500
              1001.50c  -0.006
             11023.50c  -0.017
             20000.50c  -0.083
             26000.55c  -0.012
             19000.50c  -0.019
mt8         lwtr.01t
imp:n 1 206r 0
c fuel enrichment 4.0 %
m1       92235.50c      -0.03526
         92238.50c      -0.84624
          8016.50c      -0.11850
c end of file
c
```

```
HI-STORM Storage Cask containing MPC68, 08x08 assembly @ 4.2 wt% Enrich.
c     MPC68 reflected w/60cm of water, 0.0279 g/cmsq B-10 in Boral
c
c
1     1 -10.522       -1  u=2       $ fuel
2     2 -0.0002   1  -2  u=2       $ gap
3     2 -0.0002   2  -3  u=2       $ Zr Clad
4     2 -0.0002       3  u=2       $ water in fuel region
5     2 -0.0002 -4:5     u=3       $ water in guide tubes
6     2 -0.0002  4 -5    u=3       $ guide tubes
7     2 -0.0002 -6   +7   -8   +9   u=1  lat=1
      fill= -5:4    -5:4   0:0
      1  1 1 1 1 1 1 1 1  1
      1  2 2 2 2 2 2 2 2  1
      1  2 2 2 2 2 2 2 2  1
      1  2 2 2 2 2 2 2 2  1
      1  2 2 2 3 2 2 2 2  1
      1  2 2 2 2 3 2 2 2  1
      1  2 2 2 2 2 2 2 2  1
      1  2 2 2 2 2 2 2 2  1
      1  2 2 2 2 2 2 2 2  1
      1  1 1 1 1 1 1 1 1  1
c
C  BOX TYPE R
c
8     0  -10    11  -12   13         u=4 fill=1  (0.8128 0.8128 0)
9     3  -6.55    60    -61    62    -63  #8         u=4      $ Zr flow channel
10    2 -0.0002   64    -65    66    -67  #8 #9      u=4      $ water
11    5  -7.84    20    -23    67    -14             u=4      $ 0.075" STEEL
12    2 -0.0002   20    -23    14    -15             u=4      $ WATER POCKET
13    7  -2.7     20    -23    15    -16             u=4      $ Al CLAD
14    6  -2.66    20    -23    16    -17             u=4      $ BORAL Absorber
15    7  -2.7     20    -23    17    -18             u=4      $ Al Clad
16    2 -0.0002   20    -23    18   -118             u=4      $ Water
17    5  -7.84    118:-129:65:-66                    u=4      $ Steel
18    2 -0.0002   64    -21    67   -118             u=4      $ Water
19    2 -0.0002   24    -65    67   -118             u=4      $ water
20    5  -7.84    21    -20    67   -118             u=4      $ Steel
21    5  -7.84    23    -24    67   -118             u=4      $ Steel
22    2 -0.0002  129    -64    33   -118             u=4      $ Water
c
23    5  -7.84    25    -64    30    -31             u=4      $ Steel
24    2 -0.0002   26    -25    30    -31             u=4      $ Water
25    7  -2.7     27    -26    30    -31             u=4      $ Al clad
26    6  -2.66    28    -27    30    -31             u=4      $ Boral
27    7  -2.7     29    -28    30    -31             u=4      $ Al clad
28    2 -0.0002  129    -29    30    -31             u=4      $ water
29    5  -7.84   129    -64    32    -30             u=4      $ Steel ends
30    5  -7.84   129    -64    31    -33             u=4      $ Steel ends
31    2 -0.0002  129    -64    66    -32             u=4      $ Water
c
c    Type A box - Boral only on left side
c
32    0  -10    11  -12   13         u=6 fill=1  (0.8128 0.8128 0)
33    3  -6.55    60    -61    62    -63  #8         u=6      $ Zr flow channel
34    2 -0.0002   64    -65    66   -118  #8 #9      u=6      $ water
35    5  -7.84    118:-129:65:-66                    u=6      $ Steel
36    2 -0.0002  129    -64    67   -118             u=6      $ Water
c
37    5  -7.84    25    -64    30    -31             u=6      $ Steel
38    2 -0.0002   26    -25    30    -31             u=6      $ Water
39    7  -2.7     27    -26    30    -31             u=6      $ Al clad
```

```
40    6  -2.66    28    -27    30   -31          u=6     $ Boral
41    7  -2.7     29    -28    30   -31          u=6     $ Al clad
42    2 -0.0002  129    -29    30   -31          u=6     $ water
43    2 -0.0002  129    -64    33   -67          u=6     $ Water
44    5  -7.84   129    -64    32   -30          u=6     $ Steel ends
45    5  -7.84   129    -64    31   -33          u=6     $ Steel ends
46    2 -0.0002  129    -64    66   -32          u=6     $ Water
c
c    Type B box -  Boral on Top only
c
47    0  -10    11  -12   13          u=7 fill=1  (0.8128 0.8128 0)
48    3  -6.55    60    -61    62   -63  #8      u=7     $ Zr flow channel
49    2 -0.0002   64    -65    66   -67  #8 #9   u=7     $ water
50    5  -7.84    20    -23    67   -14          u=7     $ 0.075" STEEL
51    2 -0.0002   20    -23    14   -15          u=7     $ WATER POCKET
52    7  -2.7     20    -23    15   -16          u=7     $ Al CLAD
53    6  -2.66    20    -23    16   -17          u=7     $ BORAL Absorber
54    7  -2.7     20    -23    17   -18          u=7     $ water
55    2 -0.0002   20    -23    18  -118          u=7     $ Water
56    5  -7.84    118:-129:65:-66                u=7     $ Steel
57    2 -0.0002   64    -21    67  -118          u=7     $ Water
58    2 -0.0002   24    -65    67  -118          u=7     $ water
59    5  -7.84    21    -20    67  -118          u=7     $ Steel
60    5  -7.84    23    -24    67  -118          u=7     $ Steel
61    2 -0.0002  129    -64    66  -118          u=7     $ Water
c
c    Type E box  - No Boral Panels
c
62    0  -10    11  -12   13          u=8 fill=1  (0.8128 0.8128 0)
63    3  -6.55    60    -61    62   -63  #8      u=8     $ Zr flow channel
64    2 -0.0002  129    -65    66  -118  #8 #9   u=8     $ water
65    5  -7.84    118:-129:65:-66                u=8     $ Steel
c
c    Type F box  - No Boral Panels or fuel
c
66    2 -0.0002  129    -65    66  -118          u=9     $ water
67    5  -7.84    118:-129:65:-66                u=9     $ Steel
c
68    2 -0.0002  -34  35  -36  37  u=5  lat=1  fill=-7:6  -7:6  0:0
               5 5 5 5 5 5 5 5 5 5 5 5 5 5
               5 9 9 9 9 9 9 9 9 9 9 9 9 5
               5 9 9 9 9 9 7 4 9 9 9 9 9 5
               5 9 9 9 7 4 4 4 4 4 9 9 9 5
               5 9 9 7 4 4 4 4 4 4 4 9 9 5
               5 9 9 7 4 4 4 4 4 4 4 9 9 5
               5 9 7 4 4 4 4 4 4 4 4 4 9 5
               5 9 8 4 4 4 4 4 4 4 4 6 9 5
               5 9 9 7 4 4 4 4 4 4 4 9 9 5
               5 9 9 8 4 4 4 4 4 4 6 9 9 5
               5 9 9 9 8 4 4 4 6 6 9 9 9 5
               5 9 9 9 9 9 8 6 9 9 9 9 9 5
               5 9 9 9 9 9 9 9 9 9 9 9 9 5
               5 5 5 5 5 5 5 5 5 5 5 5 5 5
69    0           -41               50   -49  fill=5 (8.1661  8.1661  0)
c
274   2 -0.0002  -41       360   -50   $ space below Fuel (7.3 in.)
275   5  -7.84   -42       362 -360    $ MPC Steel below Fuel (2.5 in.)
276   5  -7.84   -204      300 -362    $ Cask Steel (5.0 in.)
277   8  -2.35   -204      301  -300   $ Cask Concrete (17.0 in.)
278   5  -7.84   -204      302  -301   $ Cask Steel (2.0 in.)
c
279   2 -0.0002  -41        49  -361   $ space above Fuel (8.46 in.)
```

```
280    5  -7.84    -42       361  -363  $ MPC Steel above Fuel (10.0 in)
281    4 -1.00     -42       363  -400  $ Water (1.0 in.)
282    5  -7.84    -204      400  -401  $ Cask Steel (1.25 in.)
283    8  -2.35    -204      401  -402  $ Cask Concrete (10.5 in.)
284    5  -7.84    -204      402  -403  $ Cask Steel (4.0 in.)
c
290    5  -7.84     41  -42  360 -361   $ Radial Steel - MPC shell
291    4  -1.00     42  -200 362 -400   $ Radial Water
292    5  -7.84     200 -201 362 -400   $ Radial Steel - overpack inner shell
293    5  -7.84     201 -202 362 -400   $ Radial Steel -
294    8  -2.35     202 -203 362 -400   $ Radial Shield - Concrete Overpack
295    5  -7.84     203 -204 362 -400   $ Radial Steel - overpack outer shell
c
500    4  -1.00     500 -501 -505  (204 :-302:  403)    $ outer water reflector
501    0            505 :-500: 501      $ outside world

1      cz          0.5283      $ Fuel OD
2      cz          0.5398      $ Clad ID
3      cz          0.6134      $ Clad OD
4      cz          0.6744      $ Thimble ID
5      cz          0.7506      $ Thimble OD
6      px          0.8128      $ Pin Pitch
7      px         -0.8128
8      py          0.8128
9      py         -0.8128
10     px          6.6231      $ Channel ID
11     px         -6.6231
12     py          6.6231
13     py         -6.6231
14     py          7.8016
15     py          7.8155
16     py          7.8410
17     py          8.0467
18     py          8.0721
118    py          8.0861
20     px         -6.0325
21     px         -6.2230
23     px          6.0325
24     px          6.2230
25     px         -7.8016
26     px         -7.8155
27     px         -7.8410
28     px         -8.0467
29     px         -8.0721
129    px         -8.0861
30     py         -6.0325
31     py          6.0325
32     py         -6.2230
33     py          6.2230
34     px          7.6111
35     px         -8.7211
36     py          8.7211
37     py         -7.6111
49     pz          381.         $ Top of Active Fuel
50     pz            0          $ Start of Active Fuel
60     px         -6.9279       $ Channel OD
61     px          6.9279
62     py         -6.9279
63     py          6.9279
64     px         -7.6111       $ Cell Box ID
65     px          7.6111
66     py         -7.6111
```

```
67     py           7.6111
360    pz          -18.54    $ lower thkness = 7.30 in.
361    pz           402.49   $ upper thkness = 8.46 in.
362    pz          -24.892   $ thkness of MPC baseplate = 2.5 in.
363    pz           427.89   $ thkness of MPC lid = 10.  in.
41     cz          85.57     $ I.D. = 67.375 in.
42     cz          86.84     $ I.D. = 68.375 in.
200    cz          93.35     $ I.D. = 73.50 in.
201    cz          96.52     $ I.D. = 76.00 in.
202    cz          98.43     $ I.D. = 77.50 in.
203    cz         166.37     $ I.D. = 131.00 in.
204    cz         168.28     $ I.D. = 132.50 in.
300    pz         -37.59     $ thkness steel - 5.0 in.
301    pz         -80.77     $ thkness concrete - 17.0 in.
302    pz         -85.85     $ thkness steel - 2.0 in.
400    pz         430.43     $ thkness water - 1.0 in.
401    pz         433.605    $ thkness steel - 1.25 in.
402    pz         460.28     $ thkness concrete - 10.5 in.
403    pz         465.355     $ thkness steel - 4.0 in.
c
*500   pz -115.85  $ lower boundary
*501   pz  495.355 $ upper boundary
*505   cz  198.28  $ outer radial boundary

imp:n     1 86r 0
kcode   10000  0.94   20  120
c
sdef  par=1  erg=d1 axs=0 0 1 x=d4 y=fx d5 z=d3
c
sp1 -2 1.2895
c
si3  h 0 381.
sp3  0 1
c
c
si4  s               15 16
              13 14 15 16 17 18
           12 13 14 15 16 17 18 19
           12 13 14 15 16 17 18 19
        11 12 13 14 15 16 17 18 19 20
        11 12 13 14 15 16 17 18 19 20
           12 13 14 15 16 17 18 19
           12 13 14 15 16 17 18 19
              13 14 15 16 17 18
                    15 16
sp4  1 67r
c
ds5  s               30 30
              29 29 29 29 29 29
           28 28 28 28 28 28 28 28
           27 27 27 27 27 27 27 27
        26 26 26 26 26 26 26 26 26 26
        25 25 25 25 25 25 25 25 25 25
           24 24 24 24 24 24 24 24
           23 23 23 23 23 23 23 23
              22 22 22 22 22 22
                    21 21
c
si11  -80.6831 -67.6783
si12  -64.1985 -51.1937
si13  -47.7139 -34.7091
si14  -31.2293 -18.2245
```

```
si15  -14.7447 -1.7399
si16   1.7399   14.7447
si17   18.2245  31.2293
si18   34.7091  47.7139
si19   51.1937  64.1985
si20   67.6783  80.6831
c
si21  -80.6831 -67.6783
si22  -64.1985 -51.1937
si23  -47.7139 -34.7091
si24  -31.2293 -18.2245
si25  -14.7447 -1.7399
si26   1.7399   14.7447
si27   18.2245  31.2293
si28   34.7091  47.7139
si29   51.1937  64.1985
si30   67.6783  80.6831
sp11  0 1
sp12  0 1
sp13  0 1
sp14  0 1
sp15  0 1
sp16  0 1
sp17  0 1
sp18  0 1
sp19  0 1
sp20  0 1
sp21  0 1
sp22  0 1
sp23  0 1
sp24  0 1
sp25  0 1
sp26  0 1
sp27  0 1
sp28  0 1
sp29  0 1
sp30  0 1
c
m1          92235.50c   -0.03702  $ 4.20% E Fuel
            92238.50c   -0.84448
            8016.50c    -0.1185
m2          8016.50c    1.           $ Void
m3          40000.56c   1.           $ Zr Clad
m4          1001.50c    0.6667       $ Water
            8016.50c    0.3333
m5          24000.50c   0.01761      $ Steel
            25055.50c   0.001761
            26000.55c   0.05977
            28000.50c   0.008239
m6          5010.50c    8.0707E-03   $ Boral
            5011.50c    3.2553E-02
            6000.50c    1.0146E-02
            13027.50c   3.8054E-02
m7          13027.50c    1.           $ Al Clad
m8          13027.50c  -0.0048       $ Concrete
            14000.50c  -0.315
             8016.50c  -0.500
             1001.50c  -0.006
            11023.50c  -0.017
            20000.50c  -0.083
            26000.55c  -0.012
            19000.50c  -0.019
```

```
mt4         lwtr.01t
mt8         lwtr.01t
prdmp    j   -60   j   2
fm4      1000   1   -6
f4:n   1
sd4      1000
e4     1.000E-11   1.000E-10   5.000E-10   7.500E-10   1.000E-09   1.200E-09
       1.500E-09   2.000E-09   2.500E-09   3.000E-09
       4.700E-09   5.000E-09   7.500E-09   1.000E-08   2.530E-08
       3.000E-08   4.000E-08   5.000E-08   6.000E-08   7.000E-08
       8.000E-08   9.000E-08   1.000E-07   1.250E-07   1.500E-07
       1.750E-07   2.000E-07   2.250E-07   2.500E-07   2.750E-07
       3.000E-07   3.250E-07   3.500E-07   3.750E-07   4.000E-07
       4.500E-07   5.000E-07   5.500E-07   6.000E-07   6.250E-07
       6.500E-07   7.000E-07   7.500E-07   8.000E-07   8.500E-07
       9.000E-07   9.250E-07   9.500E-07   9.750E-07   1.000E-06
       1.010E-06   1.020E-06   1.030E-06   1.040E-06   1.050E-06
       1.060E-06   1.070E-06   1.080E-06   1.090E-06   1.100E-06
       1.110E-06   1.120E-06   1.130E-06   1.140E-06   1.150E-06
       1.175E-06   1.200E-06   1.225E-06   1.250E-06   1.300E-06
       1.350E-06   1.400E-06   1.450E-06   1.500E-06   1.590E-06
       1.680E-06   1.770E-06   1.860E-06   1.940E-06   2.000E-06
       2.120E-06   2.210E-06   2.300E-06   2.380E-06   2.470E-06
       2.570E-06   2.670E-06   2.770E-06   2.870E-06   2.970E-06
       3.000E-06   3.050E-06   3.150E-06   3.500E-06   3.730E-06
       4.000E-06   4.750E-06   5.000E-06   5.400E-06   6.000E-06
       6.250E-06   6.500E-06   6.750E-06   7.000E-06   7.150E-06
       8.100E-06   9.100E-06   1.000E-05   1.150E-05   1.190E-05
       1.290E-05   1.375E-05   1.440E-05   1.510E-05   1.600E-05
       1.700E-05   1.850E-05   1.900E-05   2.000E-05   2.100E-05
       2.250E-05   2.500E-05   2.750E-05   3.000E-05   3.125E-05
       3.175E-05   3.325E-05   3.375E-05   3.460E-05   3.550E-05
       3.700E-05   3.800E-05   3.910E-05   3.960E-05   4.100E-05
       4.240E-05   4.400E-05   4.520E-05   4.700E-05   4.830E-05
       4.920E-05   5.060E-05   5.200E-05   5.340E-05   5.900E-05
       6.100E-05   6.500E-05   6.750E-05   7.200E-05   7.600E-05
       8.000E-05   8.200E-05   9.000E-05   1.000E-04   1.080E-04
       1.150E-04   1.190E-04   1.220E-04   1.860E-04   1.925E-04
       2.075E-04   2.100E-04   2.400E-04   2.850E-04   3.050E-04
       5.500E-04   6.700E-04   6.830E-04   9.500E-04   1.150E-03
       1.500E-03   1.550E-03   1.800E-03   2.200E-03   2.290E-03
       2.580E-03   3.000E-03   3.740E-03   3.900E-03   6.000E-03
       8.030E-03   9.500E-03   1.300E-02   1.700E-02   2.500E-02
       3.000E-02   4.500E-02   5.000E-02   5.200E-02   6.000E-02
       7.300E-02   7.500E-02   8.200E-02   8.500E-02   1.000E-01
       1.283E-01   1.500E-01   2.000E-01   2.700E-01   3.300E-01
       4.000E-01   4.200E-01   4.400E-01   4.700E-01   4.995E-01
       5.500E-01   5.730E-01   6.000E-01   6.700E-01   6.790E-01
       7.500E-01   8.200E-01   8.611E-01   8.750E-01   9.000E-01
       9.200E-01   1.010E+00   1.100E+00   1.200E+00   1.250E+00
       1.317E+00   1.356E+00   1.400E+00   1.500E+00   1.850E+00
       2.354E+00   2.479E+00   3.000E+00   4.304E+00   4.800E+00
       6.434E+00   8.187E+00   1.000E+01   1.284E+01   1.384E+01
       1.455E+01   1.568E+01   1.733E+01   2.000E+01
```

SUPPLEMENT 6.I

(This Section Reserved for Future Use)

SUPPLEMENT 6.II

CRITICALITY EVALUATION OF INDIAN POINT 1 FUEL IN THE MPC-32

6.II.0 INTRODUCTION

This supplement is focused on providing additional criticality evaluations for Indian Point Unit 1 fuel (Array class 14x14E) in the MPC-32. The evaluation presented herein supplements those evaluations contained in the main body of Chapter 6 of this FSAR, and information in the main body of Chapter 6 is not repeated in this supplement. To aid the reader, the sections in this supplement are numbered in the same fashion as the corresponding sections in the main body of this chapter, i.e., Sections 6.II.1 through 6.II.6 correspond to Sections 6.1 through 6.6. Tables and figures in this supplement are labeled sequentially.

6.II.1 DISCUSSION AND RESULTS

Indian Point Unit 1 (IP1) is a nuclear power plant that was shut down in 1974. IP1 used a unique fuel assembly type identified as assembly class 14x14E in the main body of this chapter. IP1 fuel assemblies are currently stored in the IP1 spent fuel pool and need to be transferred into dry storage. The spent fuel pool at IP1 does normally not contain any soluble boron, and, while the assemblies are considered technically intact, they might not meet the requirements of intact fuel as defined in Chapter 1 of this FSAR. Specifically, records available for these assemblies are not sufficient to show that fuel assemblies have no cladding failures larger than pinhole leaks or hairline cracks, and further leakage tests of these assemblies might not be conclusive due to the age and low burnup of these assemblies. Therefore, all IP1 assemblies are required to be stored in DFCs. To qualify IP1 assemblies for dry storage in the MPC-32, this supplement therefore evaluates the following conditions:

> Assembly class 14x14E in the MPC-32 filled with pure unborated water, with intact assemblies, or assumed damaged assemblies in any location. Intact assemblies are not modeled in DFCs, while damaged assemblies are modeled in DFCs.

Results of the evaluations are summarized in Table 6.II.1 below, for intact assemblies, and for a bounding condition where all basket locations are filled with damaged fuel. The results demonstrate that the effective multiplication factor (k_{eff}) of the HI-STORM 100 System under the bounding conditions for IP1 fuel, including all biases and uncertainties evaluated with a 95% probability at the 95% confidence level, does not exceed 0.95 under all credible conditions.

6.II.2 SPENT FUEL LOADING

Calculations in this supplement are only performed for assembly class 14x14E, as characterized in the main part of this chapter in Section 6.2. Note that the calculations in this supplement are performed with an enrichment of 4.5 wt% ^{235}U, which bounds the enrichment of the actual fuel to be loaded, instead of the maximum value of 5 wt% ^{235}U used in the main part of this chapter. This is reflected in the definition of the authorized contents in Chapter 2.

6.II.3 MODEL SPECIFICATION

Calculations in this supplement are only performed for the MPC-32, using the conservative modeling assumptions described in the main part of this chapter in Section 6.3. Calculations are performed with assemblies centered in each cell, and for an eccentric condition where all assemblies are moved towards the center of the basket. Note that the active length of the fuel is conservatively assumed to be 150 inches, while the actual active fuel length is only 102 inches. The same assumption is made in the main part of this chapter for this assembly class (see Table 6.2.10). The DFCs contain outer spacers to minimize lateral movement of the DFCs in the cells. While these spacers are ½ inch thick, they are modeled as 3/8 inch for calculations with DFCs and eccentric positioning. This is conservative since it places fuel closer to each other in the center of the basket for this eccentric fuel positioning. Additionally, for the eccentric positioning, it is assumed that the content of the DFC is moved closest to the center of the basket. A single basket cell showing this condition is depicted in Figure 6.II.1. For the details on the modeling assumptions for the damaged fuel inside the DFC see the discussion in the following Section 6.II.4. This section also lists the detailed results of the calculations.

Note that all calculations in this supplement are performed for the HI-STAR overpack under fully flooded conditions. This bounds the HI-STORM storage condition, and is statistically equivalent to the condition in the HI-TRAC, as discussed in the main part of this chapter.

6.II.4 CRITICALITY CALCULATIONS

6.II.4.1 Intact Assemblies

The calculations for intact assemblies are identical to the calculations in the main part of this chapter, except that the borated water is replaced by pure water. Results of the calculations are listed in Table 6.II.2 for centered and eccentric conditions. As expected, based on the evaluations presented in the main part of this Chapter in Section 6.3, the eccentric position results in the higher reactivity. Nevertheless, all maximum k_{eff} values are below the regulatory limit by a substantial margin.

6.II.4.2 Damaged Assemblies

IP1 fuel assemblies have a stainless steel shroud/channel that surround all fuel rods, similar to BWR assemblies, although for the IP1 assembly this channel is perforated. The grid straps are apparently connected to the inside of this channel. The channel and grid straps therefore form the support structure for the assembly. In case of any damage to fuel rods, the broken rods would therefore be predominantly confined to the inside of this channel. Note that the fuel cladding of the IP1 fuel is also made from stainless steel, which has a much higher resistance to damage than the zirconium alloys used in other fuel types. Cladding damage to IP1 fuel is therefore much less likely. Nevertheless, cladding damage is conservatively assumed to occur. Local damage to individual rods would merely create slight relocation of rods within the rod array, which would have little if any effect on reactivity. More extensive damage, however, could result in the relocation of fuel rods within the assembly, i.e. create areas with reduced and increased numbers of rods within the assembly. This would have an effect on the local fuel-to-water ratio, which can significantly affect reactivity since intact PWR fuel assemblies are under-moderated, i.e. removing rods increases reactivity. To evaluate the reactivity effect of removing each individual fuel rod would be highly impractical. Instead, the damaged fuel approach models different array sizes of rods within the assembly, where each array size has a pitch so that it fills the inside of the channel. A total of 7 arrays, from 9x9 to 15x15 fuel rods are evaluated. Note that the outer dimension of the rod array is taken as the outside dimension of the channel around the rods, and the channel itself is neglected. This is conservative since it increases the area occupied by fuel and neglects steel which would provide some additional neutron absorption. Figure 6.II.1 shows the calculational model for a 12x12 array of rods. The results are shown in Table 6.II.3. In all cases, the condition is assumed to exist in all 32 assemblies of the MPC, and along the entire active length. As expected, an optimum moderation condition exists. This condition corresponds to a 12x12 array. For this condition, the reactivity is higher than for the intact assembly. However, even in this conservative and practically non-credible condition, the maximum k_{eff} is well below the regulatory limit by a substantial margin. Note that since the model assumes the cladding to remain in the fuel channel, it does not bound fuel debris. Fuel debris is therefore not qualified for the 14x14E in the MPC-32.

6.II.5 CRITICALITY BENCHMARKS

Fuel, fuel conditions, basket design and moderation conditions are bounded by the corresponding conditions in the main body of Chapter 6. The benchmark calculations in the main body are therefore directly applicable to the calculations performed in this supplement.

6.II.6 REGULATORY COMPLIANCE

In summary, the evaluation presented in this supplement demonstrate that the HI-STORM 100 System is in full compliance with the criticality requirements of 10CFR72 and consistent with NUREG-1536.

Table 6.II.1

BOUNDING MAXIMUM k_{eff} VALUES FOR ASSEMBLY CLASS 14x14E IN THE MPC-32 WITHOUT SOLUBLE BORON

Fuel Condition	Maximum Allowable Enrichment (wt% ^{235}U)	Maximum† k_{eff}
Intact	4.5	0.8770
Damaged	4.5	0.9181

† The term "maximum k_{eff}" as used here, and elsewhere in this document, means the highest possible k-effective, including bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

Table 6.II.2

MAXIMUM k_{eff} VALUES FOR ASSEMBLY CLASS 14x14E IN THE MPC-32 WITHOUT SOLUBLE BORON FOR INTACT ASSEMBLIES

Fuel Location	Maximum Allowable Enrichment (wt% ^{235}U)	Maximum† k_{eff}
Cell Centered	4.5	0.8410
Eccentric location, moved towards basket center	4.5	0.8770

† The term "maximum k_{eff}" as used here, and elsewhere in this document, means the highest possible k-effective, including bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

Table 6.II.3

MAXIMUM k_{eff} VALUES FOR ASSEMBLY CLASS 14x14E IN THE MPC-32 WITHOUT SOLUBLE BORON FOR ROD ARRAYS SIMULATING DAMAGED FUEL ASSEMBLIES

Rod Array	**Maximum Allowable Enrichment (wt% ^{235}U)**	**Maximum† k_{eff}**	
		Cell Centered	Eccentric
9x9	4.5	0.8381	0.8587
10x10	4.5	0.8722	0.8971
11x11	4.5	0.8882	0.9160
12x12	4.5	0.8906	0.9181
13x13	4.5	0.8808	0.9079
14x14	4.5	0.8615	0.8894
15x15	4.5	0.8335	0.8627

† The term "maximum k_{eff}" as used here, and elsewhere in this document, means the highest possible k-effective, including bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

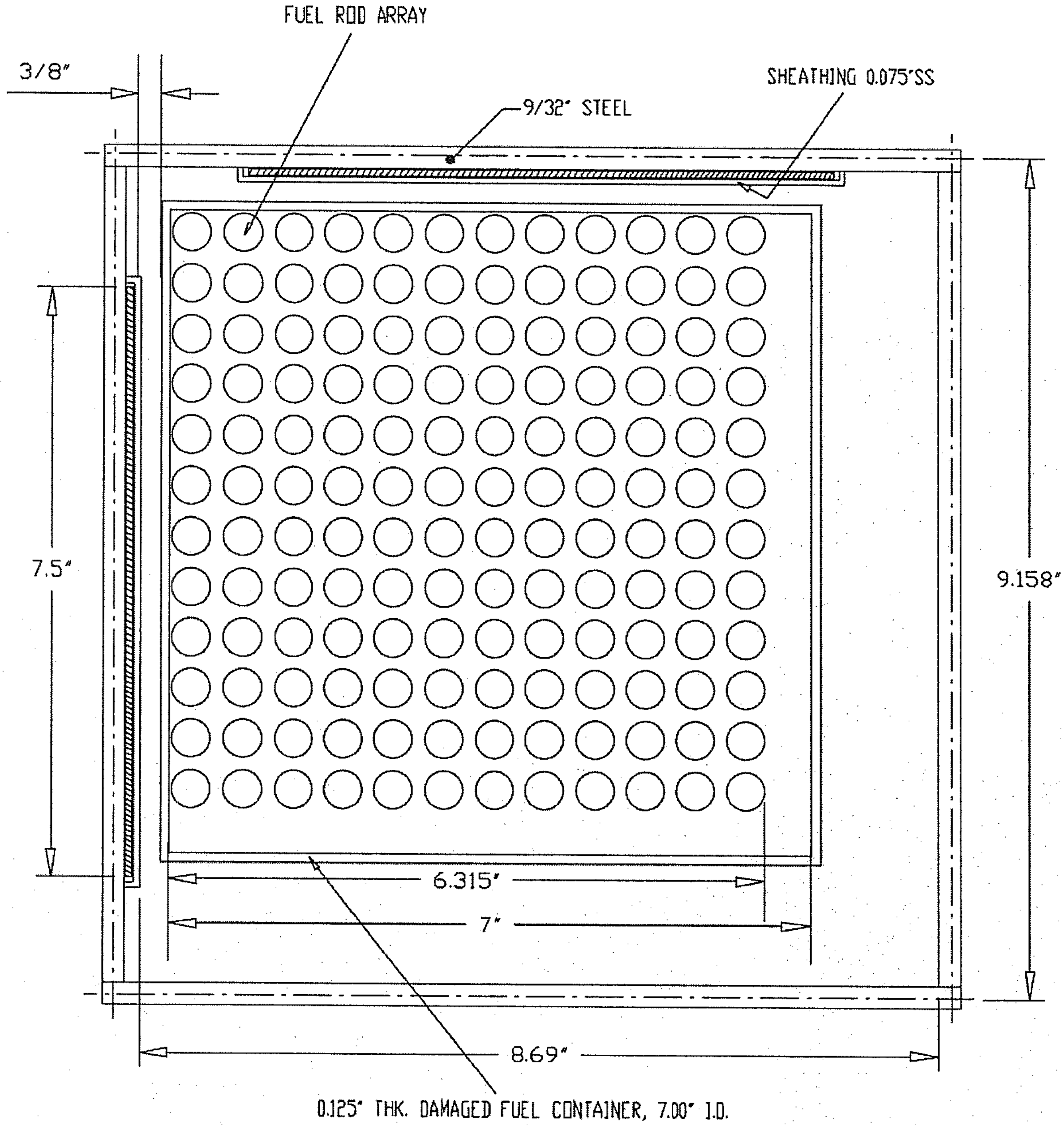

FIGURE 6.11.1; DAMAGED FUEL/FUEL DEBRIS CALCULATION MODEL (PLANAR CROSS-SECTION) WITH BARE FUEL RODS IN THE MPC-32 BASKET FOR IP1 FUEL
(SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

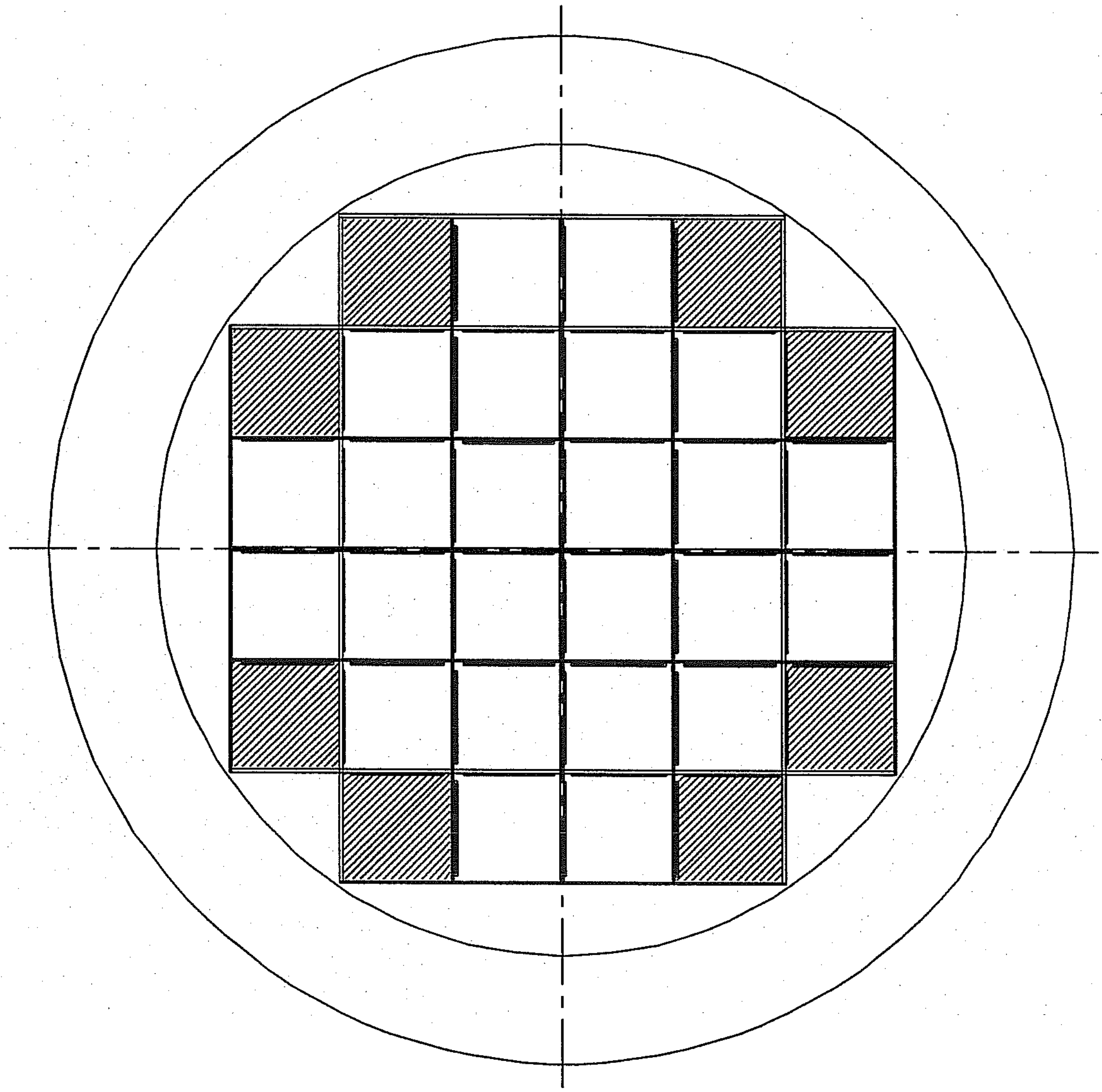

FIGURE 6.4.16; LOCATIONS OF THE DAMAGED FUEL CONTAINERS IN THE MPC-32.

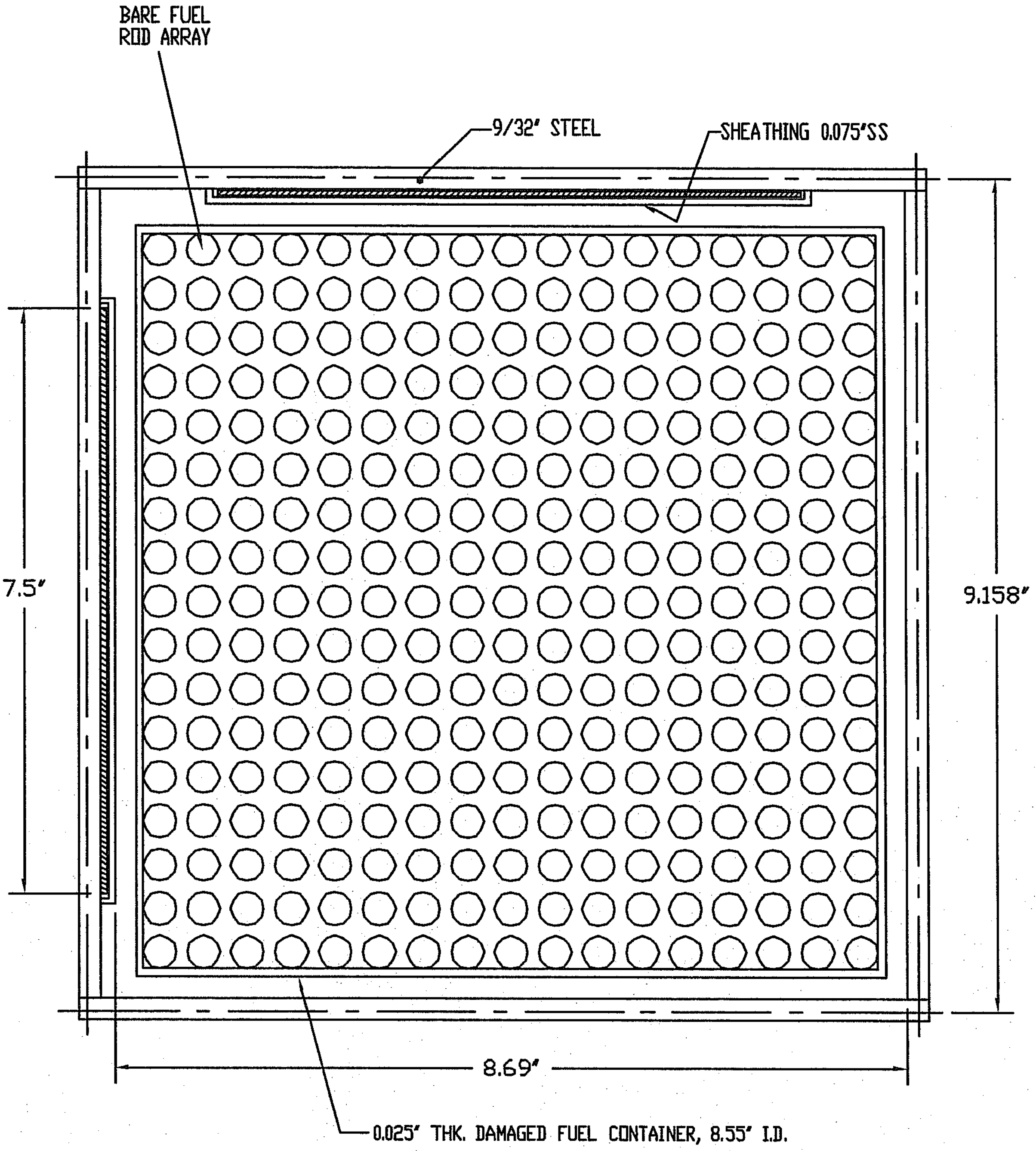

FIGURE 6.4.17j DAMAGED FUEL/FUEL DERIS CALCULATION MODEL (PLANAR CROSS-SECTION) WITH BARE FUEL RODS IN THE MPC-32 BASKET

(SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

6.5 CRITICALITY BENCHMARK EXPERIMENTS

Benchmark calculations have been made on selected critical experiments, chosen, insofar as possible, to bound the range of variables in the cask designs. The most important parameters are (1) the enrichment, (2) the water-gap size (MPC-24) or cell spacing (MPC-68), and (3) the ^{10}B loading of the neutron absorber panels. Other parameters, within the normal range of cask and fuel designs, have a smaller effect, but are also included. No significant trends were evident in the benchmark calculations or the derived bias. Detailed benchmark calculations are presented in Appendix 6.A.

The benchmark calculations were performed with the same computer codes and cross-section data, described in Section 6.4, that were used to calculate the k_{eff} values for the cask. Further, all calculations were performed on the same computer hardware, specifically, personal computers using the pentium processor.

6.6 REGULATORY COMPLIANCE

This chapter documents the criticality evaluation of the HI-STORM 100 System for the storage of spent nuclear fuel. This evaluation demonstrates that the HI-STORM 100 System is in full compliance with the criticality requirements of 10CFR72 and NUREG-1536.

Structures, systems, and components important to criticality safety, as well as the limiting fuel characteristics, are described in sufficient detail in this chapter to enable an evaluation of their effectiveness.

The HI-STORM 100 System is designed to be subcritical under all credible conditions. The criticality design is based on favorable geometry and fixed neutron poisons (Boral). An appraisal of the fixed neutron poisons has shown that they will remain effective for a storage period greater than 20 years, and there is no credible way to lose it, therefore there is no need to provide a positive means to verify their continued efficacy as required by 10CFR72.124(b).

The criticality evaluation has demonstrated that the cask will enable the storage of spent fuel for a minimum of 20 years with an adequate margin of safety. Further, the evaluation has demonstrated that the design basis accidents have no adverse effect on the design parameters important to criticality safety, and therefore, the HI-STORM 100 System is in full compliance with the double contingency requirements of 10CRF72.124. Therefore, it is concluded that the criticality design features for the HI-STORM 100 System are in compliance with 10 CFR Part 72 and that the applicable design and acceptance criteria have been satisfied. The criticality evaluation provides reasonable assurance that the HI-STORM 100 System will allow safe storage of spent fuel.

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APPENDIX 6.A: BENCHMARK CALCULATIONS

6.A.1 INTRODUCTION AND SUMMARY

Benchmark calculations have been made on selected critical experiments, chosen, in so far as possible, to bound the range of variables in the cask designs. Two independent methods of analysis were used, differing in cross section libraries and in the treatment of the cross sections. MCNP4a [6.A.1] is a continuous energy Monte Carlo code and KENO5a [6.A.2] uses group-dependent cross sections. For the KENO5a analyses reported here, the 238-group library was chosen, processed through the NITAWL-II [6.A.2] program to create a working library and to account for resonance self-shielding in uranium-238 (Nordheim integral treatment). The 238 group library was chosen to avoid or minimize the errors† (trends) that have been reported (e.g., [6.A.3 through 6.A.5]) for calculations with collapsed cross section sets.

In cask designs, the three most significant parameters affecting criticality are (1) the fuel enrichment, (2) the ^{10}B loading in the neutron absorber, and (3) the lattice spacing (or water-gap thickness if a flux-trap design is used). Other parameters, within the normal range of cask and fuel designs, have a smaller effect, but are also included in the analyses.

Table 6.A.1 summarizes results of the benchmark calculations for all cases selected and analyzed, as referenced in the table. The effect of the major variables are discussed in subsequent sections below. It is important to note that there is obviously considerable overlap in parameters since it is not possible to vary a single parameter and maintain criticality; some other parameter or parameters must be concurrently varied to maintain criticality.

One possible way of representing the data is through a spectrum index that incorporates all of the variations in parameters. KENO5a computes and prints the "energy of the average lethargy causing fission". In MCNP4a, by utilizing the tally option with the identical 238-group energy structure as in KENO5a, the number of fissions in each group may be collected and the energy of the average lethargy causing fission determined (post-processing).

Figures 6.A.1 and 6.A.2 show the calculated k_{eff} for the benchmark critical experiments as a function of the "energy of the average lethargy causing fission" for MCNP4a and KENO5a, respectively (UO_2 fuel only). The scatter in the data (even for comparatively minor variation in

† Small but observable trends (errors) have been reported for calculations with the 27-group and 44-group collapsed libraries. These errors are probably due to the use of a single collapsing spectrum when the spectrum should be different for the various cases analyzed, as evidenced by the spectrum indices.

critical parameters) represents experimental error[†] in performing the critical experiments within each laboratory, as well as between the various testing laboratories. The B&W critical experiments show a larger experimental error than the PNL criticals. This would be expected since the B&W criticals encompass a greater range of critical parameters than the PNL criticals.

Linear regression analysis of the data in Figures 6.A.1 and 6.A.2 show that there are no trends, as evidenced by very low values of the correlation coefficient (0.13 for MCNP4a and 0.21 for KENO5a). The total bias (systematic error, or mean of the deviation from a k_{eff} of exactly 1.000) for the two methods of analysis are shown in the table below.

Calculational Bias of MCNP4a and KENO5a		
	Total	Truncated
MCNP4a	0.0009 ± 0.0011	0.0021 ± 0.0006
KENO5a	0.0030 ± 0.0012	0.0036 ± 0.0009

The values of bias shown in this table include both the bias derived directly from the calculated k_{eff} values in Table 6.A.1, and a more conservative value derived by arbitrarily truncating to 1.000 any calculated value that exceeds 1.000. The bias and standard error of the bias were calculated by the following equations[††], with the standard error multiplied by the one-sided K-factor for 95% probability at the 95% confidence level from NBS Handbook 91 [6.A.18] (for the number of cases analyzed, the K-factor is ~2.05 or slightly more than 2).

$$\bar{k} = \frac{1}{n}\sum_{i=1}^{n} k_i \qquad (6.A.1)$$

† A classical example of experimental error is the corrected enrichment in the PNL experiments, first as an addendum to the initial report and, secondly, by revised values in subsequent reports for the same fuel rods.

†† These equations may be found in any standard text on statistics, for example, reference [6.A.6] (or the MCNP4a manual) and is the same methodology used in MCNP4a and in KENO5a.

$$\sigma_{\bar{k}}^2 = \frac{\sum_{i=1}^{n} k_i^2 - (\sum_{i=1}^{n} k_i)^2 / n}{n(n-1)} \quad (6.A.2)$$

$$\text{Bias} = (1 - \bar{k}) \pm K\sigma_{\bar{k}} \quad (6.A.3)$$

where k_i are the calculated reactivities for n critical experiments; $\sigma_{\bar{k}}$ is the unbiased estimator of the standard deviation of the mean (also called the standard error of the bias (mean)); and K is the one-sided multiplier for 95% probability at the 95% confidence level (NBS Handbook 91 [6.A.18]).

Formula 6.A.3 is based on the methodology of the National Bureau of Standards (now NIST) and is used to calculate the values presented on page 6.A-2. The first portion of the equation, ($1-\bar{k}$), is the actual bias which is added to the MCNP4a and KENO5a results. The second term, $K\sigma_{\bar{k}}$, which corresponds to σ_B in Section 6.4.3, is the uncertainty or standard error associated with the bias. The K values used were obtained from the National Bureau of Standards Handbook 91 and are for one-sided statistical tolerance limits for 95% probability at the 95% confidence level. The actual K values for the 56 critical experiments evaluated with MCNP4a and the 53 critical experiments evaluated with KENO5a are 2.04 and 2.05, respectively.

The larger of the calculational biases (truncated bias) was used to evaluate the maximum k_{eff} values for the cask designs.

6.A.2 Effect of Enrichment

The benchmark critical experiments include those with enrichments ranging from 2.46% to 5.74% and therefore span the enrichment range for the MPC designs. Figures 6.A.3 and 6.A.4 show the calculated k_{eff} values (Table 6.A.1) as a function of the fuel enrichment reported for the critical experiments. Linear regression analyses for these data confirms that there are no trends, as indicated by low values of the correlation coefficients (0.03 for MCNP4a and 0.38 for KENO5a). Thus, there are no corrections to the bias for the various enrichments.

As further confirmation of the absence of any trends with enrichment, the MPC-68 configuration was calculated with both MCNP4a and KENO5a for various enrichments. The cross-comparison of calculations with codes of comparable sophistication is suggested in Reg. Guide 3.41. Results of this comparison, shown in Table 6.A.2 and Figure 6.A.5, confirm no significant difference in the calculated values of k_{eff} for the two independent codes as evidenced by the 45° slope of the curve. Since it is very unlikely that two independent methods of analysis would be subject to the same error, this comparison is considered confirmation of the absence of an enrichment effect (trend) in the bias.

6.A.3 Effect of ^{10}B Loading

Several laboratories have performed critical experiments with a variety of thin absorber panels similar to the Boral panels in the cask designs. Of these critical experiments, those performed by B&W are the most representative of the cask designs. PNL has also made some measurements with absorber plates, but, with one exception (a flux-trap experiment), the reactivity worth of the absorbers in the PNL tests is very low and any significant errors that might exist in the treatment of strong thin absorbers could not be revealed.

Table 6.A.3 lists the subset of experiments using thin neutron absorbers (from Table 6.A.1) and shows the reactivity worth (Δk) of the absorber.†

No trends with reactivity worth of the absorber are evident, although based on the calculations shown in Table 6.A.3, some of the B&W critical experiments seem to have unusually large experimental errors. B&W made an effort to report some of their experimental errors. Other laboratories did not evaluate their experimental errors.

To further confirm the absence of a significant trend with ^{10}B concentration in the absorber, a cross-comparison was made with MCNP4a and KENO5a (as suggested in Reg. Guide 3.41). Results are shown in Figure 6.A.6 and Table 6.A.4 for the MPC-68 cask†† geometry. These data substantiate the absence of any error (trend) in either of the two codes for the conditions analyzed (data points fall on a 45° line, within an expected 95% probability limit).

† The reactivity worth of the absorber panels was determined by repeating the calculation with the absorber analytically removed and calculating the incremental (Δk) change in reactivity due to the absorber.

†† The MPC-68 geometry was chosen for this comparison since it contains the greater number of Boral panels and would therefore be expected to be the most sensitive to trends (errors) in calculations.

6.A.4 Miscellaneous and Minor Parameters

6.A.4.1 Reflector Material and Spacings

PNL has performed a number of critical experiments with thick steel and lead reflectors.† Analysis of these critical experiments are listed in Table 6.A.5 (subset of data in Table 6.A.1). There appears to be a small tendency toward overprediction of k_{eff} at the lower spacing, although there are an insufficient number of data points in each series to allow a quantitative determination of any trends. The tendency toward overprediction at close spacing means that the cask calculations may be slightly more conservative than otherwise.

6.A.4.2 Fuel Pellet Diameter and Lattice Pitch

The critical experiments selected for analysis cover a range of fuel pellet diameters from 0.311 to 0.444 inches, and lattice spacings from 0.476 to 1.00 inches. In the cask designs, the fuel pellet diameters range from 0.303 to 0.3835 inches O.D. (0.496 to 0.580 inch lattice spacing) for PWR fuel and from 0.3224 to 0.498 inches O.D. (0.488 to 0.740 inch lattice spacing) for BWR fuel. Thus, the critical experiments analyzed provide a reasonable representation of the fuel in the MPC designs. Based on the data in Table 6.A.1, there does not appear to be any observable trend with either fuel pellet diameter or lattice pitch, at least over the range of the critical experiments or the cask designs.

6.A.4.3 Soluble Boron Concentration Effects

Various soluble boron concentrations were used in the B&W series of critical experiments and in one PNL experiment, with boron concentrations ranging up to 2550 ppm. Results of MCNP4a (and one KENO5a) calculations are shown in Table 6.A.6. Analyses of the very high boron concentration experiments (>1300 ppm) show a tendency to slightly overpredict reactivity for the three experiments exceeding 1300 ppm. In turn, this would suggest that the evaluation of the MPC-32 with various soluble boron concentration could be slightly conservative for the high soluble boron concentration.

6.A.5 MOX Fuel

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†Parallel experiments with a depleted uranium reflector were also performed but not included in the present analysis since they are not pertinent to the Holtec cask design. A lead reflector is also not directly pertinent, but might be used in future designs.

The number of critical experiments with PuO_2 bearing fuel (MOX) is more limited than for UO_2 fuel. However, a number of MOX critical experiments have been analyzed and the results are shown in Table 6.A.7. Results of these analyses are generally above a k_{eff} of 1.00, indicating that when Pu is present, MCNP4a and KENO5a overpredict the reactivity.

This may indicate that calculation for MOX fuel will be expected to be conservative, especially with MCNP4a. It may be noted that for the larger lattice spacings, the KENO5a calculated reactivities are below 1.00, suggested that a small trend may exist with KENO5a. It is also possible that the overprediction in k_{eff} in both codes may be due to a small inadequacy in the determination of the Pu-241 decay and Am-241 growth. This possibility is supported by the consistency in calculated k_{eff} over a wide range of the spectral index (energy of the average lethargy causing fission).

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Table 6.A.1
Summary of Criticality Benchmark Calculations

	Reference	Identification	Enrich.	Calculated k_{eff} MCNP4a	Calculated k_{eff} KENO5a	EALF (eV) MCNP4a	EALF (eV) KENO5a
1	B&W-1484 (6.A.7)	Core I	2.46	0.9964 ± 0.0010	0.9898 ± 0.0006	0.1759	0.1753
2	B&W-1484 (6.A.7)	Core II	2.46	1.0008 ± 0.0011	1.0015 ± 0.0005	0.2553	0.2446
3	B&W-1484 (6.A.7)	Core III	2.46	1.0010 ± 0.0012	1.0005 ± 0.0005	0.1999	0.1939
4	B&W-1484 (6.A.7)	Core IX	2.46	0.9956 ± 0.0012	0.9901 ± 0.0006	0.1422	0.1426
5	B&W-1484 (6.A.7)	Core X	2.46	0.9980 ± 0.0014	0.9922 ± 0.0006	0.1513	0.1499
6	B&W-1484 (6.A.7)	Core XI	2.46	0.9978 ± 0.0012	1.0005 ± 0.0005	0.2031	0.1947
7	B&W-1484 (6.A.7)	Core XII	2.46	0.9988 ± 0.0011	0.9978 ± 0.0006	0.1718	0.1662
8	B&W-1484 (6.A.7)	Core XIII	2.46	1.0020 ± 0.0010	0.9952 ± 0.0006	0.1988	0.1965
9	B&W-1484 (6.A.7)	Core XIV	2.46	0.9953 ± 0.0011	0.9928 ± 0.0006	0.2022	0.1986
10	B&W-1484 (6.A.7)	Core XV††	2.46	0.9910 ± 0.0011	0.9909 ± 0.0006	0.2092	0.2014
11	B&W-1484 (6.A.7)	Core XVI††	2.46	0.9935 ± 0.0010	0.9889 ± 0.0006	0.1757	0.1713
12	B&W-1484 (6.A.7)	Core XVII	2.46	0.9962 ± 0.0012	0.9942 ± 0.0005	0.2083	0.2021

Table 6.A.1
Summary of Criticality Benchmark Calculations

	Reference	Identification	Enrich.	Calculated k_{eff} MCNP4a	Calculated k_{eff} KENO5a	EALF (eV) MCNP4a	EALF (eV) KENO5a
13	B&W-1484 (6.A.7)	Core XVIII	2.46	1.0036 ± 0.0012	0.9931 ± 0.0006	0.1705	0.1708
14	B&W-1484 (6.A.7)	Core XIX	2.46	0.9961 ± 0.0012	0.9971 ± 0.0005	0.2103	0.2011
15	B&W-1484 (6.A.7)	Core XX	2.46	1.0008 ± 0.0011	0.9932 ± 0.0006	0.1724	0.1701
16	B&W-1484 (6.A.7)	Core XXI	2.46	0.9994 ± 0.0010	0.9918 ± 0.0006	0.1544	0.1536
17	B&W-1645 (6.A.8)	S-type Fuel, w/886 ppm B	2.46	0.9970 ± 0.0010	0.9924 ± 0.0006	1.4475	1.4680
18	B&W-1645 (6.A.8)	S-type Fuel, w/746 ppm B	2.46	0.9990 ± 0.0010	0.9913 ± 0.0006	1.5463	1.5660
19	B&W-1645 (6.A.8)	SO-type Fuel, w/1156 ppm B	2.46	0.9972 ± 0.0009	0.9949 ± 0.0005	0.4241	0.4331
20	B&W-1810 (6.A.9)	Case 1 1337 ppm B	2.46	1.0023 ± 0.0010	NC	0.1531	NC
21	B&W-1810 (6.A.9)	Case 12 1899 ppm B	2.46/4.02	1.0060 ± 0.0009	NC	0.4493	NC
22	French (6.A.10)	Water Moderator 0 gap	4.75	0.9966 ± 0.0013	NC	0.2172	NC
23	French (6.A.10)	Water Moderator 2.5 cm gap	4.75	0.9952 ± 0.0012	NC	0.1778	NC
24	French (6.A.10)	Water Moderator 5 cm gap	4.75	0.9943 ± 0.0010	NC	0.1677	NC

Table 6.A.1
Summary of Criticality Benchmark Calculations

	Reference	Identification	Enrich.	Calculated k_{eff} MCNP4a	Calculated k_{eff} KENO5a	EALF (eV) MCNP4a	EALF (eV) KENO5a
25	French (6.A.10)	Water Moderator 10 cm gap	4.75	0.9979 ± 0.0010	NC	0.1736	NC
26	PNL-3602 (6.A.11)	Steel Reflector, 0 cm separation	2.35	NC	1.0004 ± 0.0006	NC	0.1018
27	PNL-3602 (6.A.11)	Steel Reflector, 1.321 cm separation	2.35	0.9980 ± 0.0009	0.9992 ± 0.0006	0.1000	0.0909
28	PNL-3602 (6.A.11)	Steel Reflector, 2.616 cm separation	2.35	0.9968 ± 0.0009	0.9964 ± 0.0006	0.0981	0.0975
29	PNL-3602 (6.A.11)	Steel Reflector, 3.912 cm separation	2.35	0.9974 ± 0.0010	0.9980 ± 0.0006	0.0976	0.0970
30	PNL-3602 (6.A.11)	Steel Reflector, Infinite separation	2.35	0.9962 ± 0.0008	0.9939 ± 0.0006	0.0973	0.0968
31	PNL-3602 (6.A.11)	Steel Reflector, 0 cm separation	4.306	NC	1.0003 ± 0.0007	NC	0.3282
32	PNL-3602 (6.A.11)	Steel Reflector, 1.321 cm separation	4.306	0.9997 ± 0.0010	1.0012 ± 0.0007	0.3016	0.3039
33	PNL-3602 (6.A.11)	Steel Reflector, 2.616 cm separation	4.306	0.9994 ± 0.0012	0.9974 ± 0.0007	0.2911	0.2927
34	PNL-3602 (6.A.11)	Steel Reflector, 5.405 cm separation	4.306	0.9969 ± 0.0011	0.9951 ± 0.0007	0.2828	0.2860
35	PNL-3602 (6.A.11)	Steel Reflector, Infinite separation	4.306	0.9910 ± 0.0020	0.9947 ± 0.0007	0.2851	0.2864
36	PNL-3602 (6.A.11)	Steel Reflector, with Boral Sheets	4.306	0.9941 ± 0.0011	0.9970 ± 0.0007	0.3135	0.3150

Table 6.A.1
Summary of Criticality Benchmark Calculations

	Reference	Identification	Enrich.	Calculated k_{eff} MCNP4a	Calculated k_{eff} KENO5a	EALF (eV) MCNP4a	EALF (eV) KENO5a
37	PNL-3626 (6.A.12)	Lead Reflector, 0 cm sepn.	4.306	NC	1.0003 ± 0.0007	NC	0.3159
38	PNL-3626 (6.A.12)	Lead Reflector, 0.55 cm sepn.	4.306	1.0025 ± 0.0011	0.9997 ± 0.0007	0.3030	0.3044
39	PNL-3626 (6.A.12)	Lead Reflector, 1.956 cm sepn.	4.306	1.0000 ± 0.0012	0.9985 ± 0.0007	0.2883	0.2930
40	PNL-3626 (6.A.12)	Lead Reflector, 5.405 cm sepn.	4.306	0.9971 ± 0.0012	0.9946 ± 0.0007	0.2831	0.2854
41	PNL-2615 (6.A.13)	Experiment 004/032 – no absorber	4.306	0.9925 ± 0.0012	0.9950 ± 0.0007	0.1155	0.1159
42	PNL-2615 (6.A.13)	Experiment 030 – Zr plates	4.306	NC	0.9971 ± 0.0007	NC	0.1154
43	PNL-2615 (6.A.13)	Experiment 013 – Steel plates	4.306	NC	0.9965 ± 0.0007	NC	0.1164
44	PNL-2615 (6.A.13)	Experiment 014 – Steel plates	4.306	NC	0.9972 ± 0.0007	NC	0.1164
45	PNL-2615 (6.A.13)	Exp. 009 1.05% Boron Steel plates	4.306	0.9982 ± 0.0010	0.9981 ± 0.0007	0.1172	0.1162
46	PNL-2615 (6.A.13)	Exp. 009 1.62% Boron Steel plates	4.306	0.9996 ± 0.0012	0.9982 ± 0.0007	0.1161	0.1173
47	PNL-2615 (6.A.13)	Exp. 031 – Boral plates	4.306	0.9994 ± 0.0012	0.9969 ± 0.0007	0.1165	0.1171
48	PNL-7167 (6.A.14)	Experiment 214R – with flux traps	4.306	0.9991 ± 0.0011	0.9956 ± 0.0007	0.3722	0.3812

Table 6.A.1
Summary of Criticality Benchmark Calculations

	Reference	Identification	Enrich.	Calculated k_{eff} MCNP4a	Calculated k_{eff} KENO5a	EALF (eV) MCNP4a	EALF (eV) KENO5a
49	PNL-7167 (6.A.14)	Experiment 214V3 –with flux trap	4.306	0.9969 ± 0.0011	0.9963 ± 0.0007	0.3742	0.3826
50	PNL-4267 (6.A.15)	Case 173 – 0 ppm B	4.306	0.9974 ± 0.0012	NC	0.2893	NC
51	PNL-4267 (6.A.15)	Case 177 – 2550 ppm B	4.306	1.0057 ± 0.0010	NC	0.5509	NC
52	PNL-5803 (6.A.16)	MOX Fuel – Type 3.2 Exp. 21	20% Pu	1.0041 ± 0.0011	1.0046 ± 0.0006	0.9171	0.8868
53	PNL-5803 (6.A.16)	MOX Fuel – Type 3.2 Exp. 43	20% Pu	1.0058 ± 0.0012	1.0036 ± 0.0006	0.2968	0.2944
54	PNL-5803 (6.A.16)	MOX Fuel – Type 3.2 Exp. 13	20% Pu	1.0083 ± 0.0011	0.9989 ± 0.0006	0.1665	0.1706
55	PNL-5803 (6.A.16)	MOX Fuel – Type 3.2 Exp. 32	20% Pu	1.0079 ± 0.0011	0.9966 ± 0.0006	0.1339	0.1165
56	WCAP-3385 (6.A.17)	Saxton Case 52 PuO_2 0.52" pitch	6.6% Pu	0.9996 ± 0.0011	1.0005 ± 0.0006	0.8665	0.8417
57	WCAP-3385 (6.A.17)	Saxton Case 52 U 0.52" pitch	5.74	1.0000 ± 0.0010	0.9956 ± 0.0007	0.4476	0.4580
58	WCAP-3385 (6.A.17)	Saxton Case 56 PuO_2 0.56" pitch	6.6% Pu	1.0036 ± 0.0011	1.0047 ± 0.0006	0.5289	0.5197
59	WCAP-3385 (6.A.17)	Saxton Case 56 borated PuO_2	6.6% Pu	1.0008 ± 0.0010	NC	0.6389	NC
60	WCAP-3385 (6.A.17)	Saxton Case 56 U 0.56" pitch	5.74	0.9994 ± 0.0011	0.9967 ± 0.0007	0.2923	0.2954

Table 6.A.1
Summary of Criticality Benchmark Calculations

	Reference	Identification	Enrich.	Calculated k_{eff} MCNP4a	Calculated k_{eff} KENO5a	EALF (eV) MCNP4a	EALF (eV) KENO5a
61	WCAP-3385 (6.A.17)	Saxton Case 79 PuO_2 0.79" pitch	6.6% Pu	1.0063 ± 0.0011	1.0133 ± 0.0006	0.1520	0.1555
62	WCAP-3385 (6.A.17)	Saxton Case 79 U 0.79" pitch	5.74	1.0039 ± 0.0011	1.0008 ± 0.0006	0.1036	0.1047

Notes: NC stands for not calculated.

† EALF is the energy of the average lethargy causing fission

†† The experimental results appear to be statistical outliers (>3σ) suggesting the possibility of unusually large experimental error. Although they could be justifiably excluded, for conservatism, they were retained in determining the calculational basis.

Table 6.A.2

COMPARISON OF MCNP4a AND KENO5a CALCULATED REACTIVITIES[†]
FOR VARIOUS ENRICHMENTS (UO_2)

Enrichment	Calculated $k_{eff} \pm 1\sigma$	
	MCNP4a	**KENO5a**
3.0	0.8465 ± 0.0011	0.8478 ± 0.0004
3.5	0.8820 ± 0.0011	0.8841 ±0.0004
3.75	0.9019 ± 0.0011	0.8987 ± 0.0004
4.0	0.9132 ± 0.0010	0.9140 ± 0.0004
4.2	0.9276 ± 0.0011	0.9237 ± 0.0004
4.5	0.9400 ± 0.0011	0.9388 ± 0.0004

† Based on the MPC-68 with the GE 8x8R

Table 6.A.3

MCNP4a CALCULATED REACTIVITIES FOR
CRITICAL EXPERIMENTS WITH NEUTRON ABSORBERS (UO_2)

Ref.	Experiment		Δk Worth of Absorber	MCNP4a Calculated k_{eff}	EALF† (eV)
6.A.13	PNL-2615	Boral Sheet	0.0139	0.9994 ± 0.0012	0.1165
6.A.7	BAW-1484	Core XX	0.0165	1.0008 ± 0.0011	0.1724
6.A.13	PNL-2615	1.62% Boron-steel	0.0165	0.9996 ± 0.0012	0.1161
6.A.7	BAW-1484	Core XIX	0.0202	0.9961 ± 0.0012	0.2103
6.A.7	BAW-1484	Core XXI	0.0243	0.9994 ± 0.0010	0.1544
6.A.7	BAW-1484	Core XVII	0.0519	0.9962 ± 0.0012	0.2083
6.A.11	PNL-3602	Boral Sheet	0.0708	0.9941 ± 0.0011	0.3135
6.A.7	BAW-1484	Core XV	0.0786	0.9910 ± 0.0011	0.2092
6.A.7	BAW-1484	Core XVI	0.0845	0.9935 ± 0.0010	0.1757
6.A.7	BAW-1484	Core XIV	0.1575	0.9953 ± 0.0011	0.2022
6.A.7	BAW-1484	Core XIII	0.1738	1.0020 ± 0.0011	0.1988
6.A.14	PNL-7167	Expt 214R flux trap	0.1931	0.9991 ± 0.0011	0.3722

† EALF is the energy of the average lethargy causing fission

Table 6.A.4
COMPARISON OF MCNP4a AND KENO5a
CALCULATED REACTIVITIES† FOR VARIOUS BORON LOADINGS (UO_2)

^{10}B, g/cm^2	**Calcualted $k_{eff} \pm 1\sigma$**	
	MCNP4a	**KENO5a**
0.005	1.0381 ± 0.0012	1.0340 ± 0.0004
0.010	0.9960 ±0.0010	0.9941 ± 0.0004
0.015	0.9727 ± 0.0009	0.9713 ± 0.0004
0.020	0.9541 ± 0.0012	0.9560 ± 0.0004
0.025	0.9433 ± 0.0011	0.9428 ± 0.0004
0.03	0.9325 ± 0.0011	0.9338 ± 0.0004
0.035	0.9234 ± 0.0011	0.9251 ± 0.0004
0.04	0.9173 ± 0.0011	0.9179 ± 0.0004

† based on 4.5% enrichment GE 8x8R in the MPC-68 cask.

Table 6.A.5

CALCULATIONS FOR CRITICAL EXPERIMENTS WITH THICK LEAD AND STEEL REFLECTORS† (UO_2)

Ref.	Case	Enrichment, wt%	Separation, cm	MCNP4a k_{eff}	KENO5a k_{eff}
6.A.11	Steel Reflector	2.35	1.321	0.9980 ± 0.0009	0.9992 ± 0.0006
		2.35	2.616	0.9968 ± 0.0009	0.9964 ± 0.0006
		2.35	3.912	0.9974 ± 0.0010	0.9980 ± 0.0006
		2.35	∞	0.9962 ± 0.0008	0.9939 ± 0.0006
6.A.11	Steel Reflector	4.306	1.321	0.9997 ± 0.0010	1.0012 ± 0.0007
		4.306	2.616	0.9994 ± 0.0012	0.9974 ± 0.0007
		4.306	3.405	0.9969 ± 0.0011	0.9951 ± 0.0007
		4.306	∞	0.9910 ± 0.0020	0.9947 ± 0.0007
6.A.11	Lead Reflector	4.306	0.55	1.0025 ± 0.0011	0.9997 ± 0.0007
		4.306	1.956	1.0000 ± 0.0012	0.9985 ± 0.0007
		4.306	5.405	0.9971 ± 0.0012	0.9946 ± 0.0007

† Arranged in order of increasing reflector fuel spacing.

Table 6.A.6

CALCULATIONS FOR CRITICAL EXPERIMENTS WITH VARIOUS SOLUBLE BORON CONCENTRATIONS (UO_2)

Reference	Experiment	Boron Concentration ppm	Calculated k_{eff}	
			MCNP4a	KENO5a
6.A.15	PNL-4267	0	0.9974 ± 0.0012	-
6.A.8	BAW-1645-4	886	0.9970 ± 0.0010	0.9924 ± 0.0006
6.A.9	BAW-1810	1337	1.0023 ± 0.0010	-
6.A.9	BAW-1810	1899	1.0060 ± 0.0009	-
6.A.15	PNL-4267	2550	1.0057 ± 0.0010	-

Table 6.A.7

CALCULATIONS FOR CRITICAL EXPERIMENTS WITH MOX FUEL

Reference	Case[†]	MCNP4a		KENO 5a	
		k_{eff}	EALF[††] (eV)	k_{eff}	EALF[††] (eV)
PNL-5803 [6.A.16]	MOX Fuel – Exp No 21	1.0041±0.0011	0.9171	1.0046±0.0006	0.8868
	MOX Fuel – Exp No 43	1.0058±0.0012	0.2968	1.0036±0.0006	0.2944
	MOX Fuel – Exp No 13	1.0083±0.0011	0.1665	0.9989±0.0006	0.1706
	MOX Fuel – Exp No 32	1.0079±0.0011	0.1139	0.9966±0.0006	0.1165
WCAP- 3385-54 [6.A.17]	Saxton @ 0.52" pitch	0.9996±0.0011	0.8665	1.0005±0.0006	0.8417
	Saxton @ 0.56" pitch	1.0036±0.0011	0.5289	1.0047±0.0006	0.5197
	Saxton @ 0.56" pitch borated	1.0008±0.0010	0.6389	NC	NC
	Saxton @ 0.79" pitch	1.0063±0.0011	0.1520	1.0133±0.0006	0.1555

[†] Arranged in order of increasing lattice spacing.

[††] EALF is the energy of the average lethargy causing fission.

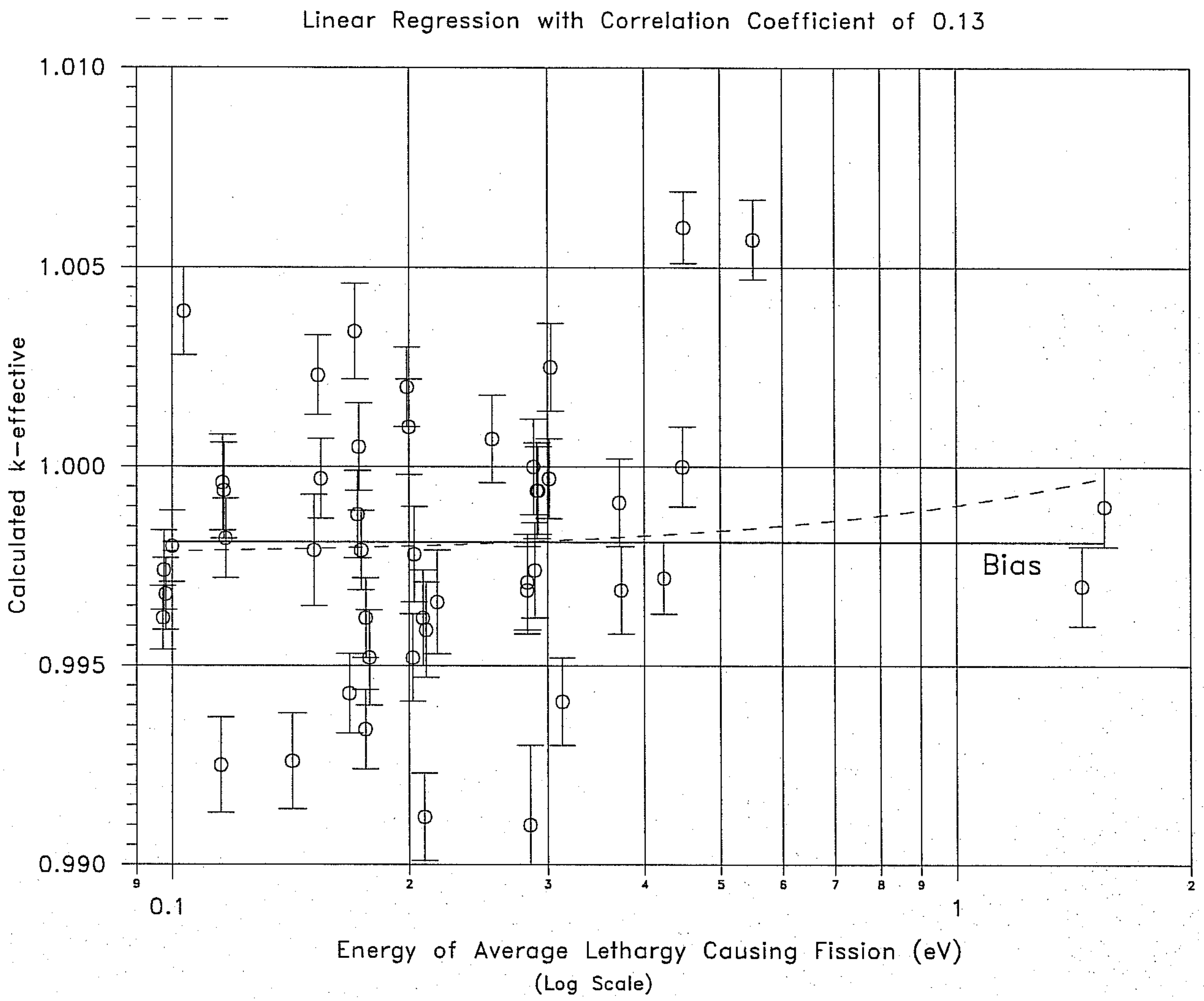

FIGURE 6.A.1 MCNP4a CALCULATED k-eff VALUES FOR VARIOUS VALUES OF THE SPECTRAL INDEX

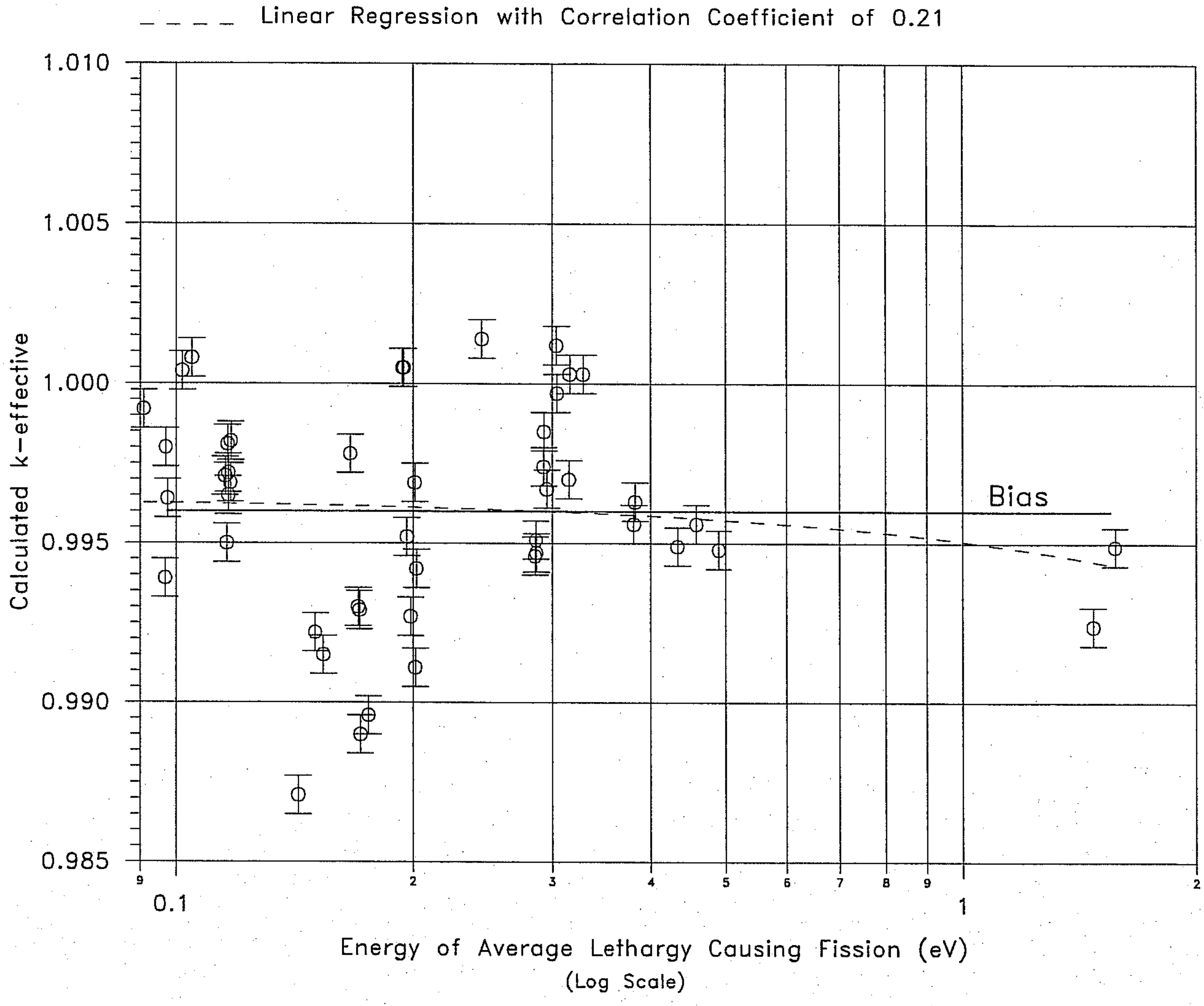

FIGURE 6.A.2 KENO5a CALCULATED k-eff VALUES FOR VARIOUS VALUES OF THE SPECTRAL INDEX

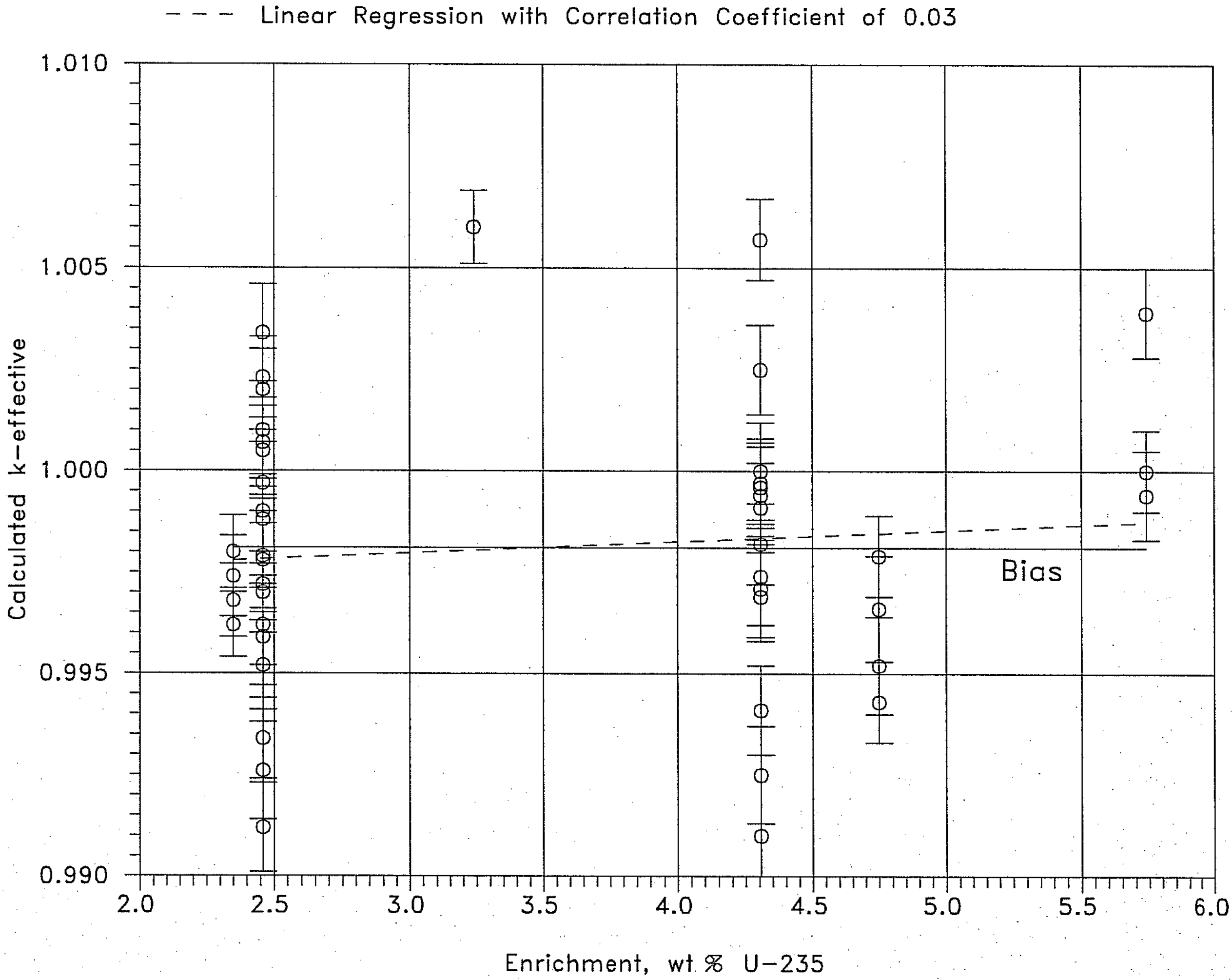

FIGURE 6.A.3 MCNP4a CALCULATED k-eff VALUES AT VARIOUS U-235 ENRICHMENTS

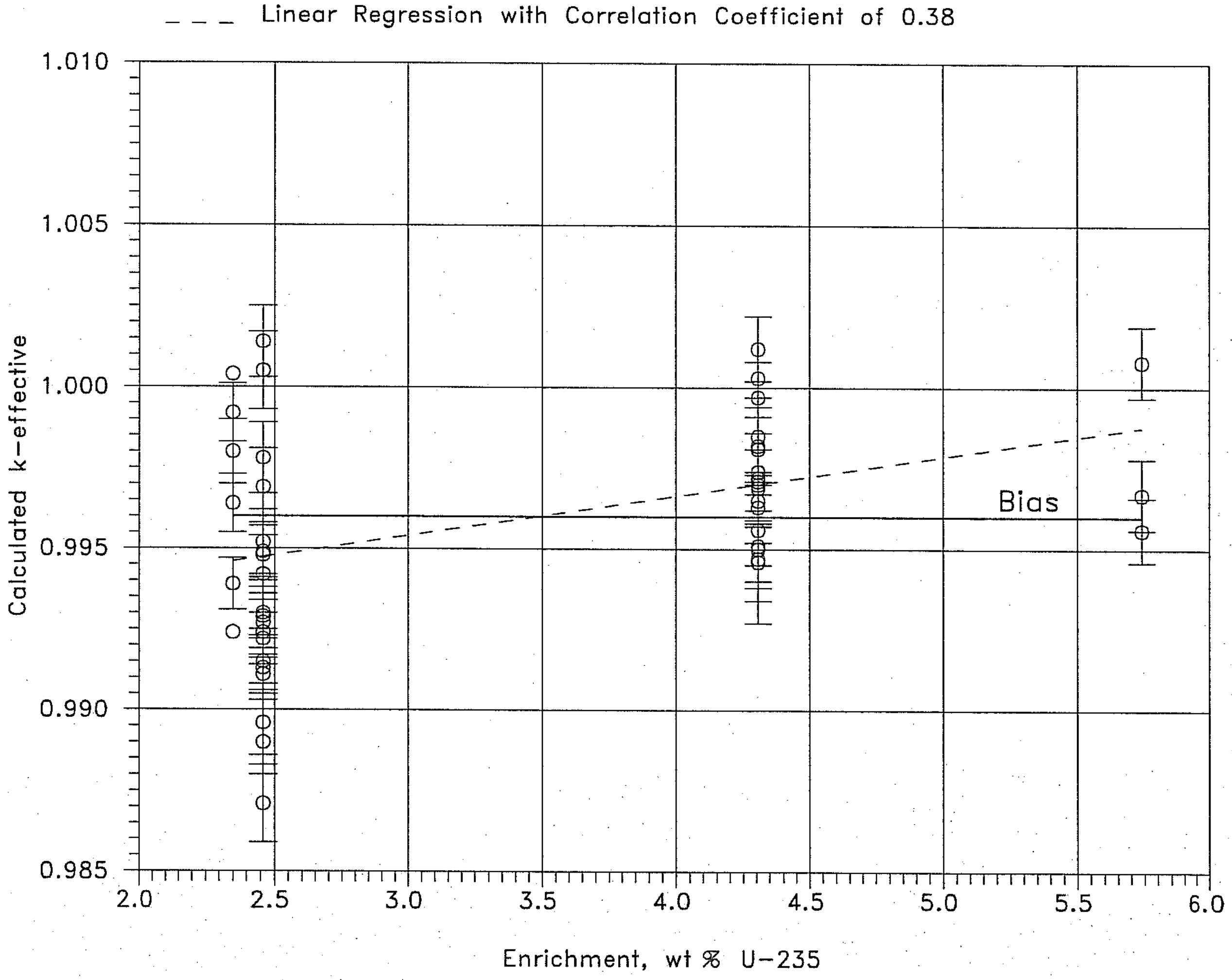

FIGURE 6.A.4 KENO5a CALCULATED k-eff VALUES AT VARIOUS U-235 ENRICHMENTS

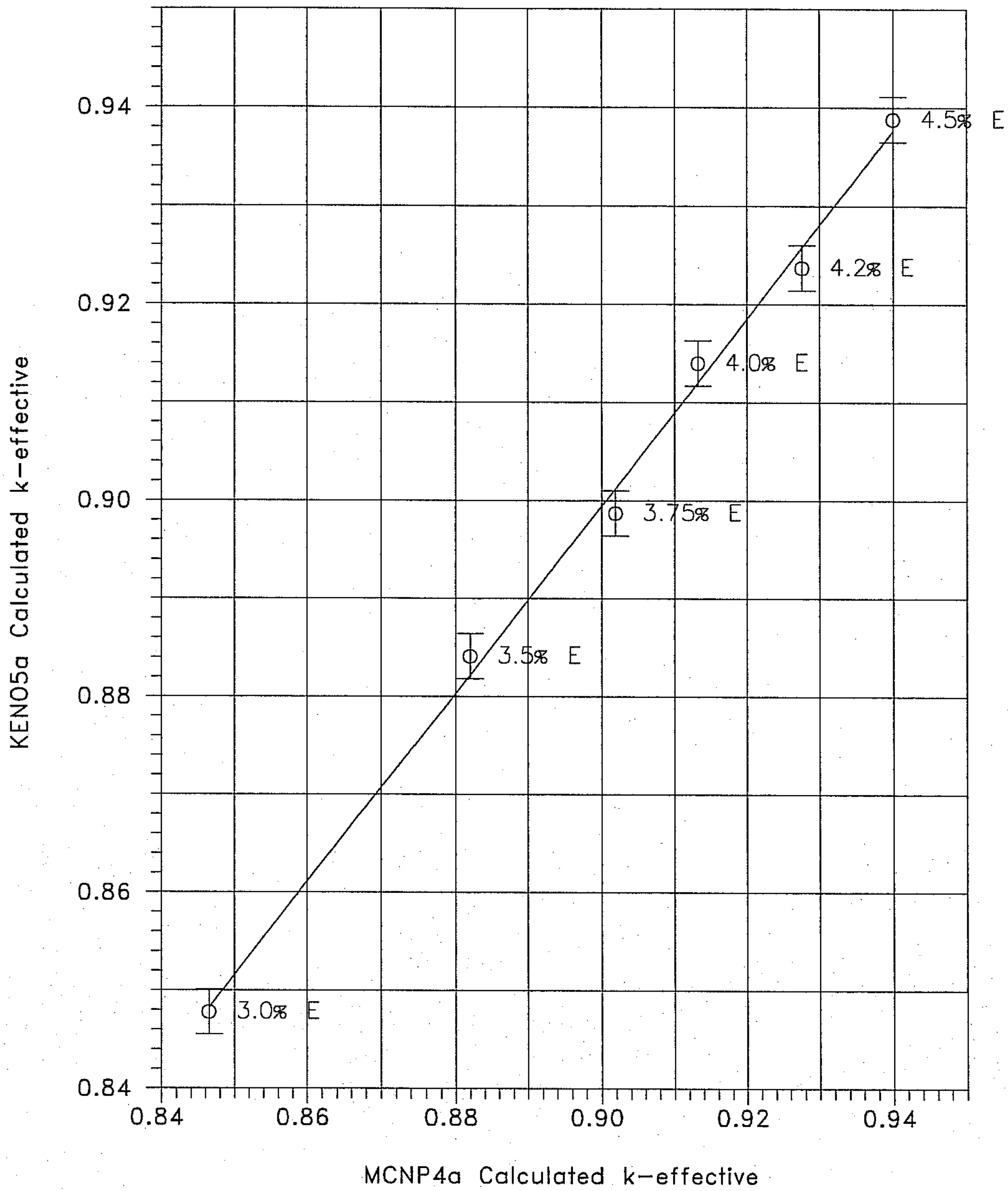

FIGURE 6.A.5 COMPARISON OF MCNP4a AND KENO5a CALCULATIONS FOR VARIOUS FUEL ENRICHMENTS

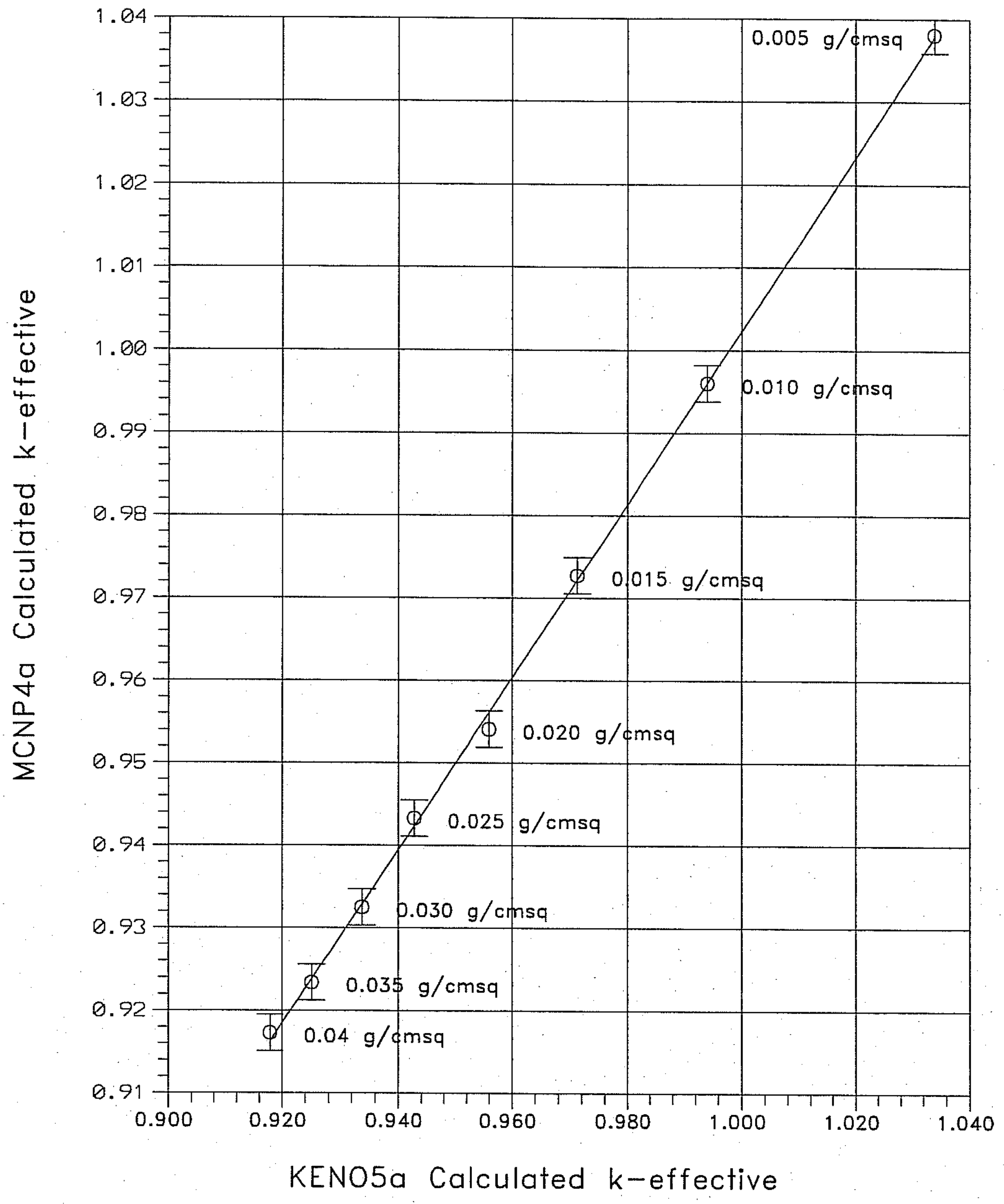

FIGURE 6.A.6 COMPARISON OF MCNP4a AND KENO5a CALCULATIONS FOR VARIOUS BORON-10 AREAL DENSITIES

APPENDIX 6.B: DISTRIBUTED ENRICHMENTS IN BWR FUEL

Fuel assemblies used in BWRs utilize fuel rods of varying enrichments as a means of controlling power peaking during in-core operation. For calculations involving BWR assemblies, the use of a uniform (planar-average) enrichment, as opposed to the distributed enrichments normally used in BWR fuel, produces conservative results. Calculations have been performed to confirm that this statement remains valid in the geometry of the MPC-68. These calculations are based on fuel assembly designs currently in use and two hypothetical distributions, all intended to illustrate that calculations with uniform average enrichments are conservative.

The average enrichment is calculated as the linear average of the various fuel rod enrichments, i.e.,

$$\overline{E} = \frac{1}{n} \sum_{i=1}^{n} E_i ,$$

where E_i is the enrichment in each of the n rods, and $\overline{E}$ is the assembly average enrichment. This parameter conservatively characterizes the fuel assembly and is readily available for specific fuel assemblies in determining the acceptability of the assembly for placement in the MPC-68 cask.

The criticality calculations for average and distributed enrichment cases are compared in Table 6.B.1 to illustrate and confirm the conservatism inherent in using average enrichments. With two exceptions, the cases analyzed represent realistic designs currently in use and encompass fuel with different ratios of maximum pin enrichment to average assembly enrichment. The two exceptions are hypothetical cases intended to extend the models to higher enrichments and to demonstrate that using the average enrichment remains conservative.

Table 6.B.1 shows that, in all cases, the averaged enrichment yields conservative values of reactivity relative to distributed enrichments for both the actual fuel designs and the hypothetical higher enrichment cases. Thus, it is concluded that uniform average enrichments will always yield higher (more conservative) values for reactivity than the corresponding distributed enrichments.†

† This conclusion implicitly assumes the higher enrichment fuel rods are located internal to the assembly (as in BWR fuel), and the lower enriched rods are on the outside.

Table 6.B.1

COMPARISON CALCULATIONS FOR BWR FUEL WITH AVERAGE AND DISTRIBUTED ENRICHMENTS

Case	Average %E	Peak Rod E%	Calculated k_{eff}	
			Average E	Distributed E
8x8C04	3.01	3.80	0.8549	0.8429
8x8C04	3.934	4.9	0.9128	0.9029
8x8D05	3.42	3.95	0.8790	0.8708
8x8D05	3.78	4.40	0.9030	0.8974
8x8D05	3.90	4.90	0.9062	0.9042
9x9B01	4.34	4.71	0.9347	0.9285
9x9D01	3.35	4.34	0.8793	0.8583
Hypothetical #1 (48 outer rods of 3.967%E,14 inner rods of 5.0%)	4.20	5.00	0.9289	0.9151
Hypothetical #2 (48 outer rods of 4.354%E,14 inner rods of 5.0%)	4.50	5.00	0.9422	0.9384

APPENDIX 6.C: CALCULATIONAL SUMMARY

The following table lists the maximum k_{eff} (including bias, uncertainties, and calculational statistics), MCNP calculated k_{eff}, standard deviation, and energy of average lethargy causing fission (EALF) for each of the candidate fuel types and basket configurations.

Table 6.C.1
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES AND BASKET CONFIGURATIONS

MPC-24					
Fuel Assembly Designation	**Cask**	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
14x14A01	HI-STAR	0.9295	0.9252	0.0008	0.2084
14x14A02	HI-STAR	0.9286	0.9242	0.0008	0.2096
14x14A03	HI-STORM	0.3080	0.3047	0.0003	3.37E+04
14x14A03	HI-TRAC	0.9283	0.9239	0.0008	0.2096
14x14A03	HI-STAR	0.9296	0.9253	0.0008	0.2093
14x14B01	HI-STAR	0.9159	0.9117	0.0007	0.2727
14x14B02	HI-STAR	0.9169	0.9126	0.0008	0.2345
14x14B03	HI-STAR	0.9110	0.9065	0.0009	0.2545
14x14B04	HI-STAR	0.9084	0.9039	0.0009	0.2563
B14x14B01	HI-TRAC	0.9237	0.9193	0.0008	0.2669
B14x14B01	HI-STAR	0.9228	0.9185	0.0008	0.2675
14x14C01	HI-TRAC	0.9273	0.9230	0.0008	0.2758
14x14C01	HI-STAR	0.9258	0.9215	0.0008	0.2729
14x14C02	HI-STAR	0.9265	0.9222	0.0008	0.2765
14x14C03	HI-TRAC	0.9274	0.9231	0.0008	0.2839
14x14C03	HI-STAR	0.9287	0.9242	0.0009	0.2825

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES AND BASKET CONFIGURATIONS

MPC-24					
Fuel Assembly Designation	**Cask**	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
14x14D01	HI-TRAC	0.8531	0.8488	0.0008	0.3316
14x14D01	HI-STAR	0.8507	0.8464	0.0008	0.3308
14x14E01	HI-STAR	0.7598	0.7555	0.0008	0.3890
14x14E02	HI-TRAC	0.7627	0.7586	0.0007	0.3591
14x14E02	HI-STAR	0.7627	0.7586	0.0007	0.3607
14x14E03	HI-STAR	0.6952	0.6909	0.0008	0.2905
15x15A01	HI-TRAC	0.9205	0.9162	0.0008	0.2595
15x15A01	HI-STAR	0.9204	0.9159	0.0009	0.2608
15x15B01	HI-STAR	0.9369	0.9326	0.0008	0.2632
15C15B02	HI-STAR	0.9338	0.9295	0.0008	0.2640
15x15B03	HI-STAR	0.9362	0.9318	0.0008	0.2632
15x15B04	HI-STAR	0.9370	0.9327	0.0008	0.2612
15x15B05	HI-STAR	0.9356	0.9313	0.0008	0.2606
15x15B06	HI-STAR	0.9366	0.9324	0.0007	0.2638
B15x15B01	HI-TRAC	0.9387	0.9344	0.0008	0.2616
B15x15B01	HI-STAR	0.9388	0.9343	0.0009	0.2626
15x15C01	HI-STAR	0.9255	0.9213	0.0007	0.2493
15x15C02	HI-STAR	0.9297	0.9255	0.0007	0.2457
15x15C03	HI-STAR	0.9297	0.9255	0.0007	0.2440
15x15C04	HI-STAR	0.9311	0.9268	0.0008	0.2435
B15x15C01	HI-TRAC	0.9362	0.9319	0.0008	0.2374
B15x15C01	HI-STAR	0.9361	0.9316	0.0009	0.2385

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-24					
Fuel Assembly Designation	**Cask**	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
15x15D01	HI-STAR	0.9341	0.9298	0.0008	0.2822
15x15D02	HI-STAR	0.9367	0.9324	0.0008	0.2802
15x15D03	HI-STAR	0.9354	0.9311	0.0008	0.2844
15x15D04	HI-TRAC	0.9354	0.9309	0.0009	0.2963
15x15D04	HI-STAR	0.9339	0.9292	0.0010	0.2958
15x15E01	HI-TRAC	0.9392	0.9349	0.0008	0.2827
15x15E01	HI-STAR	0.9368	0.9325	0.0008	0.2826
15x15F01	HI-STORM	0.3648	0.3614	0.0003	3.03E+04
15x15F01	HI-TRAC	0.9393	0.9347	0.0009	0.2925
15x15F01	HI-STAR	0.9395	0.9350	0.0009	0.2903
15x15G01	HI-TRAC	0.8878	0.8836	0.0007	0.3347
15x15G01	HI-STAR	0.8876	0.8833	0.0008	0.3357
15x15H01	HI-TRAC	0.9333	0.9288	0.0009	0.2353
15x15H01	HI-STAR	0.9337	0.9292	0.0009	0.2349
16x16A01	HI-STORM	0.3447	0.3412	0.0004	3.15E+04
16x16A01	HI-TRAC	0.9273	0.9228	0.0009	0.2710
16x16A01	HI-STAR	0.9287	0.9244	0.0008	0.2704
16x16A02	HI-STAR	0.9263	0.9221	0.0007	0.2702
17x17A01	HI-STORM	0.3243	0.3210	0.0003	3.23E+04
17x17A01	HI-TRAC	0.9378	0.9335	0.0008	0.2133
17x17A01	HI-STAR	0.9368	0.9325	0.0008	0.2131
17x17A02	HI-STAR	0.9329	0.9286	0.0008	0.2018

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-24					
Fuel Assembly Designation	**Cask**	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
17x17B01	HI-STAR	0.9288	0.9243	0.0009	0.2607
17x17B02	HI-STAR	0.9290	0.9247	0.0008	0.2596
17x17B03	HI-STAR	0.9243	0.9199	0.0008	0.2625
17x17B04	HI-STAR	0.9324	0.9279	0.0009	0.2576
17x17B05	HI-STAR	0.9266	0.9222	0.0008	0.2539
17x17B06	HI-TRAC	0.9318	0.9275	0.0008	0.2570
17x17B06	HI-STAR	0.9311	0.9268	0.0008	0.2593
17x17C01	HI-STAR	0.9293	0.9250	0.0008	0.2595
17x17C02	HI-TRAC	0.9319	0.9274	0.0009	0.2610
17x17C02	HI-STAR	0.9336	0.9293	0.0008	0.2624

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-68					
Fuel Assembly Designation	**Cask**	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
6x6A01	HI-STAR	0.7539	0.7498	0.0007	0.2754
6x6A02	HI-STAR	0.7517	0.7476	0.0007	0.2510
6x6A03	HI-STAR	0.7545	0.7501	0.0008	0.2494
6x6A04	HI-STAR	0.7537	0.7494	0.0008	0.2494
6x6A05	HI-STAR	0.7555	0.7512	0.0008	0.2470
6x6A06	HI-STAR	0.7618	0.7576	0.0008	0.2298
6x6A07	HI-STAR	0.7588	0.7550	0.0005	0.2360
6x6A08	HI-STAR	0.7808	0.7766	0.0007	0.2527
B6x6A01	HI-TRAC	0.7732	0.7691	0.0007	0.2458
B6x6A01	HI-STAR	0.7727	0.7685	0.0007	0.2460
B6x6A02	HI-TRAC	0.7785	0.7741	0.0008	0.2411
B6x6A02	HI-STAR	0.7782	0.7738	0.0008	0.2408
B6x6A03	HI-TRAC	0.7886	0.7846	0.0007	0.2311
B6x6A03	HI-STAR	0.7888	0.7846	0.0007	0.2310
6x6B01	HI-STAR	0.7604	0.7563	0.0007	0.2461
6x6B02	HI-STAR	0.7618	0.7577	0.0007	0.2450
6x6B03	HI-STAR	0.7619	0.7578	0.0007	0.2439
6x6B04	HI-STAR	0.7686	0.7644	0.0008	0.2286
6x6B05	HI-STAR	0.7824	0.7785	0.0006	0.2184
B6x6B01	HI-TRAC	0.7833	0.7794	0.0006	0.2181
B6x6B01	HI-STAR	0.7822	0.7783	0.0006	0.2190

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-68					
Fuel Assembly Designation	**Cask**	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
6x6C01	HI-STORM	0.2759	0.2726	0.0003	1.59E+04
6x6C01	HI-TRAC	0.8024	0.7982	0.0008	0.2135
6x6C01	HI-STAR	0.8021	0.7980	0.0007	0.2139
7x7A01	HI-TRAC	0.7963	0.7922	0.0007	0.2016
7x7A01	HI-STAR	0.7974	0.7932	0.0008	0.2015
7x7B01	HI-STAR	0.9372	0.9330	0.0007	0.3658
7x7B02	HI-STAR	0.9301	0.9260	0.0007	0.3524
7x7B03	HI-STAR	0.9313	0.9271	0.0008	0.3438
7x7B04	HI-STAR	0.9311	0.9270	0.0007	0.3816
7x7B05	HI-STAR	0.9350	0.9306	0.0008	0.3382
7x7B06	HI-STAR	0.9298	0.9260	0.0006	0.3957
B7x7B01	HI-TRAC	0.9367	0.9324	0.0008	0.3899
B7x7B01	HI-STAR	0.9375	0.9332	0.0008	0.3887
B7x7B02	HI-STORM	0.4061	0.4027	0.0003	2.069E+04
B7x7B02	HI-TRAC	0.9385	0.9342	0.0008	0.3952
B7x7B02	HI-STAR	0.9386	0.9344	0.0007	0.3983
8x8A01	HI-TRAC	0.7662	0.7620	0.0008	0.2250
8x8A01	HI-STAR	0.7685	0.7644	0.0007	0.2227
8x8A02	HI-TRAC	0.7690	0.7650	0.0007	0.2163
8x8A02	HI-STAR	0.7697	0.7656	0.0007	0.2158
8x8B01	HI-STAR	0.9310	0.9265	0.0009	0.2935
8x8B02	HI-STAR	0.9227	0.9185	0.0007	0.2993

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-68					
Fuel Assembly Designation	**Cask**	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
8x8B03	HI-STAR	0.9299	0.9257	0.0008	0.3319
8x8B04	HI-STAR	0.9236	0.9194	0.0008	0.3700
B8x8B01	HI-TRAC	0.9352	0.9310	0.0008	0.3393
B8x8B01	HI-STAR	0.9346	0.9301	0.0009	0.3389
B8x8B02	HI-TRAC	0.9401	0.9359	0.0007	0.3331
B8x8B02	HI-STAR	0.9385	0.9343	0.0008	0.3329
B8x8B03	HI-STORM	0.3934	0.3900	0.0004	1.815E+04
B8x8B03	HI-TRAC	0.9427	0.9385	0.0008	0.3278
B8x8B03	HI-STAR	0.9416	0.9375	0.0007	0.3293
8x8C01	HI-STAR	0.9315	0.9273	0.0007	0.2822
8x8C02	HI-STAR	0.9313	0.9268	0.0009	0.2716
8x8C03	HI-STAR	0.9329	0.9286	0.0008	0.2877
8x8C04	HI-STAR	0.9348	0.9307	0.0007	0.2915
8x8C05	HI-STAR	0.9353	0.9312	0.0007	0.2971
8x8C06	HI-STAR	0.9353	0.9312	0.0007	0.2944
8x8C07	HI-STAR	0.9314	0.9273	0.0007	0.2972
8x8C08	HI-STAR	0.9339	0.9298	0.0007	0.2915
8x8C09	HI-STAR	0.9301	0.9260	0.0007	0.3183
8x8C10	HI-STAR	0.9317	0.9275	0.0008	0.3018
8x8C11	HI-STAR	0.9328	0.9287	0.0007	0.3001
8x8C12	HI-STAR	0.9285	0.9242	0.0008	0.3062
B8x8C01	HI-TRAC	0.9348	0.9305	0.0008	0.3114

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-68					
Fuel Assembly Designation	**Cask**	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
B8x8C01	HI-STAR	0.9357	0.9313	0.0009	0.3141
B8x8C02	HI-STORM	0.3714	0.3679	0.0004	2.30E+04
B8x8C02	HI-TRAC	0.9402	0.9360	0.0008	0.3072
B8x8C02	HI-STAR	0.9425	0.9384	0.0007	0.3081
B8x8C03	HI-TRAC	0.9429	0.9386	0.0008	0.3045
B8x8C03	HI-STAR	0.9418	0.9375	0.0008	0.3056
8x8D01	HI-STAR	0.9342	0.9302	0.0006	0.2733
8x8D02	HI-STAR	0.9325	0.9284	0.0007	0.2750
8x8D03	HI-STAR	0.9351	0.9309	0.0008	0.2731
8x8D04	HI-STAR	0.9338	0.9296	0.0007	0.2727
8x8D05	HI-STAR	0.9339	0.9294	0.0009	0.2700
8x8D06	HI-STAR	0.9365	0.9324	0.0007	0.2777
8x8D07	HI-STAR	0.9341	0.9297	0.0009	0.2694
8x8D08	HI-STAR	0.9376	0.9332	0.0009	0.2841
B8x8D01	HI-TRAC	0.9408	0.9368	0.0006	0.2773
B8x8D01	HI-STAR	0.9403	0.9363	0.0007	0.2778
8x8E01	HI-TRAC	0.9309	0.9266	0.0008	0.2834
8x8E01	HI-STAR	0.9312	0.9270	0.0008	0.2831
8x8F01	HI-TRAC	0.9396	0.9356	0.0006	0.2255
8x8F01	HI-STAR	0.9411	0.9366	0.0009	0.2264
9x9A01	HI-STAR	0.9353	0.9310	0.0008	0.2875
9x9A02	HI-STAR	0.9388	0.9345	0.0008	0.2228

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-68					
Fuel Assembly Designation	**Cask**	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
9x9A03	HI-STAR	0.9351	0.9310	0.0007	0.2837
9x9A04	HI-STAR	0.9396	0.9355	0.0007	0.2262
B9x9A01	HI-STORM	0.3365	0.3331	0.0003	1.78E+04
B9x9A01	HI-TRAC	0.9434	0.9392	0.0007	0.2232
B9x9A01	HI-STAR	0.9417	0.9374	0.0008	0.2236
9x9B01	HI-STAR	0.9380	0.9336	0.0008	0.2576
9x9B02	HI-STAR	0.9373	0.9329	0.0009	0.2578
9x9B03	HI-STAR	0.9417	0.9374	0.0008	0.2545
B9x9B01	HI-TRAC	0.9417	0.9376	0.0007	0.2504
B9x9B01	HI-STAR	0.9436	0.9394	0.0008	0.2506
9x9C01	HI-TRAC	0.9377	0.9335	0.0008	0.2697
9x9C01	HI-STAR	0.9395	0.9352	0.0008	0.2698
9x9D01	HI-TRAC	0.9387	0.9343	0.0008	0.2635
9x9D01	HI-STAR	0.9394	0.9350	0.0009	0.2625
9x9E01	HI-STAR	0.9334	0.9293	0.0007	0.2227
9x9E02	HI-STORM	0.3676	0.3642	0.0003	2.409E+04
9x9E02	HI-TRAC	0.9402	0.9360	0.0008	0.2075
9x9E02	HI-STAR	0.9401	0.9359	0.0008	0.2065
9x9F01	HI-STAR	0.9307	0.9265	0.0007	0.2899
9x9F02	HI-STORM	0.3676	0.3642	0.0003	2.409E+04
9x9F02	HI-TRAC	0.9402	0.9360	0.0008	0.2075
9x9F02	HI-STAR	0.9401	0.9359	0.0008	0.2065

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-68					
Fuel Assembly Designation	**Cask**	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
9x9G01	HI-TRAC	0.9307	0.9265	0.0007	0.2193
9x9G01	HI-STAR	0.9309	0.9265	0.0008	0.2191
10x10A01	HI-STAR	0.9377	0.9335	0.0008	0.3170
10x10A02	HI-STAR	0.9426	0.9386	0.0007	0.2159
10x10A03	HI-STAR	0.9396	0.9356	0.0007	0.3169
B10x10A01	HI-STORM	0.3379	0.3345	0.0003	1.74E+04
B10x10A01	HI-TRAC	0.9448	0.9405	0.0008	0.2214
B10x10A01	HI-STAR	0.9457	0.9414	0.0008	0.2212
10x10B01	HI-STAR	0.9384	0.9341	0.0008	0.2881
10x10B02	HI-STAR	0.9416	0.9373	0.0008	0.2333
10x10B03	HI-STAR	0.9375	0.9334	0.0007	0.2856
B10x10B01	HI-TRAC	0.9443	0.9401	0.0007	0.2380
B10x10B01	HI-STAR	0.9436	0.9395	0.0007	0.2366
10x10C01	HI-TRAC	0.9430	0.9387	0.0008	0.2424
10x10C01	HI-STAR	0.9433	0.9392	0.0007	0.2416
10x10D01	HI-TRAC	0.9383	0.9343	0.0007	0.3359
10x10D01	HI-STAR	0.9376	0.9333	0.0008	0.3355
10x10E01	HI-TRAC	0.9157	0.9116	0.0007	0.3301
10x10E01	HI-STAR	0.9185	0.9144	0.0007	0.2936

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-24 400PPM SOLUBLE BORON					
Fuel Assembly Designation	**Cask**	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
14x14A03	HI-STAR	0.8884	0.8841	0.0008	0.2501
B14x14B01	HI-STAR	0.8900	0.8855	0.0009	0.3173
14x14C03	HI-STAR	0.8950	0.8907	0.0008	0.3410
14x14D01	HI-STAR	0.8518	0.8475	0.0008	0.4395
14x14E02	HI-STAR	0.7132	0.7090	0.0007	0.4377
15x15A01	HI-STAR	0.9119	0.9076	0.0008	0.3363
B15x15B01	HI-STAR	0.9284	0.9241	0.0008	0.3398
B15x15C01	HI-STAR	0.9236	0.9193	0.0008	0.3074
15x15D04	HI-STAR	0.9261	0.9218	0.0008	0.3841
15x15E01	HI-STAR	0.9265	0.9221	0.0008	0.3656
15x15F01	HI-STORM (DRY)	0.4013	0.3978	0.0004	28685
15x15F01	HI-TRAC	0.9301	0.9256	0.0009	0.3790
15x15F01	HI-STAR	0.9314	0.9271	0.0008	0.3791
15x15G01	HI-STAR	0.8939	0.8897	0.0007	0.4392
15x15H01	HI-TRAC	0.9345	0.9301	0.0008	0.3183
15x15H01	HI-STAR	0.9366	0.9320	0.0009	0.3175
16x16A01	HI-STAR	0.8955	0.8912	0.0008	0.3227
17x17A01	HI-STAR	0.9264	0.9221	0.0008	0.2801
17x17B06	HI-STAR	0.9284	0.9241	0.0008	0.3383
17x17C02	HI-TRAC	0.9296	0.9250	0.0009	0.3447
17x17C02	HI-STAR	0.9294	0.9249	0.0009	0.3433

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-24E/MPC-24EF, UNBORATED WATER					
Fuel Assembly Designation	**Cask**	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
14x14A03	HI-STAR	0.9380	0.9337	0.0008	0.2277
B14x14B01	HI-STAR	0.9312	0.9269	0.0008	0.2927
14x14C01	HI-STAR	0.9356	0.9311	0.0009	0.3161
14x14D01	HI-STAR	0.8875	0.8830	0.0009	0.4026
14x14E02	HI-STAR	0.7651	0.7610	0.0007	0.3645
15x15A01	HI-STAR	0.9336	0.9292	0.0008	0.2879
B15x15B01	HI-STAR	0.9465	0.9421	0.0008	0.2924
B15x15C01	HI-STAR	0.9462	0.9419	0.0008	0.2631
15x15D04	HI-STAR	0.9440	0.9395	0.0009	0.3316
15x15E01	HI-STAR	0.9455	0.9411	0.0009	0.3178
15x15F01	HI-STORM (DRY)	0.3699	0.3665	0.0004	3.280e+04
15x15F01	HI-TRAC	0.9465	0.9421	0.0009	0.3297
15x15F01	HI-STAR	0.9468	0.9424	0.0008	0.3270
15x15G01	HI-STAR	0.9054	0.9012	0.0007	0.3781
15x15H01	HI-STAR	0.9423	0.9381	0.0008	0.2628
16x16A01	HI-STAR	0.9341	0.9297	0.0009	0.3019
17x17A01	HI-TRAC	0.9467	0.9425	0.0008	0.2372
17x17A01	HI-STAR	0.9447	0.9406	0.0007	0.2374
17x17B06	HI-STAR	0.9421	0.9377	0.0008	0.2888
17x17C02	HI-STAR	0.9433	0.9390	0.0008	0.2932

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-24E/MPC-24EF, 300PPM BORATED WATER					
Fuel Assembly Designation	**Cask**	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
14x14A03	HI-STAR	0.8963	0.8921	0.0008	0.2231
B14x14B01	HI-STAR	0.8974	0.8931	0.0008	0.3214
14x14C01	HI-STAR	0.9031	0.8988	0.0008	0.3445
14x14D01	HI-STAR	0.8588	0.8546	0.0007	0.4407
14x14E02	HI-STAR	0.7249	0.7205	0.0008	0.4186
15x15A01	HI-STAR	0.9161	0.9118	0.0008	0.3408
B15x15B01	HI-STAR	0.9321	0.9278	0.0008	0.3447
B15x15C01	HI-STAR	0.9271	0.9227	0.0008	0.3121
15x15D04	HI-STAR	0.9290	0.9246	0.0009	0.3950
15x15E01	HI-STAR	0.9309	0.9265	0.0009	0.3754
15x15F01	HI-STORM (DRY)	0.3897	0.3863	0.0003	3.192E+04
15x15F01	HI-TRAC	0.9333	0.9290	0.0008	0.3900
15x15F01	HI-STAR	0.9332	0.9289	0.0008	0.3861
15x15G01	HI-STAR	0.8972	0.8930	0.0007	0.4473
15x15H01	HI-TRAC	0.9399	0.9356	0.0008	0.3235
15x15H01	HI-STAR	0.9399	0.9357	0.0008	0.3248
16x16A01	HI-STAR	0.9021	0.8977	0.0009	0.3274
17x17A01	HI-STAR	0.9332	0.9287	0.0009	0.2821
17x17B06	HI-STAR	0.9316	0.9273	0.0008	0.3455
17x17C02	HI-TRAC	0.9320	0.9277	0.0008	0.2819
17x17C02	HI-STAR	0.9312	0.9270	0.0007	0.3530

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-32, 4.1% Enrichment, Bounding Cases					
Fuel Assembly Designation	**Cask**	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
14x14A03	HI-STAR	0.9041	0.9001	0.0006	0.3185
B14x14B01	HI-STAR	0.9257	0.9216	0.0007	0.4049
14x14C01	HI-STAR	0.9423	0.9382	0.0007	0.4862
14x14D01	HI-STAR	0.8970	0.8931	0.0006	0.5474
15x15A01	HI-STAR	0.9206	0.9167	0.0006	0.5072
B15x15B01	HI-STAR	0.9397	0.9358	0.0006	0.4566
B15x15C01	HI-STAR	0.9266	0.9227	0.0006	0.4167
15x15D04	HI-STAR	0.9384	0.9345	0.0006	0.5594
15x15E01	HI-STAR	0.9365	0.9326	0.0006	0.5403
15x15F01	HI-STORM (DRY)	0.4691	0.4658	0.0003	1.207E+04
15x15F01	HI-TRAC	0.9403	0.9364	0.0006	0.4938
15x15F01	HI-STAR	0.9411	0.9371	0.0006	0.4923
15x15G01	HI-STAR	0.9147	0.9108	0.0006	0.5880
15x15H01	HI-STAR	0.9276	0.9237	0.0006	0.4710
16x16A01	HI-STAR	0.9468	0.9427	0.0007	0.3925
17x17A01	HI-STAR	0.9111	0.9072	0.0006	0.4055
17x17B06	HI-STAR	0.9309	0.9269	0.0006	0.4365
17x17C02	HI-TRAC	0.9365	0.9327	0.0006	0.4468
17x17C02	HI-STAR	0.9355	0.9317	0.0006	0.4469

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-32, 5.0% Enrichment, Bounding Cases					
Fuel Assembly Designation	**Cask**	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
14x14A03	HI-STAR	0.9000	0.8959	0.0007	0.4651
B14x14B01	HI-STAR	0.9214	0.9175	0.0006	0.6009
14x14C01	HI-STAR	0.9480	0.9440	0.0006	0.6431
14x14D01	HI-STAR	0.9050	0.9009	0.0007	0.7276
15x15A01	HI-STAR	0.9230	0.9189	0.0007	0.7143
B15x15B01	HI-STAR	0.9429	0.9390	0.0006	0.7234
B15x15C01	HI-STAR	0.9307	0.9268	0.0006	0.6439
15x15D04	HI-STAR	0.9466	0.9425	0.0007	0.7525
15x15E01	HI-STAR	0.9434	0.9394	0.0007	0.7215
15x15F01	HI-STORM (DRY)	0.5142	0.5108	0.0004	1.228E+04
15x15F01	HI-TRAC	0.9470	0.9431	0.0006	0.7456
15x15F01	HI-STAR	0.9483	0.9443	0.0007	0.7426
15x15G01	HI-STAR	0.9251	0.9212	0.0006	0.9303
15x15H01	HI-STAR	0.9333	0.9292	0.0007	0.7015
16x16A01	HI-STAR	0.9474	0.9434	0.0006	0.5936
17x17A01	HI-STAR	0.9161	0.9122	0.0006	0.6141
17x17B06	HI-STAR	0.9371	0.9331	0.0006	0.6705
17x17C02	HI-TRAC	0.9436	0.9396	0.0006	0.6773
17x17C02	HI-STAR	0.9437	0.9399	0.0006	0.6780

Table 6.C.1 (continued)
CALCULATIONAL SUMMARY FOR ALL CANDIDATE FUEL TYPES
AND BASKET CONFIGURATIONS

MPC-32, 4.5% Enrichment, Bounding Cases					
Fuel Assembly Designation	**Cask**	**Maximum k_{eff}**	**Calculated k_{eff}**	**Std. Dev. (1-sigma)**	**EALF (eV)**
14x14E02	HI-STAR	0.8770	0.8729	0.0007	0.4364

Note: Maximum k_{eff} = Calculated k_{eff} + $K_c \times \sigma_c$ + Bias + σ_B
where:

K_c = 2.0
σ_c = Std. Dev. (1-sigma)
Bias = 0.0021
σ_B = 0.0006

See Subsection 6.4.3 for further explanation.

APPENDIX 6.D: SAMPLE INPUT FILES

(Total number of pages in this appendix : 35)

```
HI-TRAC Transfer Cask containing MPC24, 17x17 assembly @ 4.0 wt% Enrich.
c
c
c
c MPC-24/24E cell configuration
c
c HI-TRAC with active length 150 inch
c
c Cask Input Preprocessor
c cskinp 17a 17a mpc24n mpc24n hitrac trac150 4.0 4tf7a45 pure
c ------      cpp\17a.bat
c   added 17a.ce
c   added 17a.su
c   added 17a.sp
c ------     cpp\mpc24n.bat
c   added mpc24n.co
c   added mpc24n.ce
c   added mpc24n.su
c   added mpc24n.sp
c ------     cpp\hitrac.bat
c   added trac150.co
c   added hitrac.ce
c   added trac150.su
c   added trac150.sp
c end of comments
c
c start of cells
c
c 17x17a
c
c number of cells: 6
c cell numbers:      1 to 7
c univers numbers:   1 to 3
c surface numbers:   1 to 9
c
c number of cells: 1
1     1 -10.522     -1  u=2        $ fuel
2     4 -1.0     1  -2  u=2        $ gap
3     3 -6.55    2  -3  u=2        $ Zr Clad
4     4 -1.0        3  u=2        $ water in fuel region
5     4 -1.0  -4:5     u=3        $ water in guide tubes
6     3 -6.55   4 -5    u=3        $ guide tubes
7     4 -1.0  -6   +7   -8   +9   u=1  lat=1
      fill= -9:9    -9:9   0:0
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 2 2 2 2 2 3 2 2 3 2 2 3 2 2 2 2 2 1
      1 2 2 2 3 2 2 2 2 2 2 2 2 2 3 2 2 2 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 2 2 3 2 2 3 2 2 3 2 2 3 2 2 3 2 2 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 2 2 3 2 2 3 2 2 3 2 2 3 2 2 3 2 2 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 2 2 3 2 2 3 2 2 3 2 2 3 2 2 3 2 2 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 2 2 2 3 2 2 2 2 2 2 2 2 2 3 2 2 2 1
      1 2 2 2 2 2 3 2 2 3 2 2 3 2 2 2 2 2 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
      1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1
```

```
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
c
c     MPC-24
c
c number of cells: 102
c cell numbers :       400   to  699
c universe numbers :     4   to    9
c surface numbers :    400   to  699
c
c     Right Side
c
408      0           -410    411   -412    413    u=4 fill=1 (1)
409      5  -7.84     410  -424    413  -426    u=4
410     4 -1.0      424  -428    448  -445    u=4
411     7  -2.7      428  -528   448  -445    u=4
412     6  -2.66    528  -532   448  -445    u=4
413     7  -2.7     532  -432    448  -445    u=4
414     4 -1.0      432  -436    448  -445    u=4
415     5  -7.84     436  -440    448  -445    u=4
416     4 -1.0      440            413           u=4
417     4 -1.0      424  -440    413  -447    u=4
418     4 -1.0      424  -440    446            u=4
419     5  -7.84     424  -440    447  -448    u=4
420     5  -7.84     424  -440    445  -446    u=4
c
c    Left Side
c
421     5  -7.84     425  -411    413           u=4
422     4 -1.0      429  -425    448  -445    u=4
423     7  -2.7     529  -429    448  -445    u=4
424     6  -2.66    533 -529    448  -445    u=4
425     7  -2.7      433 -533    448  -445    u=4
426     4 -1.0      437  -433    448  -445    u=4
427     5  -7.84     441  -437    448  -445    u=4
428     4 -1.0          -441    413           u=4
429     4 -1.0      441  -425    413  -447    u=4
430     4 -1.0      441  -425    446            u=4
431     5  -7.84     441  -425    447  -448    u=4
432     5  -7.84     441  -425    445  -446    u=4
c
c     Top
c
433     5  -7.84     411  -410    412  -426    u=4
434     4 -1.0      451  -452    426  -430    u=4
435     7  -2.7      451  -452    430 -530    u=4
436     6  -2.66     451  -452   530 -534    u=4
437     7  -2.7      451  -452   534  -434    u=4
438     4 -1.0      451  -452    434  -438    u=4
439     5  -7.84     451  -452    438  -442    u=4
440     4 -1.0      411  -424    442           u=4
441     4 -1.0      411  -450    426  -442    u=4
442     4 -1.0      453  -424    426  -442    u=4
443     5  -7.84     450  -451    426  -442    u=4
444     5  -7.84     452  -453    426  -442    u=4
c
c     Bottom
c
445     5  -7.84     427              -413    u=4
446     4 -1.0      451  -452    431  -427    u=4
447     7  -2.7      451  -452   531  -431    u=4
448     6  -2.66     451  -452   535 -531    u=4
449     7  -2.7      451  -452    435 -535    u=4
```

```
450    4 -1.0     451  -452   439  -435    u=4
451    5  -7.84    451  -452   443  -439    u=4
452    4 -1.0     411              -443    u=4
453    4 -1.0     411  -450   443  -427    u=4
454    4 -1.0     453          443  -427    u=4
455    5  -7.84    450  -451   443  -427    u=4
456    5  -7.84    452  -453   443  -427    u=4
457    5  -7.84    425  -411        -427    u=4
458    4 -1.0        -425         -427    u=4
c
c     TYPE B CELL  -  Short Boral on top and right
c
c     Right Side
c
459    0          -410   411  -412   413    u=5 fill=1 (1)
460    5  -7.84    410  -424   413  -426    u=5
470    4 -1.0     424  -428  548 -545    u=5
471    7  -2.7     428  -528 548 -545    u=5
472    6  -2.66   528  -532 548 -545    u=5
473    7  -2.7    532  -432  548 -545    u=5
474    4 -1.0     432  -436  548 -545    u=5
475    5  -7.84    436  -440  548 -545    u=5
476    4 -1.0     440         413          u=5
477    4 -1.0     424  -440   413 -547    u=5
478    4 -1.0     424  -440  546            u=5
479    5  -7.84    424  -440  547 -548    u=5
480    5  -7.84    424  -440  545 -546    u=5
c
c    Left Side
c
481    5  -7.84    425  -411   413          u=5
482    4 -1.0     429  -425   448  -445    u=5
483    7  -2.7    529  -429   448  -445    u=5
484    6  -2.66   533 -529   448  -445    u=5
485    7  -2.7     433 -533   448  -445    u=5
486    4 -1.0     437  -433   448  -445    u=5
487    5  -7.84    441  -437   448  -445    u=5
488    4 -1.0        -441   413          u=5
489    4 -1.0     441  -425   413  -447    u=5
490    4 -1.0     441  -425   446          u=5
491    5  -7.84    441  -425   447  -448    u=5
492    5  -7.84    441  -425   445  -446    u=5
c
c     Top
c
493    5  -7.84    411  -410   412  -426    u=5
494    4 -1.0    551 -552   426  -430    u=5
495    7  -2.7    551 -552   430 -530    u=5
496    6  -2.66   551 -552  530 -534    u=5
497    7  -2.7    551 -552  534  -434    u=5
498    4 -1.0    551 -552  434  -438    u=5
499    5  -7.84   551 -552   438  -442    u=5
500   4 -1.0     411  -424  442          u=5
501   4 -1.0     411 -550  426  -442    u=5
502   4 -1.0    553  -424  426  -442    u=5
503   5  -7.84   550 -551  426  -442    u=5
504   5  -7.84   552 -553  426  -442    u=5
c
c     Bottom
c
505   5  -7.84   427            -413    u=5
506   4 -1.0    451  -452  431  -427    u=5
```

```
507   7  -2.7      451  -452  531  -431    u=5
508   6  -2.66     451  -452  535 -531    u=5
509   7  -2.7      451  -452   435 -535    u=5
510   4 -1.0      451  -452  439  -435    u=5
511   5  -7.84     451  -452   443  -439    u=5
512   4 -1.0      411             -443    u=5
513   4 -1.0      411  -450   443  -427    u=5
514   4 -1.0      453         443  -427    u=5
515   5  -7.84     450  -451   443  -427    u=5
516   5  -7.84     452  -453   443  -427    u=5
517   5  -7.84     425  -411         -427    u=5
518   4 -1.0         -425        -427    u=5
c
c
c
c     TYPE D CELL  -  Short Boral on left and bottom, different cell ID
c
c number of cells: 51
c
c     Right Side
c
1570   0          -1410   1411  -1412   1413    u=17 fill=1 (1)
1571   5  -7.84    1410  -1424   1413  -1426    u=17
1572   4 -1.0     1424  -1428  1448  -1445    u=17
1573   7  -2.7     1428  -1528  1448  -1445    u=17
1574   6  -2.66    1528  -1532  1448  -1445    u=17
1575   7  -2.7     1532  -1432  1448  -1445    u=17
1576   4 -1.0     1432  -1436  1448  -1445    u=17
1577   5  -7.84    1436  -1440  1448  -1445    u=17
1578   4 -1.0     1440       1413           u=17
1579   4 -1.0     1424  -1440  1413  -1447    u=17
1580   4 -1.0     1424  -1440  1446          u=17
1581   5  -7.84    1424  -1440  1447  -1448    u=17
1582   5  -7.84    1424  -1440  1445  -1446    u=17
c
c    Left Side
c
1583   5  -7.84    1425  -1411   1413         u=17
1584   4 -1.0     1429  -1425  1548 -1545    u=17
1585   7  -2.7     1529  -1429  1548 -1545    u=17
1586   6  -2.66    1533 -1529  1548 -1545    u=17
1587   7  -2.7     1433 -1533  1548 -1545    u=17
1588   4 -1.0     1437  -1433  1548 -1545    u=17
1589   5  -7.84    1441  -1437  1548 -1545    u=17
1590   4 -1.0        -1441   1413           u=17
1591   4 -1.0     1441  -1425  1413 -1547    u=17
1592   4 -1.0     1441  -1425  1546          u=17
1593   5  -7.84    1441  -1425  1547 -1548    u=17
1594   5  -7.84    1441  -1425  1545 -1546    u=17
c
c     Top
c
1595   5  -7.84    1411  -1410   1412  -1426    u=17
1596   4 -1.0     1451  -1452  1426  -1430    u=17
1597   7  -2.7     1451  -1452   1430 -1530    u=17
1598   6  -2.66    1451  -1452  1530 -1534    u=17
1599   7  -2.7     1451  -1452  1534  -1434    u=17
1600   4 -1.0     1451  -1452  1434  -1438    u=17
1601   5  -7.84    1451  -1452   1438  -1442    u=17
1602   4 -1.0     1411  -1424  1442          u=17
1603   4 -1.0     1411  -1450  1426  -1442    u=17
1604   4 -1.0     1453  -1424  1426  -1442    u=17
```

```
1605   5  -7.84    1450  -1451   1426  -1442    u=17
1606   5  -7.84    1452  -1453   1426  -1442    u=17
c
c     Bottom
c
1607   5  -7.84    1427              -1413    u=17
1608   4 -1.0    1551 -1552   1431  -1427    u=17
1609   7  -2.7    1551 -1552  1531  -1431    u=17
1610   6  -2.66   1551 -1552  1535 -1531    u=17
1611   7  -2.7    1551 -1552   1435 -1535    u=17
1612   4 -1.0    1551 -1552   1439  -1435    u=17
1613   5  -7.84   1551 -1552   1443  -1439    u=17
1614   4 -1.0     1411             -1443    u=17
1615   4 -1.0     1411 -1550   1443  -1427    u=17
1616   4 -1.0    1553           1443  -1427    u=17
1617   5  -7.84   1550 -1551   1443  -1427    u=17
1618   5  -7.84   1552 -1553   1443  -1427    u=17
1619   5  -7.84    1425  -1411         -1427    u=17
1620   4 -1.0        -1425        -1427    u=17
c
c number of cells: 29
c
c empty cell no boral, no top
c
c
751     4 -1.0   -410   411  -412   413    u=14
752     5  -7.84    410  -424   413  -426    u=14
753    5  -7.84    425  -411   413          u=14
754    4 -1.0     411  -410   412  -426    u=14
755    5  -7.84    427              -413    u=14
756    5  -7.84    425  -411        -427    u=14
757    4 -1.0     411   426               u=14
758    4 -1.0     411  -427               u=14
759    4 -1.0    -425   413               u=14
760    4 -1.0     424   413   -426        u=14
761    4 -1.0    -425  -427               u=14
c
c
701    5    -7.84    701 -702 711 -713      u=9    $ steel post
702    5    -7.84    702 -703 711 -712      u=9    $ steel post
c
711    0              701 -705 711 -715 (702:713) (703:712)
                      fill=4 (13.8506 13.8506 0) u=9
712    0              704 (-706:-716) (705:715) -717 -710
                      fill=4 (17.9489 41.5518 0  0 1 0  -1 0 0   0 0 1) u=9
713    0              (705:715) -707 714 (-706:-716)  710
                      fill=4 (41.5518 17.9489 0  0 -1 0  1 0 0   0 0 1) u=9
714    0              701 -705 717 -719
                      fill=5 (13.8506 69.253 0) u=9
715    0              707 -709 711 -715
                      fill=5 (69.253 13.8506 0) u=9
716    0              706 -708 716 -718
                      fill=17 (45.6501 45.6501 0  -1 0 0  0 -1 0  0 0 1) u=9
717    0              705 -706 717 -719
                      fill=14 (41.5518 69.253 0) u=9
718    0              707 -709 715 -716
                      fill=14 (69.253 41.5518 0 0 1 0   1 0 0   0 0 1) u=9
719    0              701 -704 715 -717
                      fill=14 (-9.75233 41.5518 0  -1 0 0  0 1 0   0 0 1) u=9
720    0              705 -707 711 -714
                      fill=14 (41.5518 -9.75233 0   0 -1 0  1 0 0   0 0 1) u=9
721    4 -1.0       (706:719) (708:718) (709:716) u=9
```

```
c
c
c
731   4 -1.0      720  721   fill=9 (0 0 0) u=19
732   4 -1.0     -720  721   fill=9 (0 0 0
                              -1 0 0  0  1 0  0 0 1) u=19
733   4 -1.0      720 -721   fill=9 (0 0 0
                               1 0 0  0 -1 0  0 0 1) u=19
734   4 -1.0     -720 -721   fill=9 (0 0 0
                              -1 0 0  0 -1 0  0 0 1) u=19
c
673   0           -41               39  -40  fill=19
c
c number of cells: 20
374   4  -1.0     -41         300   -39    $ Water below Fuel (4 in.)
375   5  -7.84   -309         302  -300    $ MPC Steel below Fuel (2.5 in.)
376   5  -7.84   -315         320  -302    $ Transfer Cask Steel (2.0 in.)
377   30 -11.34  -315         321  -320   $ Transfer Cask Lead (2.5 in.)
378   5  -7.84   -315         322  -321   $ Transfer Cask Steel (1.0 in.)
c
379   4  -1.0     -41          40  -301    $ Water above Fuel (6 in.)
380   5  -7.84   -309         301  -303    $ MPC Steel above Fuel (9.5 - 0.06 in)
381   4  -1.0    -309         303  -330   $ Water (1.5 in.)
382   5  -7.84   -315         330  -331   $ Transfer Cask Steel (0.75 in.)
383   31 -1.61   -315         331  -332   $ Transfer Cask Neutron Shield (3.25 in.)
384   5  -7.84   -315         332  -333   $ Transfer Cask Steel (0.5 in.)
c
390   5  -7.84     41  -309  300  -301     $ Radial Steel - MPC shell
391   4  -1.00    309  -310  302  -330    $ Radial Water
392   5  -7.84    310  -311  302  -330    $ Radial Steel - inner shell of Trnsfr Cask
393   30 -11.34   311  -312  302  -330    $ Radial Lead - Transfer Cask lead
394   5  -7.84    312  -313  302  -330    $ Radial Steel - outer shell of Trnsfr Cask
395   4  -1.00    313  -314  302  -330    $ Radial Water - Water Jacket
396   5  -7.84    314  -315  302  -330    $ Radial Steel - outer shell of Water Jacket
c
300   4  -1.00    340  -341 -345   (315 :-322:  333)    $ outer water reflector
301   0           345 :-340: 341      $ outside world
c end of cells
c --- empty line

c --- empty line
c start of surfaces
1      cz         0.3922    $ fuel
2      cz         0.4001    $ clad ID
3      cz         0.4572    $ clad OD
4      cz         0.5613    $ guide ID
5      cz         0.6020    $ guide OD
6      px         0.6299    $ pin pitch
7      px        -0.6299
8      py         0.6299
9      py        -0.6299
c
c
c cell-id       8.98
c cell-pitch    10.906
c wall-thkns    5/16
c angle-thkns   5/16
c boral-gap     0.0035
c boral-gap-o   0.0035
c boral-thkns   0.075
c boral-clad    0.01
c sheathing     0.0235
```

```
c boral-wide   7.5
c boral-narrow 6.25
c
c gap size     1.09
c basket-od    67.335
c
410    px        11.40460 $x 8.98/2
411    px       -11.40460 $x {410} *-1
412    py        11.40460 $x {410}
413    py       -11.40460 $x {411}
416    px        13.85062 $x (10.906 + 5/16 - 5/16) /2
417    px       -13.85062 $x -10.906 + {416}
418    py        13.85062 $x {416}
419    py       -13.85062 $x {417}
424    px        12.19835 $x {410} + 5/16     $ angle
425    px       -12.19835 $x {411} - 5/16     $ box wall
426    py        12.19835 $x {412} + 5/16
427    py       -12.19835 $x {413} - 5/16
428    px        12.20724 $x {424} + 0.0035   $ wall to boral gap
429    px       -12.20724 $x {425} - 0.0035
430    py        12.20724 $x {426} + 0.0035
431    py       -12.20724 $x {427} - 0.0035
432    px        12.39774 $x {428} + 0.075    $ boral
433    px       -12.39774 $x {429} - 0.075
434    py        12.39774 $x {430} + 0.075
435    py       -12.39774 $x {431} - 0.075
436    px        12.40663 $x {432} + 0.0035   $ boral to sheathing gap
437    px       -12.40663 $x {433} - 0.0035
438    py        12.40663 $x {434} + 0.0035
439    py       -12.40663 $x {435} - 0.0035
440    px        12.46632 $x {436} + 0.0235   $ sheathing
441    px       -12.46632 $x {437} - 0.0235
442    py        12.46632 $x {438} + 0.0235
443    py       -12.46632 $x {439} - 0.0235
445    py         9.52500 $x 7.5/2
446    py         9.58469 $x {445} + 0.0235   $ sheathing
447    py        -9.58469 $x {446} *-1
448    py        -9.52500 $x {445} *-1
450    px        -9.58469 $x {447}
451    px        -9.52500 $x {448}
452    px         9.52500 $x {445}
453    px         9.58469 $x {446}
528   px        12.23264 $x {428} + 0.01  $ Aluminum on the outside of boral
529   px       -12.23264 $x {429} - 0.01
530   py        12.23264 $x {430} + 0.01
531   py       -12.23264 $x {431} - 0.01
532   px        12.37234 $x {432} - 0.01
533   px       -12.37234 $x {433} + 0.01
534   py        12.37234 $x {434} - 0.01
535   py       -12.37234 $x {435} + 0.01
545   py         7.93750 $x 6.25/2
546   py         7.99719 $x {545} + 0.0235   $ sheathing
547   py        -7.99719 $x {546} *-1
548   py        -7.93750 $x {545} *-1
550   px        -7.99719 $x {547}
551   px        -7.93750 $x {548}
552   px         7.93750 $x {545}
553   px         7.99719 $x {546}
c
c cell-id-2 8.98
c gap-o     1.09
c
```

```
701    px        -5.0
702    px        1.90627 $x (10.906 - 8.98)/2 - 5/16 + 0.1
703    px        3.45694 $x 2.722/2
704    px        4.09829 $x 10.906 - 8.98 - 5/16
705    px        27.70124 $x 10.906
706    px        31.79953 $x 2 * 10.906 - (8.98+8.98)/2 - 5/16
707    px        55.40248 $x 2 * 10.906
708    px        59.50077 $x {707} + {704}
709    px        83.10372 $x 3 * 10.906
710    p     1  -1  0   0.1 $ diagonal x=y, offset by 0.1 to avoid intersecting corners
711    py        -4.99999 $x {701}
712    py        1.90627 $x {702}
713    py        3.45694 $x {703}
714    py        4.09829 $x {704}
715    py        27.70124 $x {705}
716    py        31.79953 $x {706}
717    py        55.40248 $x {707}
718    py        59.50077 $x {708}
719    py        83.10372 $x {709}
720    px        0.0
721    py        0.0
1410     px        11.40460 $x 8.98/2
1411     px       -11.40460 $x {1410} *-1
1412     py        11.40460 $x {1410}
1413     py       -11.40460 $x {1411}
1424     px        12.19835 $x {1410} + 5/16     $ angle
1425     px       -12.19835 $x {1411} - 5/16     $ box wall
1426     py        12.19835 $x {1412} + 5/16
1427     py       -12.19835 $x {1413} - 5/16
1428     px        12.20724 $x {1424} + 0.0035   $ wall to boral gap
1429     px       -12.20724 $x {1425} - 0.0035
1430     py        12.20724 $x {1426} + 0.0035
1431     py       -12.20724 $x {1427} - 0.0035
1432     px        12.39774 $x {1428} + 0.075    $ boral
1433     px       -12.39774 $x {1429} - 0.075
1434     py        12.39774 $x {1430} + 0.075
1435     py       -12.39774 $x {1431} - 0.075
1436     px        12.40663 $x {1432} + 0.0035   $ boral to sheathing gap
1437     px       -12.40663 $x {1433} - 0.0035
1438     py        12.40663 $x {1434} + 0.0035
1439     py       -12.40663 $x {1435} - 0.0035
1440     px        12.46632 $x {1436} + 0.0235   $ sheathing
1441     px       -12.46632 $x {1437} - 0.0235
1442     py        12.46632 $x {1438} + 0.0235
1443     py       -12.46632 $x {1439} - 0.0235
1445     py         9.52500 $x 7.5/2
1446     py         9.58469 $x {1445} + 0.0235   $ sheathing
1447     py        -9.58469 $x {1446} *-1
1448     py        -9.52500 $x {1445} *-1
1450     px        -9.58469 $x {1447}
1451     px        -9.52500 $x {1448}
1452     px         9.52500 $x {1445}
1453     px         9.58469 $x {1446}
1528    px        12.23264 $x {1428} + 0.01  $ Aluminum on the outside of boral
1529    px       -12.23264 $x {1429} - 0.01
1530    py        12.23264 $x {1430} + 0.01
1531    py       -12.23264 $x {1431} - 0.01
1532    px        12.37234 $x {1432} - 0.01
1533    px       -12.37234 $x {1433} + 0.01
1534    py        12.37234 $x {1434} - 0.01
1535    py       -12.37234 $x {1435} + 0.01
1545    py         7.93750 $x 6.25/2
```

```
1546   py        7.99719 $x {1545} + 0.0235   $ sheathing
1547   py       -7.99719 $x {1546} *-1
1548   py       -7.93750 $x {1545} *-1
1550   px       -7.99719 $x {1547}
1551   px       -7.93750 $x {1548}
1552   px        7.93750 $x {1545}
1553   px        7.99719 $x {1546}
39    pz        0.0      $ bottom of active fuel assembly
40    pz      381.0      $ top of active fuel assembly
41    cz       85.57     $ MPC
300   pz      -10.16     $ lower water thkness = 4 in.
301   pz      396.24     $ upper water thkness = 6 in.
302   pz      -16.51     $ thkness of MPC baseplate = 2.5 in.
303   pz      420.22     $ thkness of MPC lid = 9.5 -0.06 in.
309   cz       86.84     $ I.D. = 68.375 in.
310   cz       87.31     $ I.D. = 68.75 in.
311   cz       89.22     $ I.D. = 70.25 in.
312   cz      100.65     $ I.D. = 79.25 in.
313   cz      103.19     $ I.D. = 81.25 in.
314   cz      116.80     $ I.D. = 91.97 in.
315   cz      118.07     $ I.D. = 92.972 in.
320   pz      -21.59     $ thkness steel - 2.0 in.
321   pz      -27.94     $ thkness lead - 2.5 in.
322   pz      -30.48     $ thkness steel - 1.0 in.
330   pz      424.03     $ thkness water - 1.5 in.
331   pz      425.93     $ thkness steel - 0.75 in.
332   pz      434.19     $ thkness neutron shield - 3.25 in.
333   pz      435.46     $ thkness steel - 0.5 in.
c
*340  pz  -60.48  $ lower boundary
*341  pz  465.46  $ upper boundary
*345  cz  148.07  $ outer radial boundary
c end of surfaces
c --- empty line

c --- empty line
tr1 0 0 0
kcode    10000  .94  20  120
dbcn 7j 1e7
sdef  par=1  erg=d1 axs=0 0 1 x=d4 y=fx d5 z=d3
c
sp1  -2 1.2895
c
sp3  0 1
c
si4  s        13 14
           12 13 14 15
        11 12 13 14 15 16
        11 12 13 14 15 16
           12 13 14 15
              13 14
sp4  1 23r
c
ds5  s              26 26
                 25 25 25 25
              24 24 24 24 24 24
              23 23 23 23 23 23
                 22 22 22 22
                    21 21
c
si11  -79.25435 -57.61355
si12  -51.88077 -30.23997
```

```
si13  -24.50719 -2.86639
si14    2.86639   24.50719
si15   30.23997   51.88077
si16   57.61355   79.25435
c
si21  -79.25435 -57.61355
si22  -51.88077 -30.23997
si23  -24.50719 -2.86639
si24    2.86639   24.50719
si25   30.23997   51.88077
si26   57.61355   79.25435
c
sp11  0 1
sp12  0 1
sp13  0 1
sp14  0 1
sp15  0 1
sp16  0 1
sp21  0 1
sp22  0 1
sp23  0 1
sp24  0 1
sp25  0 1
sp26  0 1
c
m3          40000.56c    1.            $ Zr Clad
m4          1001.50c     0.6667        $ Water
            8016.50c     0.3333
m5          24000.50c    0.01761       $ Steel
            25055.50c    0.001761
            26000.55c    0.05977
            28000.50c    0.008239
m6          5010.50c    -0.054427      $ Boral Central Section @ 0.02 g/cmsq
            5011.50c    -0.241373
            13027.50c   -0.6222
            6000.50c    -0.0821
m7          13027.50c    1.0
mt4        lwtr.01t
prdmp     j   -120    j    2
fm4       1000    1    -6
f4:n    1
sd4       1000
e4     1.000E-11    1.000E-10    5.000E-10    7.500E-10    1.000E-09    1.200E-09
       1.500E-09    2.000E-09    2.500E-09    3.000E-09
       4.700E-09    5.000E-09    7.500E-09    1.000E-08    2.530E-08
       3.000E-08    4.000E-08    5.000E-08    6.000E-08    7.000E-08
       8.000E-08    9.000E-08    1.000E-07    1.250E-07    1.500E-07
       1.750E-07    2.000E-07    2.250E-07    2.500E-07    2.750E-07
       3.000E-07    3.250E-07    3.500E-07    3.750E-07    4.000E-07
       4.500E-07    5.000E-07    5.500E-07    6.000E-07    6.250E-07
       6.500E-07    7.000E-07    7.500E-07    8.000E-07    8.500E-07
       9.000E-07    9.250E-07    9.500E-07    9.750E-07    1.000E-06
       1.010E-06    1.020E-06    1.030E-06    1.040E-06    1.050E-06
       1.060E-06    1.070E-06    1.080E-06    1.090E-06    1.100E-06
       1.110E-06    1.120E-06    1.130E-06    1.140E-06    1.150E-06
       1.175E-06    1.200E-06    1.225E-06    1.250E-06    1.300E-06
       1.350E-06    1.400E-06    1.450E-06    1.500E-06    1.590E-06
       1.680E-06    1.770E-06    1.860E-06    1.940E-06    2.000E-06
       2.120E-06    2.210E-06    2.300E-06    2.380E-06    2.470E-06
       2.570E-06    2.670E-06    2.770E-06    2.870E-06    2.970E-06
       3.000E-06    3.050E-06    3.150E-06    3.500E-06    3.730E-06
       4.000E-06    4.750E-06    5.000E-06    5.400E-06    6.000E-06
```

```
       6.250E-06   6.500E-06   6.750E-06   7.000E-06   7.150E-06
       8.100E-06   9.100E-06   1.000E-05   1.150E-05   1.190E-05
       1.290E-05   1.375E-05   1.440E-05   1.510E-05   1.600E-05
       1.700E-05   1.850E-05   1.900E-05   2.000E-05   2.100E-05
       2.250E-05   2.500E-05   2.750E-05   3.000E-05   3.125E-05
       3.175E-05   3.325E-05   3.375E-05   3.460E-05   3.550E-05
       3.700E-05   3.800E-05   3.910E-05   3.960E-05   4.100E-05
       4.240E-05   4.400E-05   4.520E-05   4.700E-05   4.830E-05
       4.920E-05   5.060E-05   5.200E-05   5.340E-05   5.900E-05
       6.100E-05   6.500E-05   6.750E-05   7.200E-05   7.600E-05
       8.000E-05   8.200E-05   9.000E-05   1.000E-04   1.080E-04
       1.150E-04   1.190E-04   1.220E-04   1.860E-04   1.925E-04
       2.075E-04   2.100E-04   2.400E-04   2.850E-04   3.050E-04
       5.500E-04   6.700E-04   6.830E-04   9.500E-04   1.150E-03
       1.500E-03   1.550E-03   1.800E-03   2.200E-03   2.290E-03
       2.580E-03   3.000E-03   3.740E-03   3.900E-03   6.000E-03
       8.030E-03   9.500E-03   1.300E-02   1.700E-02   2.500E-02
       3.000E-02   4.500E-02   5.000E-02   5.200E-02   6.000E-02
       7.300E-02   7.500E-02   8.200E-02   8.500E-02   1.000E-01
       1.283E-01   1.500E-01   2.000E-01   2.700E-01   3.300E-01
       4.000E-01   4.200E-01   4.400E-01   4.700E-01   4.995E-01
       5.500E-01   5.730E-01   6.000E-01   6.700E-01   6.790E-01
       7.500E-01   8.200E-01   8.611E-01   8.750E-01   9.000E-01
       9.200E-01   1.010E+00   1.100E+00   1.200E+00   1.250E+00
       1.317E+00   1.356E+00   1.400E+00   1.500E+00   1.850E+00
       2.354E+00   2.479E+00   3.000E+00   4.304E+00   4.800E+00
       6.434E+00   8.187E+00   1.000E+01   1.284E+01   1.384E+01
       1.455E+01   1.568E+01   1.733E+01   2.000E+01
si3  h 0 381.00
m30          82000.50c   1.0      $ Lead
m31           6000.50c  -27.660   $ Neutron Shield Holtite-A (NS-4-FR)
             1001.50c   -5.920
            13027.50c  -21.285
             7014.50c   -1.98
             8016.50c  -42.372
             5010.50c   -0.141
             5011.50c   -0.642
imp:n 1 207r 0
c fuel enrichment 4.0 %
m1      92235.50c     -0.03526
        92238.50c     -0.84624
         8016.50c     -0.11850
c end of file
c
```

```
HI-TRAC Transfer Cask containing MPC68, 08x08 assembly @ 4.2 wt% Enrich.
c     reflected w/60cm of water, 0.0279 g/cmsq B-10 in Boral
c
c
1      1 -10.522      -1  u=2       $ fuel
2      4 -1.0      1  -2  u=2       $ gap
3      3 -6.55     2  -3  u=2       $ Zr Clad
4      4 -1.0         3  u=2       $ water in fuel region
5      4 -1.0    -4:5     u=3       $ water in guide tubes
6      4 -1.00    4 -5    u=3       $ guide tubes
7      4 -1.0    -6    +7   -8    +9    u=1  lat=1
       fill= -5:4    -5:4   0:0
       1  1 1 1 1 1 1 1 1  1
       1  2 2 2 2 2 2 2 2  1
       1  2 2 2 2 2 2 2 2  1
       1  2 2 2 2 2 2 2 2  1
       1  2 2 2 3 2 2 2 2  1
       1  2 2 2 2 3 2 2 2  1
       1  2 2 2 2 2 2 2 2  1
       1  2 2 2 2 2 2 2 2  1
       1  2 2 2 2 2 2 2 2  1
       1  1 1 1 1 1 1 1 1  1
c
C  BOX TYPE R
c
8      0  -10    11  -12   13          u=4 fill=1 (0.8128 0.8128 0)
9      3  -6.55    60    -61    62   -63  #8        u=4      $ Zr flow channel
10     4  -1.      64    -65    66   -67  #8 #9     u=4      $ water
11     5  -7.84    20    -23    67   -14            u=4      $ 0.075" STEEL
12     4  -1.      20    -23    14   -15            u=4      $ WATER POCKET
13     7  -2.7     20    -23    15   -16            u=4      $ Al CLAD
14     6  -2.66    20    -23    16   -17            u=4      $ BORAL Absorber
15     7  -2.7     20    -23    17   -18            u=4      $ Al Clad
16     4  -1.      20    -23    18  -118            u=4      $ Water
17     5  -7.84    118:-129:65:-66                  u=4      $ Steel
18     4  -1.      64    -21    67   -118           u=4      $ Water
19     4  -1.      24    -65    67   -118           u=4      $ water
20     5  -7.84    21    -20    67   -118           u=4      $ Steel
21     5  -7.84    23    -24    67   -118           u=4      $ Steel
22     4  -1.     129    -64    33   -118           u=4      $ Water
c
23     5  -7.84    25    -64    30   -31            u=4      $ Steel
24     4  -1.      26    -25    30   -31            u=4      $ Water
25     7  -2.7     27    -26    30   -31            u=4      $ Al clad
26     6  -2.66    28    -27    30   -31            u=4      $ Boral
27     7  -2.7     29    -28    30   -31            u=4      $ Al clad
28     4  -1.     129    -29    30   -31            u=4      $ water
29     5  -7.84   129    -64    32   -30            u=4      $ Steel ends
30     5  -7.84   129    -64    31   -33            u=4      $ Steel ends
31     4  -1.     129    -64    66   -32            u=4      $ Water
c
c   Type A box - Boral only on left side
c
32     0  -10    11  -12    13          u=6 fill=1 (0.8128 0.8128 0)
33     3  -6.55    60    -61    62   -63  #8        u=6      $ Zr flow channel
34     4  -1.      64    -65    66  -118  #8 #9     u=6      $ water
35     5  -7.84    118:-129:65:-66                  u=6      $ Steel
36     4  -1.     129    -64    67   -118           u=6      $ Water
c
37     5  -7.84    25    -64    30   -31            u=6      $ Steel
38     4  -1.      26    -25    30   -31            u=6      $ Water
39     7  -2.7     27    -26    30   -31            u=6      $ Al clad
```

```
40     6  -2.66     28    -27     30    -31              u=6      $ Boral
41     7  -2.7      29    -28     30    -31              u=6      $ Al clad
42     4  -1.      129    -29     30    -31              u=6      $ water
43     4  -1.      129    -64     33    -67              u=6      $ Water
44     5  -7.84    129    -64     32    -30              u=6      $ Steel ends
45     5  -7.84    129    -64     31    -33              u=6      $ Steel ends
46     4  -1.      129    -64     66    -32              u=6      $ Water
c
c     Type B box -  Boral on Top only
c
47     0  -10    11  -12    13           u=7 fill=1  (0.8128 0.8128 0)
48     3  -6.55     60    -61     62    -63  #8          u=7      $ Zr flow channel
49     4  -1.       64    -65     66    -67  #8 #9       u=7      $ water
50     5  -7.84     20    -23     67    -14              u=7      $ 0.075" STEEL
51     4  -1.       20    -23     14    -15              u=7      $ WATER POCKET
52     7  -2.7      20    -23     15    -16              u=7      $ Al CLAD
53     6  -2.66     20    -23     16    -17              u=7      $ BORAL Absorber
54     7  -2.7      20    -23     17    -18              u=7      $ water
55     4  -1.       20    -23     18  -118               u=7      $ Water
56     5  -7.84     118:-129:65:-66                      u=7      $ Steel
57     4  -1.       64    -21     67   -118              u=7      $ Water
58     4  -1.       24    -65     67   -118              u=7      $ water
59     5  -7.84     21    -20     67   -118              u=7      $ Steel
60     5  -7.84     23    -24     67   -118              u=7      $ Steel
61     4  -1.      129    -64     66   -118              u=7      $ Water
c
c     Type E box  - No Boral Panels
c
62     0  -10    11  -12    13           u=8 fill=1  (0.8128 0.8128 0)
63     3  -6.55     60    -61     62    -63  #8          u=8      $ Zr flow channel
64     4  -1.      129    -65     66  -118   #8 #9       u=8      $ water
65     5  -7.84     118:-129:65:-66                      u=8      $ Steel
c
c     Type F box  - No Boral Panels or fuel
c
66     4  -1.      129    -65     66  -118               u=9      $ water
67     5  -7.84     118:-129:65:-66                      u=9      $ Steel
c
68     4  -1.0     -34   35   -36   37  u=5  lat=1  fill=-7:6  -7:6  0:0
                 5 5 5 5 5 5 5 5 5 5 5 5 5 5
                 5 9 9 9 9 9 9 9 9 9 9 9 9 5
                 5 9 9 9 9 9 7 4 9 9 9 9 9 5
                 5 9 9 9 7 4 4 4 4 4 9 9 9 5
                 5 9 9 7 4 4 4 4 4 4 4 9 9 5
                 5 9 9 7 4 4 4 4 4 4 4 9 9 5
                 5 9 7 4 4 4 4 4 4 4 4 4 9 5
                 5 9 8 4 4 4 4 4 4 4 4 6 9 5
                 5 9 9 7 4 4 4 4 4 4 4 9 9 5
                 5 9 9 8 4 4 4 4 4 4 6 9 9 5
                 5 9 9 9 8 4 4 4 6 6 9 9 9 5
                 5 9 9 9 9 9 8 6 9 9 9 9 9 5
                 5 9 9 9 9 9 9 9 9 9 9 9 9 5
                 5 5 5 5 5 5 5 5 5 5 5 5 5 5
69     0            -41                 50   -49  fill=5 (8.1661  8.1661  0)
c
274    4  -1.0     -41       360   -50    $ Water below Fuel (7.3 in.)
275    5  -7.84    -42       362 -360     $ MPC Steel below Fuel (2.5 in.)
276    5  -7.84    -205      300 -362     $ Transfer Cask Steel (2.0 in.)
277    8 -11.34    -205      301   -300   $ Transfer Cask Lead (2.5 in.)
278    5  -7.84    -205      302   -301   $ Transfer Cask Steel (1.0 in.)
c
279    4  -1.0     -41        49   -361   $ Water above Fuel (8.46 in.)
```

```
280   5  -7.84    -42       361   -363  $ MPC Steel above Fuel (10.0 in)
281   4  -1.0     -42       363   -400  $ Water (1.5 in.)
282   5  -7.84    -205      400   -401  $ Transfer Cask Steel (0.75 in.)
283   9  -1.61    -205      401   -402  $ Transfer Cask Neutron Shield (3.25 in.)
284   5  -7.84    -205      402   -403  $ Transfer Cask Steel (0.5 in.)
c
290   5  -7.84     41  -42  360 -361   $ Radial Steel - MPC shell
291   4  -1.00     42  -200 362 -400   $ Radial Water
292   5  -7.84     200 -201 362 -400   $ Radial Steel - inner shell of Trnsfr Cask
293   8 -11.34     201 -202 362 -400   $ Radial Lead - Transfer Cask lead
294   5  -7.84     202 -203 362 -400   $ Radial Steel - outer shell of Trnsfr Cask
295   4  -1.00     203 -204 362 -400   $ Radial Water - Water Jacket
296   5  -7.84     204 -205 362 -400   $ Radial Steel - outer shell of Water Jacket
c
500   4  -1.00     500 -501 -505  (205 :-302:  403)    $ outer water reflector
501   0            505 :-500: 501      $ outside world

1      cz          0.5283      $ Fuel OD
2      cz          0.5398      $ Clad ID
3      cz          0.6134      $ Clad OD
4      cz          0.6744      $ Thimble ID
5      cz          0.7506      $ Thimble OD
6      px          0.8128      $ Pin Pitch
7      px         -0.8128
8      py          0.8128
9      py         -0.8128
10     px          6.6231      $ Channel ID
11     px         -6.6231
12     py          6.6231
13     py         -6.6231
14     py          7.8016
15     py          7.8155
16     py          7.8410
17     py          8.0467
18     py          8.0721
118    py          8.0861
20     px         -6.0325
21     px         -6.2230
23     px          6.0325
24     px          6.2230
25     px         -7.8016
26     px         -7.8155
27     px         -7.8410
28     px         -8.0467
29     px         -8.0721
129    px         -8.0861
30     py         -6.0325
31     py          6.0325
32     py         -6.2230
33     py          6.2230
34     px          7.6111
35     px         -8.7211
36     py          8.7211
37     py         -7.6111
49     pz         381.          $ Top of Active Fuel
50     pz           0           $ Start of Active Fuel
60     px          -6.9279      $ Channel OD
61     px           6.9279
62     py          -6.9279
63     py           6.9279
64     px          -7.6111      $ Cell Box ID
65     px           7.6111
```

```
66    py          -7.6111
67    py           7.6111
360   pz         -18.54    $ lower water thkness = 7.30 in.
361   pz          402.49   $ upper water thkness = 8.46 in.
362   pz         -24.892   $ thkness of MPC baseplate = 2.5 in.
363   pz          427.89   $ thkness of MPC lid = 10.  in.
41    cz         85.57     $ I.D. = 67.375 in.
42    cz         86.84     $ I.D. = 68.375 in.
200   cz         87.31     $ I.D. = 68.75 in.
201   cz         89.22     $ I.D. = 70.25 in.
202   cz        100.65     $ I.D. = 79.25 in.
203   cz        103.19     $ I.D. = 81.25 in.
204   cz        116.80     $ I.D. = 91.97 in.
205   cz        118.07     $ I.D. = 92.972 in.
300   pz        -29.97     $ thkness steel - 2.0 in.
301   pz        -36.32     $ thkness lead - 2.5 in.
302   pz        -38.86     $ thkness steel - 1.0 in.
400   pz        431.70     $ thkness water - 1.5 in.
401   pz        433.61     $ thkness steel - 0.75 in.
402   pz        441.87     $ thkness neutron shield - 3.25 in.
403   pz        443.14     $ thkness steel - 0.5 in.
c
*500  pz  -68.86  $ lower boundary
*501  pz  473.14  $ upper boundary
*505  cz  148.07  $ outer radial boundary

imp:n     1 87r 0
kcode   10000  0.94   20  120
c
sdef  par=1  erg=d1 axs=0 0 1 x=d4 y=fx d5 z=d3
c
sp1 -2 1.2895
c
si3  h 0 381.
sp3  0 1
c
c
si4  s             15 16
             13 14 15 16 17 18
          12 13 14 15 16 17 18 19
          12 13 14 15 16 17 18 19
       11 12 13 14 15 16 17 18 19 20
       11 12 13 14 15 16 17 18 19 20
          12 13 14 15 16 17 18 19
          12 13 14 15 16 17 18 19
             13 14 15 16 17 18
                   15 16
sp4  1 67r
c
ds5  s             30 30
             29 29 29 29 29 29
          28 28 28 28 28 28 28 28
          27 27 27 27 27 27 27 27
       26 26 26 26 26 26 26 26 26 26
       25 25 25 25 25 25 25 25 25 25
          24 24 24 24 24 24 24 24
          23 23 23 23 23 23 23 23
             22 22 22 22 22 22
                   21 21
c
si11  -80.6831 -67.6783
si12  -64.1985 -51.1937
```

Table 6.3.1

CASMO-3 CALCULATIONS FOR EFFECT OF TOLERANCES AND TEMPERATURE

Change in Nominal Parameter[†]	**Δk for Maximum Tolerance**		**Action/Modeling Assumption**
	MPC-24[‡]	**MPC-68**	
Reduce Fixed Neutron Absorber Width to Minimum	N/A[†††] min.= nom.= 7.5" and 6.25"	N/A[†††] min. = nom. = 4.75"	Assume minimum fixed neutron absorber width
Increase UO_2 Density to Maximum	+0.0017 max. = 10.522 g/cc nom. = 10.412 g/cc	+0.0014 max. = 10.522 g/cc nom. = 10.412 g/cc	Assume maximum UO_2 density
Reduce Box Inside Dimension (I.D.) to Minimum	-0.0005 min.= 8.86" nom. = 8.92"	See Table 6.3.2	Assume maximum box I.D. for the MPC-24
Increase Box Inside Dimension (I.D.) to Maximum	+0.0007 max. = 8.98" nom. = 8.92"	-0.0030 max. = 6.113" nom. = 6.053"	Assume minimum box I.D. for the MPC-68
Decrease Water Gap to Minimum	+0.0069 min. = 1.09" nom. = 1.15"	N/A	Assume minimum water gap in the MPC-24

† Reduction (or increase) in a parameter indicates that the parameter is changed to its minimum (or maximum) value.

‡ Calculations for the MPC-24 were performed with CASMO-4 [6.3.1-6.3.3].

††† The fixed neutron absorber width for the MPC-68 is 4.75" +0.125", -0" , the fixed neutron absorber widths for the MPC-24 are 7.5" +0.125", -0" and 6.25" +0.125" –0" (i.e., the nominal and minimum values are the same).

Table 6.3.1 (continued)

CASMO-3 CALCULATIONS FOR EFFECT OF TOLERANCES AND TEMPERATURE

Change in Nominal Parameter	Δk Maximum Tolerance		Action/Modeling Assumption
	MPC-24‡	MPC-68	
Increase in Temperature 20°C 40°C 70°C 100°C	 Ref. -0.0030 -0.0089 -0.0162	 Ref. -0.0039 -0.0136 -0.0193	Assume 20°C
10% Void in Moderator 20°C with no void 20°C 100°C	 Ref. -0.0251 -0.0412	 Ref. -0.0241 -0.0432	Assume no void
Removal of Flow Channel (BWR)	N/A	-0.0073	Assume flow channel present for MPC-68

‡ Calculations for the MPC-24 were performed with CASMO-4 [6.3.1-6.3.3].

Table 6.3.2

MCNP4a EVALUATION OF BASKET MANUFACTURING TOLERANCES[†]

Pitch		Box I.D.		Box Wall Thickness		MCNP4a Calculated k_{eff}
MPC-24[††] (17x17A01 @ 4.0% Enrichment)						
nominal	(10.906")	maximum	(8.98")	nominal	(5/16")	0.9325±0.0008[†††]
minimum	(10.846")	nominal	(8.92")	nominal	(5/16")	0.9300±0.0008
nominal	(10.906")	nom. - 0.04"	(8.88")	nom. + 0.05"	(0.3625")	0.9305±0.0007
MPC-68 (8x8C04 @ 4.2% Enrichment)						
minimum	(6.43")	minimum	(5.993")	nominal	(1/4")	0.9307±0.0007
nominal	(6.49")	nominal	(6.053")	nominal	(1/4")	0.9274±0.0007
maximum	(6.55")	maximum	(6.113")	nominal	(1/4")	0.9272±0.0008
nom. + 0.05"	(6.54")	nominal	(6.053")	nom. + 0.05"	(0.30")	0.9267±0.0007

Notes:

1. Values in parentheses are the actual value used.

† Tolerance for pitch and box I.D. are ± 0.06".
Tolerance for box wall thickness is +0.05", -0.00".

†† All calculations for the MPC-24 assume minimum water gap thickness (1.09").

††† Numbers are 1σ statistical uncertainties.

Table 6.3.2 (cont.)

MCNP4a EVALUATION OF BASKET MANUFACTURING TOLERANCES†

Pitch	Box I.D.	Box Wall Thickness	MCNP4a Calculated k_{eff}
MPC-24 (17x17A @ 5.0% Enrichment) 400ppm soluble boron			
nominal (10.906")	maximum (8.98")	nominal (5/16")	0.9236±0.0007††
maximum (10.966")	maximum (8.98")	nominal (5/16")	0.9176±0.0008
minimum (10.846")	nominal (8.92")	nominal (5/16")	0.9227±0.0010
minimum (10.846")	minimum (8.86")	nominal (5/16")	0.9159±0.0008
nominal (10.906")	nominal-0.04" (8.88")	nom.+0.05" (0.3625")	0.9232±0.0009
nominal (10.906")	nominal (8.92")	nominal (5/16")	0.9158±0.0007
MPC-32 (17x17A @ 5.0% Enrichment) 2600 ppm soluble boron†††			
minimum (9.158")	minimum (8.69")	nominal (9/32")	0.9085±0.0007
nominal (9.218")	nominal (8.75")	nominal (9/32")	0.9028±0.0007
maximum (9.278")	maximum (8.81")	nominal (9/32")	0.8996±0.0008
nominal+0.05" (9.268")	nominal (8.75")	nominal+0.05" (0.331")	0.9023±0.0008
minimum+0.05"(9.208")	minimum (8.69")	nominal+0.05" (0.331")	0.9065±0.0007
maximum (9.278")	Maximum-0.05" (8.76")	nominal+0.05" (0.331")	0.9030±0.0008

Notes:

1. Values in parentheses are the actual value used.

† Tolerance for pitch and box I.D. are ± 0.06".
Tolerance for box wall thickness is +0.05", -0.00".

†† Numbers are 1σ statistical uncertainties.

††† for 0.075" sheathing thickness. See Section 6.3.1 and Table 6.3.5 for reactivity effect of sheathing thickness.

Table 6.3.3

BASKET DIMENSIONAL ASSUMPTIONS

Basket Type	Pitch	Box I.D.	Box Wall Thickness	Water-Gap Flux Trap
MPC-24	nominal (10.906")	maximum (8.98")	nominal (5/16")	minimum (1.09")
MPC-24E	nominal (10.847")	maximum (8.81", 9.11" for DFC Positions)	nominal (5/16")	minimum (1.076", 0.776" for DFC Positions)
MPC-32	Minimum (9.158")	Minimum† (8.69")	Nominal (9/32")	N/A
MPC-68	minimum (6.43")	Minimum (5.993")	nominal (1/4")	N/A

† for 0.075" sheathing thickness. See Section 6.3.1 and Table 6.3.5 for reactivity effect of sheathing thickness.

Table 6.3.4

COMPOSITION OF THE MAJOR COMPONENTS OF THE HI-STORM 100 SYSTEM

MPC-24, MPC-24E and MPC-32		
UO_2 5.0% ENRICHMENT, DENSITY (g/cc) = 10.522		
Nuclide	**Atom-Density**	**Wgt. Fraction**
8016	4.696E-02	1.185E-01
92235	1.188E-03	4.408E-02
92238	2.229E-02	8.374E-01
UO_2 4.0% ENRICHMENT, DENSITY (g/cc) = 10.522		
Nuclide	**Atom-Density**	**Wgt. Fraction**
8016	4.693E-02	1.185E-01
92235	9.505E-04	3.526E-02
92238	2.252E-02	8.462E-01
BORAL (0.02 g ^{10}B/cm sq), DENSITY (g/cc) = 2.660 (MPC-24)		
Nuclide	**Atom-Density**	**Wgt. Fraction**
5010	8.707E-03	5.443E-02
5011	3.512E-02	2.414E-01
6012	1.095E-02	8.210E-02
13027	3.694E-02	6.222E-01
BORAL (0.0279 g ^{10}B/cm sq), DENSITY (g/cc) = 2.660 (MPC-24E and MPC-32)		
Nuclide	**Atom-Density**	**Wgt. Fraction**
5010	8.071E-03	5.089E-02
5011	3.255E-02	2.257E-01
6012	1.015E-02	7.675E-02
13027	3.805E-02	6.467E-01

Table 6.3.4 (continued)

COMPOSITION OF THE MAJOR COMPONENTS OF THE HI-STORM 100 SYSTEM

METAMIC (0.02 g ^{10}B/cm sq), DENSITY (g/cc) = 2.648 (MPC-24)		
Nuclide	**Atom-Density**	**Wgt. Fraction**
5010	6.314E-03	3.965E-02
5011	2.542E-02	1.755E-01
6012	7.932E-02	5.975E-02
13027	4.286E-02	7.251E-01
METAMIC (0.0279 g ^{10}B/cm sq), DENSITY (g/cc) = 2.646 (MPC-24E and MPC-32)		
Nuclide	**Atom-Density**	**Wgt. Fraction**
5010	6.541E-03	4.110E-02
5011	2.633E-02	1.819E-01
6012	8.217E-03	6.193E-02
13027	4.223E-02	7.151E-01

Table 6.3.4 (continued)

COMPOSITION OF THE MAJOR COMPONENTS OF THE HI-STORM 100 SYSTEM

BORATED WATER, 300 PPM, DENSITY (g/cc)=1.00		
Nuclide	**Atom-Density**	**Wt. Fraction**
5010	3.248E-06	5.400E-05
5011	1.346E-05	2.460E-04
1001	6.684E-02	1.1186E-01
8016	3.342E-02	8.8784E-01
BORATED WATER, 400PPM, DENSITY (g/cc)=1.00		
Nuclide	**Atom-Density**	**Wgt. Fraction**
5010	4.330E-06	7.200E-05
5011	1.794E-05	3.280E-04
1001	6.683E-02	1.1185E-01
8016	3.341E-02	8.8775E-01
BORATED WATER, 1900PPM, DENSITY (g/cc)=1.00		
Nuclide	Atom-Density	**Wgt. Fraction**
5010	2.057E-05	3.420E-04
5011	8.522E-05	1.558E-03
1001	6.673E-02	1.1169E-01
8016	3.336E-02	8.8641E-01
BORATED WATER, 2600PPM, DENSITY (g/cc)=0.93		
Nuclide	Atom-Density	**Wgt. Fraction**
5010	2.618e-05	4.680E-04
5011	1.085e-04	2.132E-03
1001	6.201e-02	1.1161E-01
8016	3.101e-02	8.8579E-01

Table 6.3.4 (continued)

COMPOSITION OF THE MAJOR COMPONENTS OF THE HI-STORM 100 SYSTEM

MPC-68		
UO_2 4.2% ENRICHMENT, DENSITY (g/cc) = 10.522		
Nuclide	**Atom-Density**	**Wgt. Fraction**
8016	4.697E-02	1.185E-01
92235	9.983E-04	3.702E-02
92238	2.248E-02	8.445E-01
UO_2 3.0% ENRICHMENT, DENSITY (g/cc) = 10.522		
Nuclide	**Atom-Density**	**Wgt. Fraction**
8016	4.695E-02	1.185E-01
92235	7.127E-04	2.644E-02
92238	2.276E-02	8.550E-01
MOX FUEL†, DENSITY (g/cc) = 10.522		
Nuclide	**Atom-Density**	**Wgt. Fraction**
8016	4.714E-02	1.190E-01
92235	1.719E-04	6.380E-03
92238	2.285E-02	8.584E-01
94239	3.876E-04	1.461E-02
94240	9.177E-06	3.400E-04
94241	3.247E-05	1.240E-03
94242	2.118E-06	7.000E-05

† The Pu-238, which is an absorber, was conservatively neglected in the MOX description for analysis purposes.

Table 6.3.4 (continued)

COMPOSITION OF THE MAJOR COMPONENTS OF THE HI-STORM 100 SYSTEM

BORAL (0.0279 g ^{10}B/cm sq), DENSITY (g/cc) = 2.660		
Nuclide	**Atom-Density**	**Wgt. Fraction**
5010	8.071E-03	5.089E-02
5011	3.255E-02	2.257E-01
6012	1.015E-02	7.675E-02
13027	3.805E-02	6.467E-01
METAMIC (0.0279 g ^{10}B/cm sq), DENSITY (g/cc) = 2.646		
Nuclide	**Atom-Density**	**Wgt. Fraction**
5010	6.541E-03	4.110E-02
5011	2.633E-02	1.819E-01
6012	8.217E-03	6.193E-02
13027	4.223E-02	7.151E-01
FUEL IN THORIA RODS, DENSITY (g/cc) = 10.522		
Nuclide	**Atom-Density**	**Wgt. Fraction**
8016	4.798E-02	1.212E-01
92235	4.001E-04	1.484E-02
92238	2.742E-05	1.030E-03
90232	2.357E-02	8.630E-01
COMMON MATERIALS		
ZR CLAD, DENSITY (g/cc) = 6.550		
Nuclide	**Atom-Density**	**Wgt. Fraction**
40000	4.323E-02	1.000E+00
MODERATOR (H_2O), DENSITY (g/cc) = 1.000		
Nuclide	**Atom-Density**	**Wgt. Fraction**
1001	6.688E-02	1.119E-01
8016	3.344E-02	8.881E-01

Table 6.3.4 (continued)

COMPOSITION OF THE MAJOR COMPONENTS OF THE HI-STORM 100 SYSTEM

STAINLESS STEEL, DENSITY (g/cc) = 7.840		
Nuclide	**Atom-Density**	**Wgt. Fraction**
24000	1.761E-02	1.894E-01
25055	1.761E-03	2.001E-02
26000	5.977E-02	6.905E-01
28000	8.239E-03	1.000E-01
ALUMINUM, DENSITY (g/cc) = 2.700		
Nuclide	**Atom-Density**	**Wgt. Fraction**
13027	6.026E-02	1.000E+00

Table 6.3.4 (continued)

COMPOSITION OF THE MAJOR COMPONENTS OF THE HI-STORM 100 SYSTEM

CONCRETE, DENSITY (g/cc) = 2.35		
Nuclide	**Atom-Density**	**Wgt. Fraction**
1001	8.806E-03	6.000E-03
8016	4.623E-02	5.000E-01
11000	1.094E-03	1.700E-02
13027	2.629E-04	4.800E-03
14000	1.659E-02	3.150E-01
19000	7.184E-04	1.900E-02
20000	3.063E-03	8.300E-02
26000	3.176E-04	1.200E-02
LEAD, DENSITY (g/cc) = 11.34		
Nuclide	**Atom-Density**	**Wgt. Fraction**
82000	3.296E-02	1.0
HOLTITE-A, DENSITY (g/cc) = 1.61		
1001	5.695E-02	5.920E-02
5010	1.365E-04	1.410E-03
5011	5.654E-04	6.420E-03
6012	2.233E-02	2.766E-01
7014	1.370E-03	1.980E-02
8016	2.568E-02	4.237E-01
13027	7.648E-03	2.129E-01

Table 6.3.5

REACTIVITY EFFECT OF SHEATHING THICKNESS FOR THE MPC-32

Assembly Class	**Enrichment (wt% ^{235}U)**	**Soluble Boron (ppm)**	**Maximum k_{eff}**		**Difference in Maximum k_{eff}**
			Sheathing 0.075" Min. Cell ID 8.69"	**Sheathing 0.035" Min. Cell ID 8.73"**	
15x15F	5.0	2600	0.9483	0.9476	-0.0008
15x15F	1.7	0	0.8914	0.8909	-0.0005

Table 6.3.6

REACTIVITY EFFECTS OF ECCENTRIC POSITIONING OF CONTENT (FUEL ASSEMBLIES AND DFCs) IN BASKET CELLS

CASE	Contents centered (Reference)	Content moved towards center of basket		Content moved towards basket periphery	
	Maximum k_{eff}	Maximum k_{eff}	k_{eff} Difference to Reference	Maximum k_{eff}	k_{eff} Difference to Reference
MPC-24E/EF, Intact Fuel and Damaged Fuel/Fuel Debris, 5% Enrichment, 600ppm Soluble Boron	0.9185	0.9178	-0.0007	0.9132	-0.0053
MPC-32/32F, Intact Fuel, Assembly Class 16x16A, 4.1% Enrichment, 1300ppm Soluble Boron	0.9429	0.9468	0.0039	0.9068	-0.0361
MPC-32/32F, Intact Fuel, Assembly Class 15x15B, 5.0% Enrichment, 2400ppm Soluble Boron	0.9473	0.9493	0.0020	0.9306	-0.0167
MPC-32/32F, Intact Fuel and Damaged Fuel/Fuel Debris, Assembly Class 15x15F (Intact), 5% Enrichment, 2900ppm Soluble Boron	0.9378	0.9397	0.0019	0.9277	-0.0101

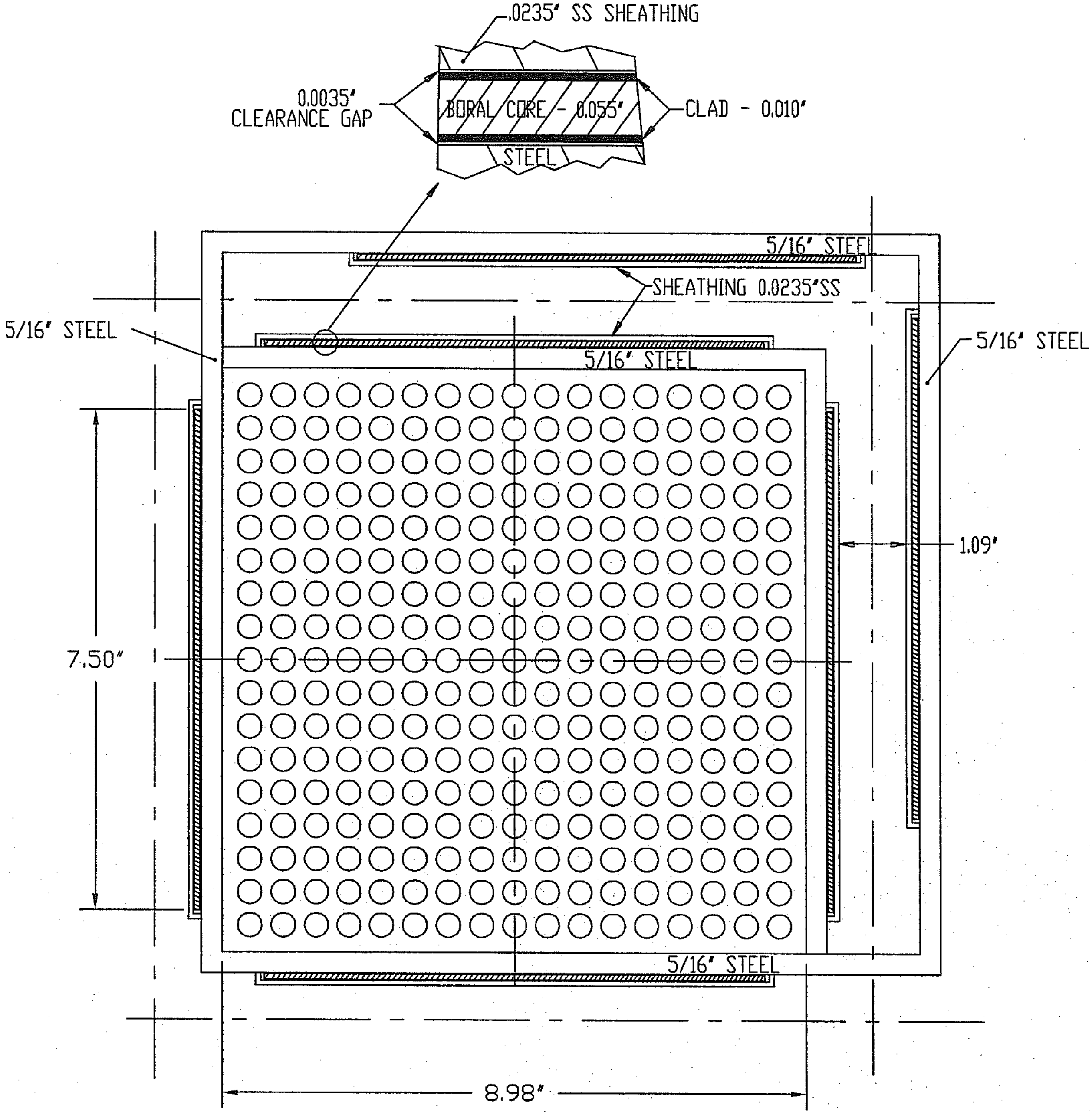

FIGURE 6.3.1j TYPICAL CELL IN THE CALCULATION MODEL (PLANAR CROSS-SECTION) WITH REPRESENTATIVE FUEL IN THE MPC-24 BASKET

(SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

NOTE: THESE DIMENSIONS WERE CONSERVATIVELY USED FOR CRITICALITY ANALYSES.

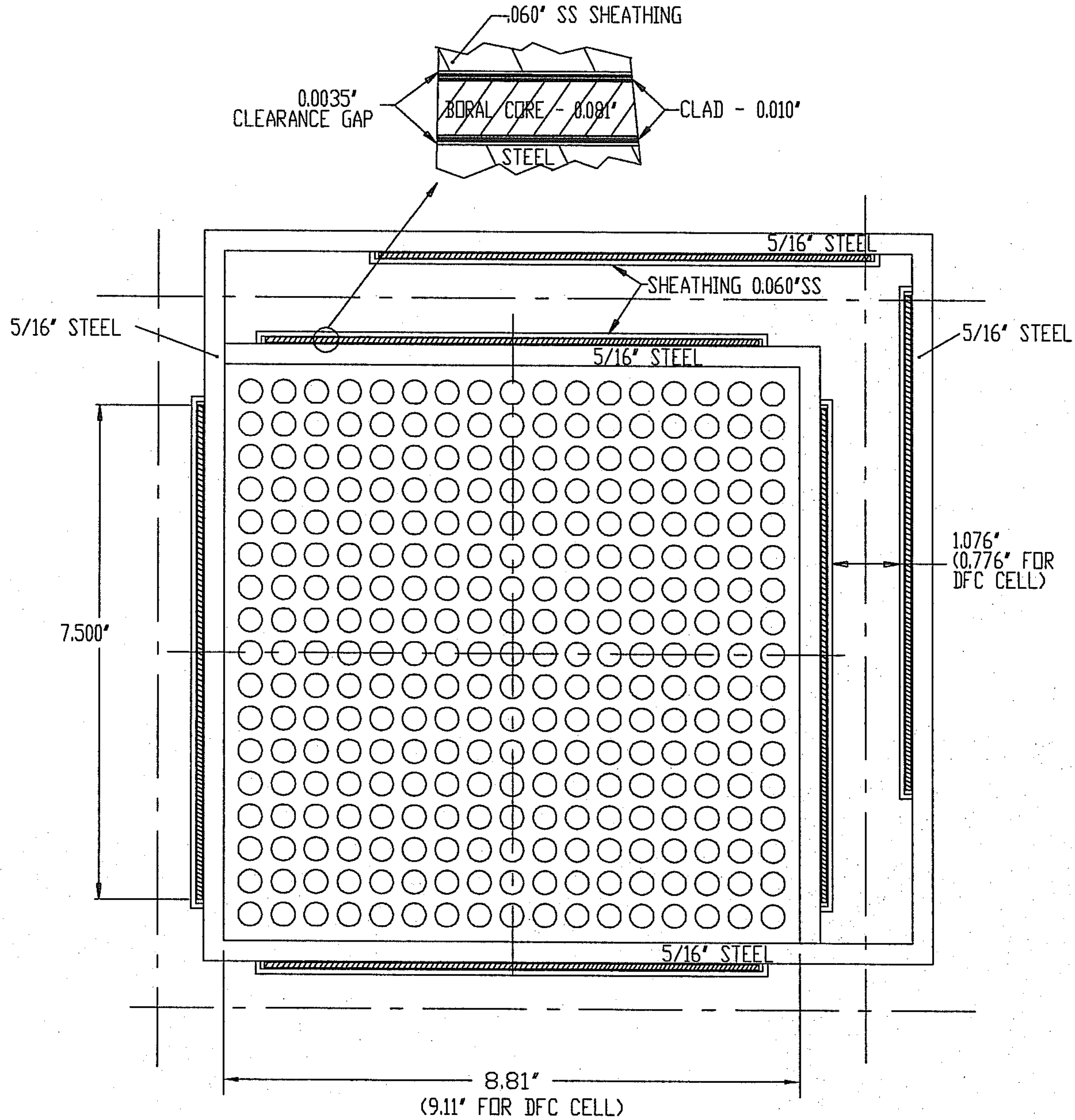

FIGURE 6.3.1A; TYPICAL CELL IN THE CALCULATION MODEL (PLANAR CROSS-SECTION) WITH REPRESENTATIVE FUEL IN THE MPC-24E BASKET

(SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

NOTE: THESE DIMENSIONS WERE CONSERVATIVELY USED FOR CRITICALITY ANALYSES.

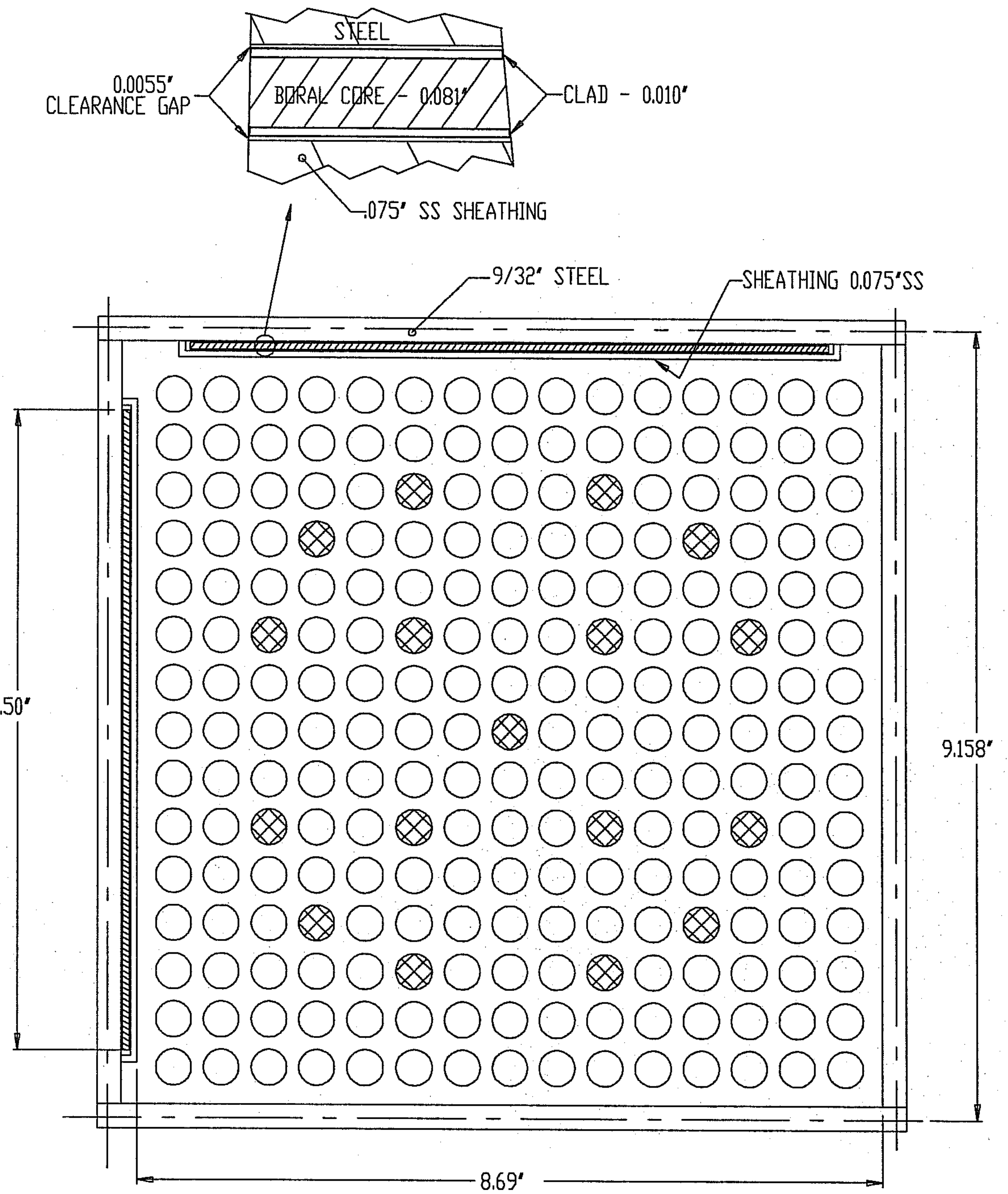

FIGURE 6.3.2j TYPICAL CELL IN THE CALCULATION MODEL (PLANAR CROSS-SECTION) WITH REPRESENTATIVE FUEL IN THE MPC-32 BASKET

(SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

NOTE: THESE DIMENSIONS WERE CONSERVATIVELY USED FOR CRITICALITY ANALYSES.

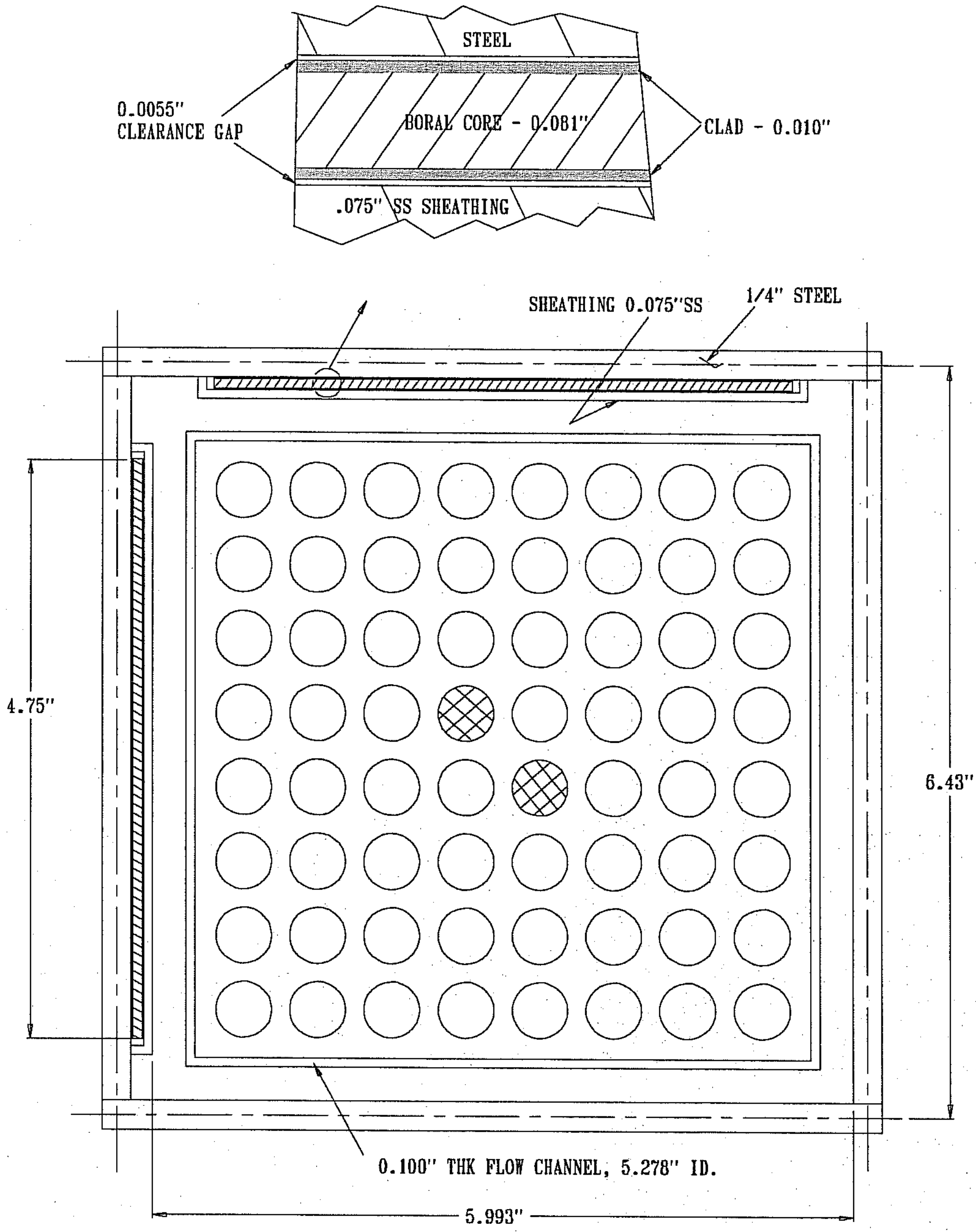

FIGURE 6.3.3; TYPICAL CELL IN THE CALCULATION MODEL (PLANAR CROSS-SECTION) WITH REPRESENTATIVE FUEL IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

NOTE: THESE DIMENSIONS WERE CONSERVATIVELY USED FOR CRITICALITY ANALYSES.

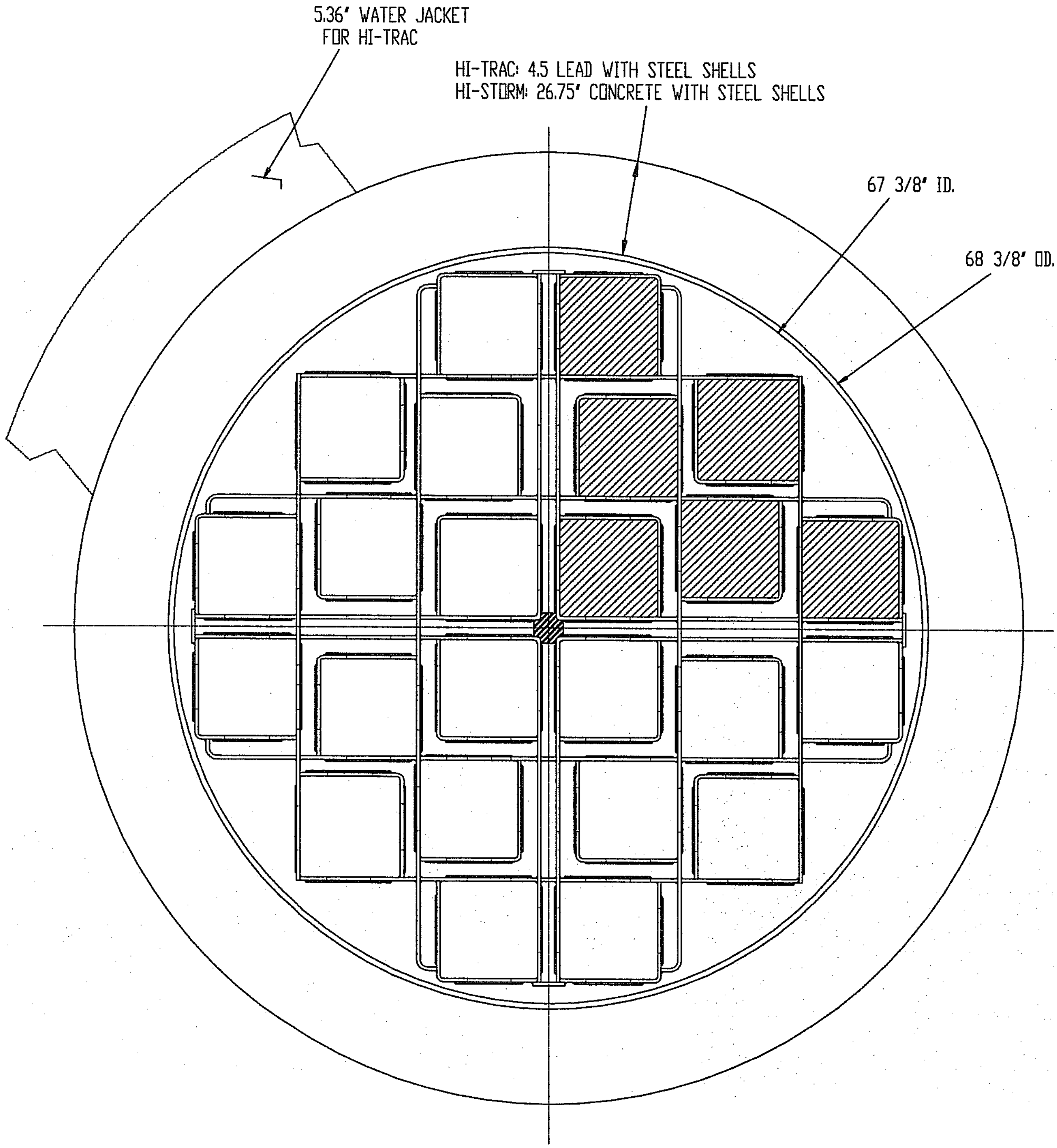

FIGURE 6.3.4; CALCULATION MODEL (PLANAR CROSS-SECTION) WITH FUEL ILLUSTRATED IN ONE QUADRANT OF THE MPC -24 AND THE MPC-24E.

(SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

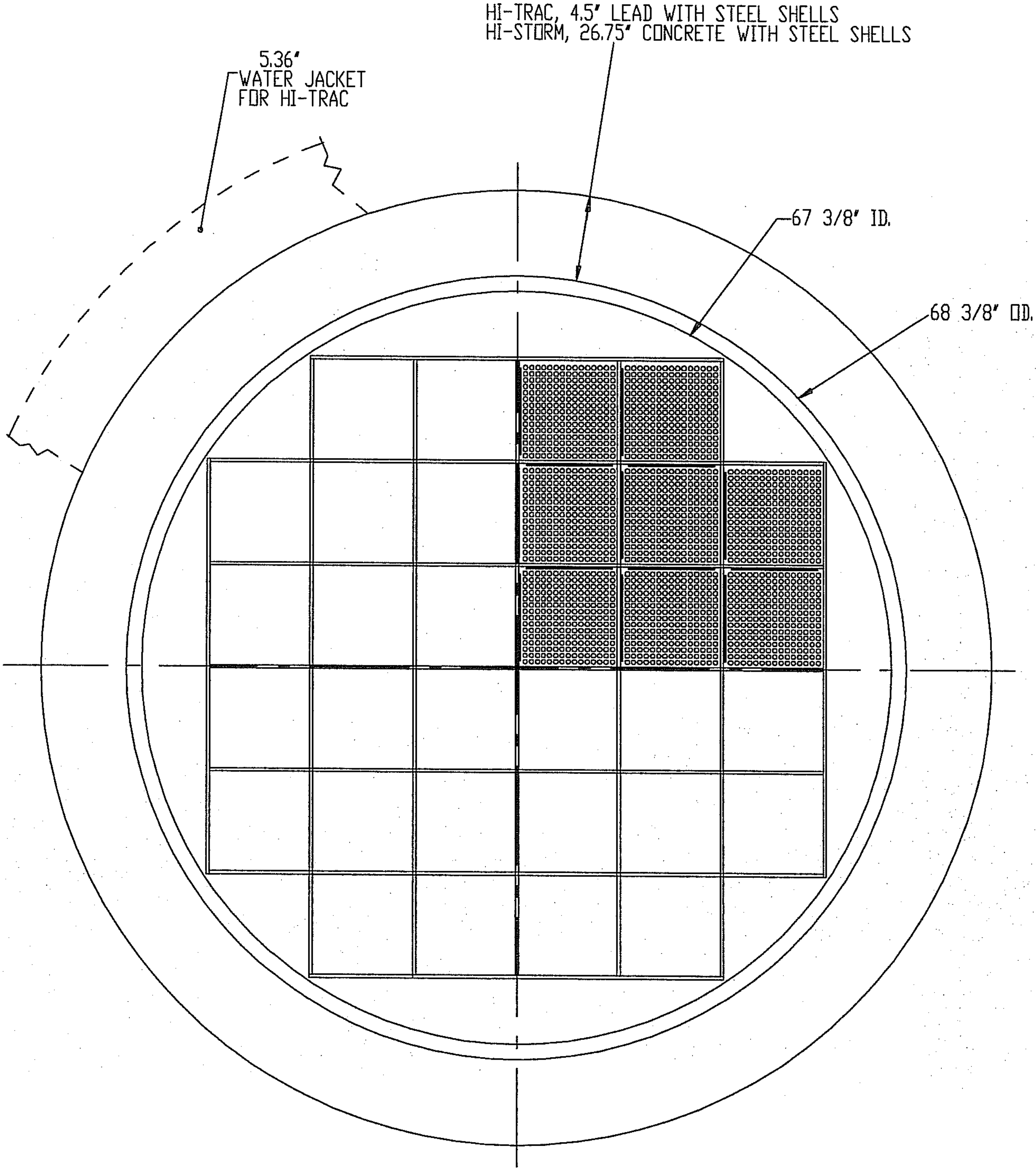

FIGURE 6.3.5j CALCULATION MODEL (PLANAR CROSS-SECTION) WITH FUEL ILLUSTRATED IN ONE QUADRANT OF THE MPC-32.

(SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

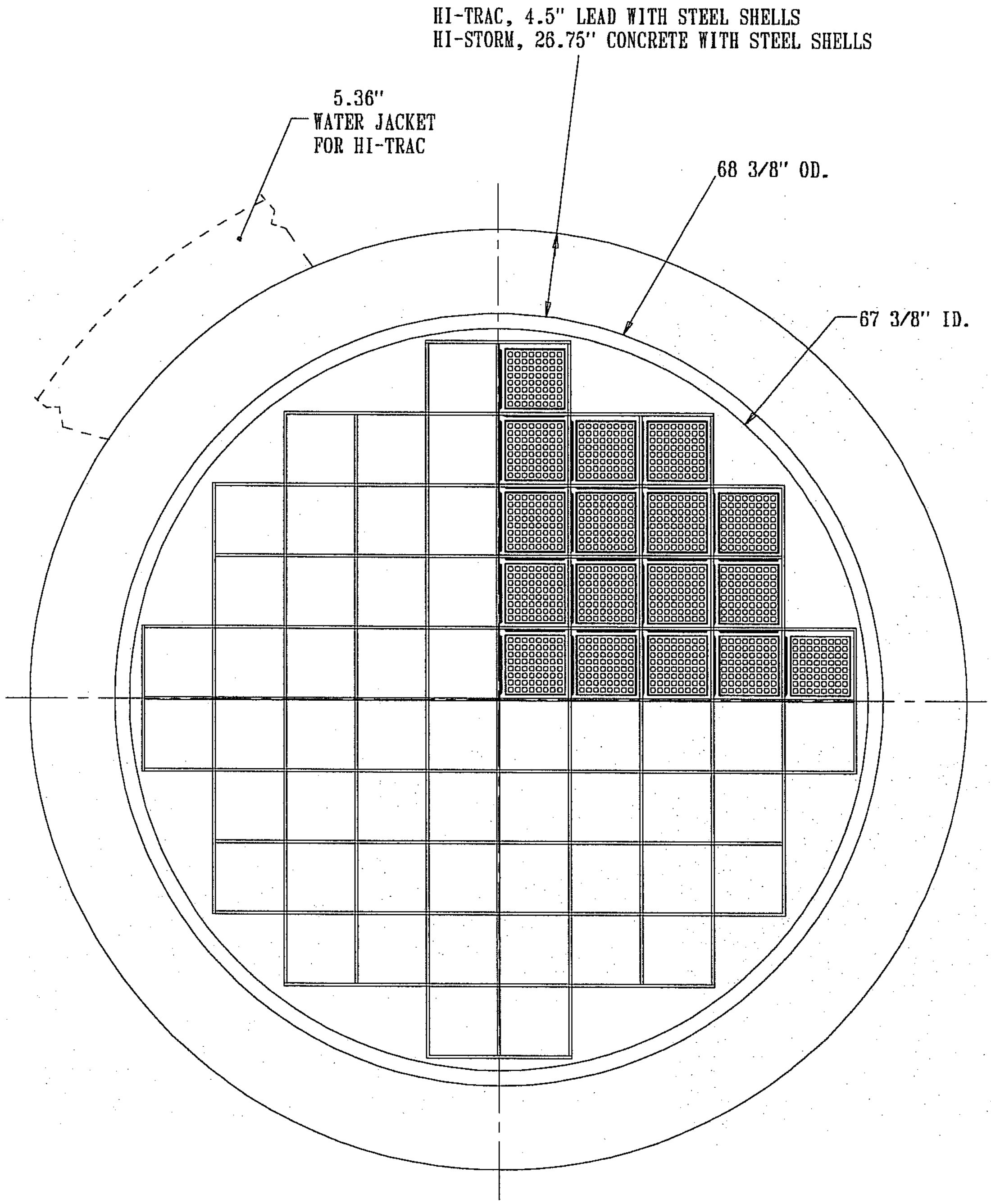

FIGURE 6.3.6; CALCULATION MODEL (PLANAR CROSS-SECTION) WITH FUEL ILLUSTRATED IN ONE QUADRANT OF THE MPC-68
(SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

	ACTIVE FUEL LENGTH	LOWER WATER THICKNESS	UPPER WATER THICKNESS
MPC-68	SEE TABLE 6.2.1	7.30 IN.	8.46 IN.
MPC-24,-24E & -32	SEE TABLE 6.2.2	4.0 IN.	6.0 IN.

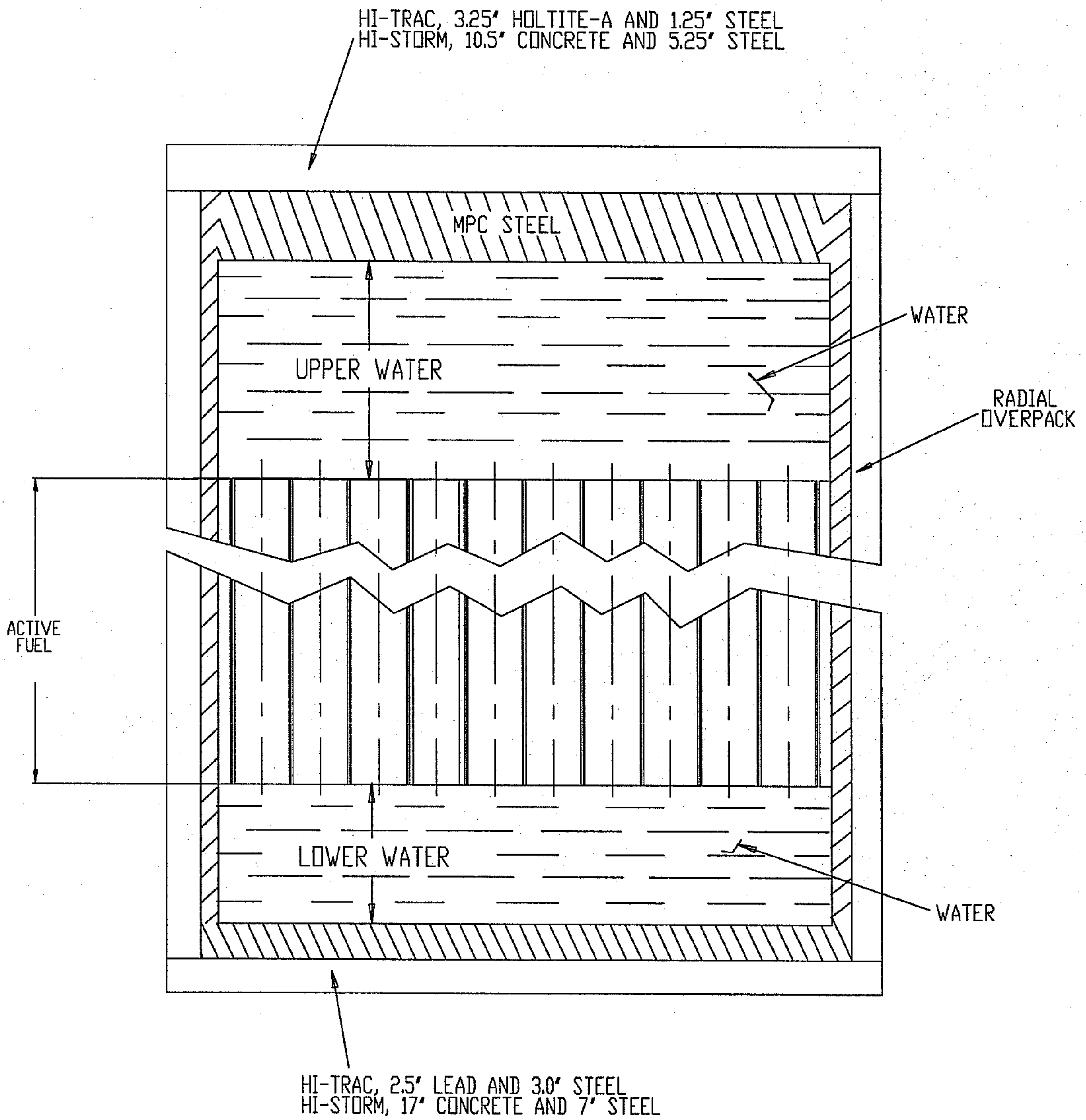

FIGURE 6.3.7; SKETCH OF THE CALCULATIONAL MODEL IN THE AXIAL DIRECTION

6.4 CRITICALITY CALCULATIONS

6.4.1 Calculational or Experimental Method

6.4.1.1 Basic Criticality Safety Calculations

The principal method for the criticality analysis is the general three-dimensional continuous energy Monte Carlo N-Particle code MCNP4a [6.1.4] developed at the Los Alamos National Laboratory. MCNP4a was selected because it has been extensively used and verified and has all of the necessary features for this analysis. MCNP4a calculations used continuous energy cross-section data based on ENDF/B-V, as distributed with the code [6.1.4]. Independent verification calculations were performed with NITAWL-KENO5a [6.1.5], which is a three-dimensional multigroup Monte Carlo code developed at the Oak Ridge National Laboratory. The KENO5a calculations used the 238-group cross-section library, which is based on ENDF/B-V data and is distributed as part of the SCALE-4.3 package [6.4.1], in association with the NITAWL-II program [6.1.6], which adjusts the uranium-238 cross sections to compensate for resonance self-shielding effects. The Dancoff factors required by NITAWL-II were calculated with the CELLDAN code [6.1.13], which includes the SUPERDAN code [6.1.7] as a subroutine.

The convergence of a Monte Carlo criticality problem is sensitive to the following parameters: (1) number of histories per cycle, (2) the number of cycles skipped before averaging, (3) the total number of cycles and (4) the initial source distribution. The MCNP4a criticality output contains a great deal of useful information that may be used to determine the acceptability of the problem convergence. This information was used in parametric studies to develop appropriate values for the aforementioned criticality parameters to be used in the criticality calculations for this submittal. Based on these studies, a minimum of 5,000 histories were simulated per cycle, a minimum of 20 cycles were skipped before averaging, a minimum of 100 cycles were accumulated, and the initial source was specified as uniform over the fueled regions (assemblies). Further, the output was examined to ensure that each calculation achieved acceptable convergence. These parameters represent an acceptable compromise between calculational precision and computational time. Appendix 6.D provides sample input files for the MPC-24 and MPC-68 basket in the HI-STORM 100 System.

CASMO-3 [6.1.9] was used for determining the small incremental reactivity effects of manufacturing tolerances. Although CASMO-3 has been extensively benchmarked, these calculations are used only to establish direction of reactivity uncertainties due to manufacturing tolerances (and their magnitude). This allows the MCNP4a calculational model to use the worst combination of manufacturing tolerances. Table 6.3.1 shows results of the CASMO-3 calculations.

6.4.2 Fuel Loading or Other Contents Loading Optimization

The basket designs are intended to safely accommodate fuel with enrichments indicated in Tables 6.1.1 through 6.1.8 . These calculations were based on the assumption that the HI-STORM 100 System (HI-TRAC transfer cask) was fully flooded with clean unborated water or water containing specific minimum soluble boron concentrations. In all cases, the calculations include bias and calculational uncertainties, as well as the reactivity effects of manufacturing tolerances, determined by assuming the worst case geometry.

6.4.2.1 Internal and External Moderation

As required by NUREG-1536, calculations in this section demonstrate that the HI-STORM 100 System remains subcritical for all credible conditions of moderation.

6.4.2.1.1 Unborated Water

With a neutron absorber present (i.e., the fixed neutron absorber sheets or the steel walls of the storage compartments), the phenomenon of a peak in reactivity at a hypothetical low moderator density (sometimes called "optimum" moderation) does not occur to any significant extent. In a definitive study, Cano, et al. [6.4.2] has demonstrated that the phenomenon of a peak in reactivity at low moderator densities does not occur in the presence of strong neutron absorbing material or in the absence of large water spaces between fuel assemblies in storage. Nevertheless, calculations for a single reflected cask were made to confirm that the phenomenon does not occur with low density water inside or outside the casks.

Calculations for the MPC designs with internal and external moderators of various densities are shown in Table 6.4.1. For comparison purposes, a calculation for a single unreflected cask (Case 1) is also included in Table 6.4.1. At 100% external moderator density, Case 2 corresponds to a single fully-flooded cask, fully reflected by water. Figure 6.4.10 plots calculated k_{eff} values ($\pm 2\sigma$) as a function of internal moderator density for both MPC designs with 100% external moderator density (i.e., full water reflection). Results listed in Table 6.4.1 support the following conclusions:

- For each type of MPC, the calculated k_{eff} for a fully-flooded cask is independent of the external moderator (the small variations in the listed values are due to statistical uncertainties which are inherent to the calculational method (Monte Carlo)), and

- For each type of MPC, reducing the internal moderation results in a monotonic reduction in reactivity, with no evidence of any optimum moderation. Thus, the fully flooded condition corresponds to the highest reactivity, and the phenomenon of optimum low-density moderation does not occur and is not applicable to the HI-STORM 100 System.

For each of the MPC designs, the maximum k_{eff} values are shown to be less than or statistically equal to that of a single internally flooded unreflected cask and are below the regulatory limit of 0.95.

6.4.2.1.2 Borated Water

With the presence of a soluble neutron absorber in the water, the discussion in the previous section is not always applicable. Calculations were made to determine the optimum moderator density for the MPC designs that require a minimum soluble boron concentration.

Calculations for the MPC designs with various internal moderator densities are shown in Table 6.4.6. As shown in the previous section, the external moderator density has a negligible effect on the reactivity, and is therefore not varied. Water containing soluble boron has a slightly higher density than pure water. Therefore, water densities up to 1.005 g/cm^3 were analyzed for the higher soluble boron concentrations. Additionally, for the higher soluble boron concentrations, analyses have been performed with empty (voided) guide tubes. This variation is discussed in detail in Section 6.4.8. Results listed in the Table 6.4.6 support the following conclusions:

- For all cases with a soluble boron concentration of up to 1900ppm, and for a soluble boron concentration of 2600ppm assuming voided guide tubes, the conclusion of the Section 6.4.2.1.1 applies, i.e. the maximum reactivity is corresponds to 100% moderator density.

- For 2600ppm soluble boron concentration with filled guide tubes, the results presented in Table 6.4.6 indicate that there is a maximum of the reactivity somewhere between 0.90 g/cm^3 and 1.00 g/cm^3 moderator density. However, a distinct maximum can not be identified, as the reactivities in this range are very close. For the purpose of the calculations with 2600ppm soluble boron concentration, a moderator density of 0.93 g/cm^3 was chosen, which corresponds to the highest calculated reactivity listed in Table 6.4.6.

The calculations documented in this chapter also use soluble boron concentrations other than 1900 ppm and 2600 ppm in the MPC-32/32F. For the MPC-32 loaded with intact fuel only, soluble boron concentrations between 1300 ppm and 2600 ppm are used. For the MPC-32/32F loaded with intact fuel, damaged fuel and fuel debris, soluble boron concentrations between 1500 ppm and 2900 ppm are used. In order to determine the optimum moderation condition for each assembly class at the corresponding soluble boron level, evaluations are performed with filled and voided guide tubes, and for water densities of 1.0 g/cm^3 and 0.93 g/cm^3 for each class and enrichment level. Results for the MPC-32 loaded with intact fuel only are listed in Table 6.4.10 for an initial enrichment of 5.0 wt% ^{235}U and in Table 6.4.11 for an initial enrichment of 4.1 wt% ^{235}U. Corresponding results for the MPC-32/32F loaded with intact fuel, damaged fuel and fuel debris are listed in Table 6.4.14. The highest value listed in these tables for each assembly class is listed as the bounding value in Section 6.1.

6.4.2.2 Partial Flooding

As required by NUREG-1536, calculations in this section address partial flooding in the HI-STORM 100 System and demonstrate that the fully flooded condition is the most reactive.

The reactivity changes during the flooding process were evaluated in both the vertical and horizontal positions for all MPC designs. For these calculations, the cask is partially filled (at various levels) with full density (1.0 g/cc) water and the remainder of the cask is filled with steam consisting of ordinary water at partial density (0.002 g/cc), as suggested in NUREG-1536. Results of these calculations are shown in Table 6.4.2. In all cases, the reactivity increases monotonically as the water level rises, confirming that the most reactive condition is fully flooded.

6.4.2.3 Clad Gap Flooding

As required by NUREG-1536, the reactivity effect of flooding the fuel rod pellet-to-clad gap regions, in the fully flooded condition, has been investigated. Table 6.4.3 presents maximum k_{eff} values that demonstrate the positive reactivity effect associated with flooding the pellet-to-clad gap regions. These results confirm that it is conservative to assume that the pellet-to-clad gap regions are flooded. For all cases that involve flooding, the pellet-to-clad gap regions are assumed to be flooded with clean, unborated water.

6.4.2.4 Preferential Flooding

Two different potential conditions of preferential flooding are considered: preferential flooding of the MPC basket itself (i.e. different water levels in different basket cells), and preferential flooding involving Damaged Fuel Containers.

Preferential flooding of the MPC basket itself for any of the MPC fuel basket designs is not possible because flow holes are present on all four walls of each basket cell and on the two flux trap walls at both the top and bottom of the MPC basket. The flow holes are sized to ensure that they cannot be blocked by crud deposits (see Chapter 11). The fuel cladding satisfies the "acceptance criteria to limit spent fuel reconfiguration in storage casks" (ISG-11, Rev. 3), since temperatures remain below their design limits (as demonstrated in Chapter 4). For damaged fuel assemblies and fuel debris, the assemblies or debris are pre-loaded into stainless steel Damaged Fuel Containers fitted with mesh screens which prevent damaged fuel assemblies or fuel debris from blocking the basket flow holes. Therefore, the flow holes cannot be blocked.

However, when DFCs are present in the MPC, a condition could exist during the draining of the MPC, where the DFCs are still partly filled with water while the remainder of the MPC is dry. This condition would be the result of the water tension across the mesh screens. The maximum water level inside the DFCs for this condition is calculated from the dimensions of the mesh screen and the surface tension of water. The wetted perimeter of the screen openings is no more than 50 ft per square inch of screen. With a surface tension of water of 0.005 lbf/ft, this results in a maximum pressure across the screen of 0.25 psi, corresponding to a maximum water height in the DFC of 7 inches. For added conservatism, a value of 12 inches is used. Assuming this condition, calculations are performed for all three possible DFC configurations:

- MPC-68 or MPC-68F with 68 DFCs (Assembly Classes 6x6A/B/C, 7x7A and 8x8A)
- MPC-68 or MPC-68FF with 16 DFCs (All BWR Assembly Classes)
- MPC-24E or MPC-24EF with 4 DFCs (All PWR Assembly Classes)
- MPC-32 or MPC-32F with 8 DFCs (All PWR Assembly Classes)

For each configuration, the case resulting in the highest maximum k_{eff} for the fully flooded condition (see Section 6.4.4) is re-analyzed assuming the preferential flooding condition. For these analyses, the lower 12 inches of the active fuel in the DFCs and the water region below the active fuel (see Figure 6.3.7) are filled with full density water (1.0 g/cc). The remainder of the cask is filled with steam consisting of ordinary water at partial density (0.002 g/cc). Table 6.4.4 lists the maximum k_{eff} for the four configurations in comparison with the maximum k_{eff} for the fully flooded condition. For all configurations, the preferential flooding condition results in a lower maximum k_{eff} than the fully flooded condition. Thus, the preferential flooding condition is bounded by the fully flooded condition.

Once established, the integrity of the MPC confinement boundary is maintained during all credible off-normal and accident conditions, and thus, the MPC cannot be flooded. In summary, it is concluded that the MPC fuel baskets cannot be preferentially flooded, and that the potential preferential flooding conditions involving DFCs are bounded by the result for the fully flooded condition listed in Section 6.4.4.

6.4.2.5 Design Basis Accidents

The analyses presented in Chapters 3 and 11 demonstrate that the damage resulting from the design basis accidents is limited to a loss of the water jacket for the HI-TRAC transfer cask and minor damage to the concrete radiation shield for the HI-STORM storage cask, which have no adverse effect on the design parameters important to criticality safety.

As reported in Chapter 3, Table 3.4.4, the minimum factor of safety for either MPC as a result of the hypothetical cask drop or tip-over accident is 1.1 against the Level D allowables for Subsection NG, Section III of the ASME Code. Therefore, because the maximum box wall stresses are well within the ASME Level D allowables, the flux-trap gap change will be insignificant compared to the characteristic dimension of the flux trap.

In summary, the design basis accidents have no adverse effect on the design parameters important to criticality safety, and therefore, there is no increase in reactivity as a result of any of the credible off-normal or accident conditions involving handling, packaging, transfer or storage. Consequently, the HI-STORM 100 System is in full compliance with the requirement of 10CRF72.124, which states that "before a nuclear criticality accident is possible, at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety."

6.4.3 Criticality Results

Results of the design basis criticality safety calculations for the condition of full flooding with water (limiting cases) are presented in section 6.2 and summarized in Section 6.1. To demonstrate the applicability of the HI-STAR analyses, results of the design basis criticality safety calculations for the HI-STAR cask (limiting cases) are also summarized in Section 6.1 for comparison. These data confirm that for each of the candidate fuel types and basket configurations the effective multiplication factor (k_{eff}), including all biases and uncertainties at a 95-percent confidence level, do not exceed 0.95 under all credible normal, off-normal, and accident conditions.

Additional calculations (CASMO-3) at elevated temperatures confirm that the temperature coefficients of reactivity are negative as shown in Table 6.3.1. This confirms that the calculations for the storage baskets are conservative.

In calculating the maximum reactivity, the analysis used the following equation:

$$k_{eff}^{max}=k_c+K_c\sigma_c+Bias+\sigma_B$$

where:

⇒ $\boldsymbol{k_c}$ is the calculated k_{eff} under the worst combination of tolerances;

⇒ $\boldsymbol{K_c}$ is the K multiplier for a one-sided statistical tolerance limit with 95% probability at the 95% confidence level [6.1.8]. Each final k_{eff} value calculated by MCNP4a (or KENO5a) is the result of averaging 100 (or more) cycle k_{eff} values, and thus, is based on a sample size of 100. The K multiplier corresponding to a sample size of 100 is 1.93. However, for this analysis a value of 2.00 was assumed for the K multiplier, which is larger (more conservative) than the value corresponding to a sample size of 100;

⇒ $\boldsymbol{\sigma_c}$ is the standard deviation of the calculated k_{eff}, as determined by the computer code (MCNP4a or KENO5a);

⇒ ***Bias*** is the systematic error in the calculations (code dependent) determined by comparison with critical experiments in Appendix 6.A; and

⇒ $\boldsymbol{\sigma_B}$ is the standard error of the bias (which includes the K multiplier for 95% probability at the 95% confidence level; see Appendix 6.A).

The critical experiment benchmarking and the derivation of the bias and standard error of the bias (95% probability at the 95% confidence level) are presented in Appendix 6.A.

6.4.4 Damaged Fuel and Fuel Debris

Damaged fuel assemblies and fuel debris are required to be loaded into Damaged Fuel Containers (DFCs) prior to being loaded into the MPC. Five (5) different DFC types with different cross sections are analyzed. Three (3) of these DFCs are designed for BWR fuel assemblies, two (2) are designed for PWR fuel assemblies. Two of the DFCs for BWR fuel are specifically designed for fuel assembly classes 6x6A, 6x6B, 6x6C, 7x7A and 8x8A. These assemblies have a smaller cross section, a shorter active length and a low initial enrichment of 2.7 wt% ^{235}U, and therefore a low reactivity. The analysis for these assembly classes is presented in the following Section 6.4.4.1. The remaining three DFCs are generic DFCs designed for all BWR and PWR assembly classes. The criticality analysis for these generic DFCs is presented in Section 6.4.4.2.

6.4.4.1 MPC-68, MPC-68F or MPC-68FF loaded with Assembly Classes 6x6A, 6x6B, 6x6C, 7x7A and 8x8A

This section only addresses criticality calculations and results for assembly classes 6x6A, 6x6B, 6x6C, 7x7A and 8x8A, loaded into the MPC-68, MPC-68F or MPC-68FF. Up to 68 DFCs with these assembly classes are permissible to be loaded into the MPC. Two different DFC types with slightly different cross-sections are analyzed. DFCs containing fuel debris must be stored in the MPC-68F or MPC-68FF. DFCs containing damaged fuel assemblies may be stored in the MPC-68, MPC-68F or MPC-68FF. Evaluation of the capability of storing damaged fuel and fuel debris (loaded in DFCs) is limited to very low reactivity fuel in the MPC-68F. Because the MPC-68 and MPC-68FF have a higher specified ^{10}B loading, the evaluation of the MPC-68F conservatively bounds the storage of damaged BWR fuel assemblies in a standard MPC-68 or MPC-68FF. Although the maximum planar-average enrichment of the damaged fuel is limited to 2.7% ^{235}U as specified in Section 2.1.9, analyses have been made for three possible scenarios, conservatively assuming fuel†† of 3.0% enrichment. The scenarios considered included the following:

1. Lost or missing fuel rods, calculated for various numbers of missing rods in order to determine the maximum reactivity. The configurations assumed for analysis are illustrated in Figures 6.4.2 through 6.4.8.
2. Broken fuel assembly with the upper segments falling into the lower segment creating a close-packed array (described as a 8x8 array). For conservatism, the array analytically retained the same length as the original fuel assemblies in this analysis. This configuration is illustrated in Figure 6.4.9.
3. Fuel pellets lost from the assembly and forming powdered fuel dispersed through a volume equivalent to the height of the original fuel. (Flow channel and clad material assumed to disappear).

Results of the analyses, shown in Table 6.4.5, confirm that, in all cases, the maximum reactivity is well below the regulatory limit. There is no significant difference in reactivity between the two DFC types. Collapsed fuel reactivity (simulating fuel debris) is low because of the reduced moderation. Dispersed powdered fuel results in low reactivity because of the increase in ^{238}U neutron capture (higher effective resonance integral for ^{238}U absorption).

The loss of fuel rods results in a small increase in reactivity (i.e., rods assumed to collapse, leaving a smaller number of rods still intact). The peak reactivity occurs for 8 missing rods, and a smaller (or larger) number of intact rods will have a lower reactivity, as indicated in Table 6.4.5.

The analyses performed and summarized in Table 6.4.5 provide the relative magnitude of the effects on the reactivity. This information coupled with the maximum k_{eff} values listed in Table 6.1.3 and the conservatism in the analyses, demonstrates that the maximum k_{eff} of the damaged

†† 6x6A01 and 7x7A01 fuel assemblies were used as representative assemblies.

fuel in the most adverse post-accident condition will remain well below the regulatory requirement of $k_{eff} < 0.95$.

6.4.4.2 Generic BWR and PWR Damaged Fuel and Fuel Debris

The MPC-24E, MPC-24EF, MPC-32, MPC-32F, MPC-68 and MPC-68FF are designed to contain PWR and BWR damaged fuel and fuel debris, loaded into generic DFCs. The number of generic DFCs is limited to 16 for the MPC-68 and MPC-68FF, to 4 for the MPC-24E and MPC-24EF, and to 8 for the MPC-32 and MPC-32F. The permissible locations of the DFCs are shown in Figure 6.4.11 for the MPC-68/68FF, in Figure 6.4.12 for the MPC-24E/24EF and in Figure 6.4.16 for the MPC-32/32F.

Damaged fuel assemblies are assemblies with known or suspected cladding defects greater than pinholes or hairlines, or with missing rods, but excluding fuel assemblies with gross defects (for a full definition see Table 1.0.1). Therefore, apart from possible missing fuel rods, damaged fuel assemblies have the same geometric configuration as intact fuel assemblies and consequently the same reactivity. Missing fuel rods can result in a slight increase of reactivity. After a drop accident, however, it can not be assumed that the initial geometric integrity is still maintained. For a drop on either the top or bottom of the cask, the damaged fuel assemblies could collapse. This would result in a configuration with a reduced length, but increased amount of fuel per unit length. For a side drop, fuel rods could be compacted to one side of the DFC. In either case, a significant relocation of fuel within the DFC is possible, which creates a greater amount of fuel in some areas of the DFC, whereas the amount of fuel in other areas is reduced. Fuel debris can include a large variety of configurations ranging from whole fuel assemblies with severe damage down to individual fuel pellets.

In the cases of fuel debris or relocated damaged fuel, there is the potential that fuel could be present in axial sections of the DFCs that are outside the basket height covered with the fixed neutron absorber. However, in these sections, the DFCs are not surrounded by any intact fuel, only by basket cell walls, non-fuel hardware, and water and for the MPC-68/68FF by a maximum of one other DFC. Studies have shown that this condition does not result in any significant effect on reactivity, compared to a condition where the damaged fuel and fuel debris is restricted to the axial section of the basket covered by the fixed neutron absorber. All calculations for generic BWR and PWR damaged fuel and fuel debris are therefore performed assuming that fuel is present only in the axial sections covered by the fixed neutron absorber, and the results are directly applicable to any situation where damaged fuel and fuel debris is located outside these sections in the DFCs.

To address all the situations listed above and identify the configuration or configurations leading to the highest reactivity, it is impractical to analyze a large number of different geometrical configurations for each of the fuel classes. Instead, a bounding approach is taken which is based on the analysis of regular arrays of bare fuel rods without cladding. Details and results of the analyses are discussed in the following sections.

All calculations for generic damaged fuel and fuel debris are performed using a full cask model with the maximum permissible number of Damaged Fuel Containers. For the MPC-68 and MPC-68FF, the model therefore contains 52 intact assemblies, and 16 DFCs in the locations shown in Figure 6.4.11. For the MPC-24E and MPC-24EF, the model consists of 20 intact assemblies, and 4 DFCs in the locations shown in Figure 6.4.12. For the MPC-32 and MPC-32, the model consists of 24 intact assemblies, and 8 DFCs in the locations shown in Figure 6.4.16. The bounding assumptions regarding the intact assemblies and the modeling of the damaged fuel and fuel debris in the DFCs are discussed in the following sections.

Note that since a modeling approach is used that bounds both damaged fuel and fuel debris without distinguishing between these two conditions, the term 'damaged fuel' as used throughout this chapter designates both damaged fuel and fuel debris.

6.4.4.2.1 Bounding Intact Assemblies

Intact BWR assemblies stored together with DFCs are limited to a maximum planar average enrichment of 3.7 wt% ^{235}U, regardless of the fuel class. The results presented in Table 6.1.7 are for different enrichments for each class, ranging between 2.7 and 4.2 wt% ^{235}U, making it difficult to identify the bounding assembly. Therefore, additional calculations were performed for the bounding assembly in each assembly class with a planar average enrichment of 3.7 wt%. The results are summarized in Table 6.4.7 and demonstrate that the assembly classes 9x9E and 9x9F have the highest reactivity. These two classes share the same bounding assembly (see footnotes for Tables 6.2.33 and 6.2.34 for further details). This bounding assembly is used as the intact BWR assembly for all calculations with DFCs.

Intact PWR assemblies stored together with DFCs in the MPC-24E are limited to a maximum enrichment of 4.0 wt% ^{235}U without credit for soluble boron and to a maximum enrichment of 5.0 wt% with credit for soluble boron, regardless of the fuel class. The results presented in Table 6.1.3 are for different enrichments for each class, ranging between 4.2 and 5.0 wt% ^{235}U, making it difficult to directly identify the bounding assembly. However, Table 6.1.4 shows results for an enrichment of 5.0 wt% for all fuel classes, with a soluble boron concentration of 300 ppm. The assembly class 15x15H has the highest reactivity. This is consistent with the results in Table 6.1.3, where the assembly class 15x15H is among the classes with the highest reactivity, but has the lowest initial enrichment. Therefore, in the MPC-24E, the 15x15H assembly is used as the intact PWR assembly for all calculations with DFCs.

Intact PWR assemblies stored together with DFCs in the MPC-32 are limited to a maximum enrichment of 5.0 wt%, regardless of the fuel class. Table 6.1.5 and Table 6.1.6 show results for enrichments of 4.1 wt% and 5.0 wt%, respectively, for all fuel classes. Since different minimum soluble boron concentrations are used for different groups of assembly classes, the assembly class with the highest reactivity in each group is used as the intact assembly for the calculations with DFCs in the MPC-32. These assembly classes are

- 14x14C for all 14x14 assembly classes;
- 15x15B for assembly classes 15x15A, B, C and G;
- 15x15F for assembly classes 15x15D, E, F and H;
- 16x16A; and
- 17x17C for all 17x17 assembly classes.

6.4.4.2.2 Bare Fuel Rod Arrays

A conservative approach is used to model both damaged fuel and fuel debris in the DFCs, using arrays of bare fuel rods:

- Fuel in the DFCs is arranged in regular, rectangular arrays of bare fuel rods, i.e. all cladding and other structural material in the DFC is replaced by water.

- For cases with soluble boron, additional calculations are performed with reduced water density in the DFC. This is to demonstrate that replacing all cladding and other structural material with borated water is conservative.

- The active length of these rods is chosen to be the maximum active fuel length of all fuel assemblies listed in Section 6.2, which is 155 inch for BWR fuel and 150 inch for PWR fuel.

- To ensure the configuration with optimum moderation and highest reactivity is analyzed, the amount of fuel per unit length of the DFC is varied over a large range. This is achieved by changing the number of rods in the array and the rod pitch. The number of rods are varied between 9 (3x3) and 189 (17x17) for BWR fuel, and between 64 (8x8) and 729 (27x27) for PWR fuel.

- Analyses are performed for the minimum, maximum and typical pellet diameter of PWR and BWR fuel.

This is a very conservative approach to model damaged fuel, and to model fuel debris configurations such as severely damaged assemblies and bundles of individual fuel rods, as the absorption in the cladding and structural material is neglected.

This is also a conservative approach to model fuel debris configurations such as bare fuel pellets due to the assumption of an active length of 155 inch (BWR) or 150 inch (PWR). The actual height of bare fuel pellets in a DFC would be significantly below these values due to the limitation of the fuel mass for each basket position.

To demonstrate the level of conservatism, additional analyses are performed with the DFC containing various realistic assembly configurations such as intact assemblies, assemblies with missing fuel rods and collapsed assemblies, i.e. assemblies with increased number of rods and decreased rod pitch.

As discussed in Section 6.4.4.2, all calculations are performed for full cask models, containing the maximum permissible number of DFCs together with intact assemblies.

As an example of the damaged fuel model used in the analyses, Figure 6.4.17 shows the basket cell of an MPC-32 with a DFC containing a 17x17 array of bare fuel rods.

Graphical presentations of the calculated maximum k_{eff} for typical cases as a function of the fuel mass per unit length of the DFC are shown in Figures 6.4.13 (BWR) and 6.4.14 (PWR, MPC-24E/EF with pure water). The results for the bare fuel rods show a distinct peak in the maximum k_{eff} at about 2 kg UO_2/inch for BWR fuel, and at about 3.5 kgUO_2/inch for PWR fuel.

The realistic assembly configurations are typically about 0.01 (delta-k) or more below the peak results for the bare fuel rods, demonstrating the conservatism of this approach to model damaged fuel and fuel debris configurations such as severely damaged assemblies and bundles of fuel rods.

For fuel debris configurations consisting of bare fuel pellets only, the fuel mass per unit length would be beyond the value corresponding to the peak reactivity. For example, for DFCs filled with a mixture of 60 vol% fuel and 40 vol% water the fuel mass per unit length is 3.36 kgUO_2/inch for the BWR DFC and 7.92 kgUO_2/inch for the PWR DFC. The corresponding reactivities are significantly below the peak reactivity. The difference is about 0.005 (delta-k) for BWR fuel and 0.01 (delta-k) or more for PWR fuel. Furthermore, the filling height of the DFC would be less than 70 inches in these examples due to the limitation of the fuel mass per basket position, whereas the calculation is conservatively performed for a height of 155 inch (BWR) or 150 inch (PWR). These results demonstrate that even for the fuel debris configuration of bare fuel pellets, the model using bare fuel rods is a conservative approach.

6.4.4.2.3 Distributed Enrichment in BWR Fuel

BWR fuel usually has an enrichment distribution in each planar cross section, and is characterized by the maximum planar average enrichment. For intact fuel it has been shown that using the average enrichment for each fuel rod in a cross section is conservative, i.e. the reactivity is higher than calculated for the actual enrichment distribution (See Appendix 6.B). For damaged fuel assemblies, additional configurations are analyzed to demonstrate that the distributed enrichment does not have a significant impact on the reactivity of the damaged assembly under accident conditions. Specifically, the following two scenarios were analyzed:

- As a result of an accident, fuel rods with lower enrichment relocate from the top part to the bottom part of the assembly. This results in an increase of the average enrichment in the top part, but at the same time the amount of fuel in that area is reduced compared to the intact assembly.
- As a result of an accident, fuel rods with higher enrichment relocate from the top part to the bottom part of the assembly. This results in an increase of the average enrichment in the bottom part, and at the same time the amount of fuel in that area is increased compared to the intact assembly, leading to a reduction of the water content.

In both scenarios, a compensation of effects on reactivity is possible, as the increase of reactivity due to the increased planar average enrichment might be offset by the possible reduction of reactivity due to the change in the fuel to water ratio. A selected number of calculations have been performed for these scenarios and the results show that there is only a minor change in reactivity. These calculations are shown in Figure 6.4.13 in the group of the explicit assemblies. Consequently, it is appropriate to qualify damaged BWR fuel assemblies and fuel debris based on the maximum planar average enrichment. For assemblies with missing fuel rods, this maximum planar average enrichment has to be determined based on the enrichment and number of rods still present in the assembly when loaded into the DFC.

6.4.4.2.4 Results for MPC-68 and MPC-68FF

The MPC-68 and MPC-68FF allows the storage of up to sixteen DFCs in the shaded cells on the periphery of the basket shown in Figure 6.4.11. In the MPC-68FF, up to 8 of these cells may contain DFCs with fuel debris. The various configurations outlined in Sections 6.4.4.2.2 and 6.4.4.2.3 are analyzed with an enrichment of the intact fuel of 3.7% ^{235}U and an enrichment of damaged fuel or fuel debris of 4.0% ^{235}U. For the intact assembly, the bounding assembly of the 9x9E and 9x9F fuel classes was chosen. This assembly has the highest reactivity of all BWR assembly classes for the initial enrichment of 3.7 wt% ^{235}U, as demonstrated in Table 6.4.7. The results for the various configurations are summarized in Figure 6.4.13 and in Table 6.4.8. Figure 6.4.13 shows the maximum k_{eff}, including bias and calculational uncertainties, for various actual and hypothetical damaged fuel or fuel debris configurations as a function of the fuel mass per unit length of the DFC. Table 6.4.8 lists the highest maximum k_{eff} for the various configurations. All maximum k_{eff} values are below the 0.95 regulatory limit.

6.4.4.2.5 Results for MPC-24E and MPC-24EF

The MPC-24E allows the storage of up to four DFCs with damaged fuel in the four outer fuel baskets cells shaded in Figure 6.4.12. The MPC-24EF allows storage of up to four DFCs with damaged fuel or fuel debris in these locations. These locations are designed with a larger box ID to accommodate the DFCs. For an enrichment of 4.0 wt% ^{235}U for the intact fuel, damaged fuel and fuel debris, and assuming no soluble boron, the results for the various configurations outlined in Section 6.4.4.2.2 are summarized in Figure 6.4.14 and in Table 6.4.9. Figure 6.4.14 shows the maximum k_{eff}, including bias and calculational uncertainties, for various actual and hypothetical damaged fuel and fuel debris configurations as a function of the fuel mass per unit length of the DFC. For the intact assemblies, the 15x15H assembly class was chosen. This assembly class has the highest reactivity of all PWR assembly classes for a given initial enrichment. This is demonstrated in Table 6.1.4. Table 6.4.9 lists the highest maximum k_{eff} for the various configurations. All maximum k_{eff} values are below the 0.95 regulatory limit.

For an enrichment of 5.0 wt% ^{235}U for the intact fuel, damaged fuel and fuel debris, a minimum soluble boron concentration of 600 ppm is required. For this condition, calculations are performed for various hypothetical fuel debris configurations (i.e. bare fuel rods) as a function of the fuel mass per unit length of the DFC. Additionally, calculations are performed with reduced water densities in the DFC. The various conditions of damaged fuel, such as assemblies with missing rods or collapsed assemblies, were not analyzed, since the results in Figure 6.4.14 clearly demonstrate that these conditions are bounded by the hypothetical model for fuel debris based on regular arrays of bare fuel rods. Again, the 15x15H assembly class was chosen as the intact assembly since this assembly class has the highest reactivity of all PWR assembly classes as demonstrated in Table 6.1.4. The results are summarized in Table 6.4.12. Similar to the calculations with pure water (see Figure 6.4.14), the results for borated water show a distinct peak of the maximum k_{eff} as a function of the fuel mass per unit length. Therefore, for each condition, the table lists only the highest maximum k_{eff}, including bias and calculational uncertainties, i.e. the point of optimum moderation. The results show that the reactivity decreases with decreasing water density. This demonstrates that replacing all cladding and other structural material with water is conservative even in the presence of soluble boron in the water. All maximum k_{eff} values are below the 0.95 regulatory limit.

6.4.4.2.6 Results for MPC-32 and MPC-32F

The MPC-32 allows the storage of up to eight DFCs with damaged fuel in the outer fuel basket cells shaded in Figure 6.4.16. The MPC-32F allows storage of up to eight DFCs with damaged fuel or fuel debris in these locations. For the MPC-32 and MPC-32F, additional cases are analyzed due to the high soluble boron level required for this basket:

- The assembly classes of the intact assemblies are grouped, and minimum required soluble boron levels are determined separately for each group. The analyses are performed for the bounding assembly class in each group. The bounding assembly classes are listed in Section 6.4.4.2.1.

- Evaluations of conditions with voided and filled guide tubes and various water densities in the MPC and DFC are performed to identify the most reactive condition.

In general, all calculations performed for the MPC-32 show the same principal behavior as for the MPC-24 (see Figure 6.4.14), i.e. the reactivity as a function of the fuel mass per unit length for the bare fuel rod array shows a distinct peak. Therefore, for each condition analyzed, only the highest maximum k_{eff}, i.e. the calculated peak reactivity, is listed in the tables. Evaluations of different diameters of the bare fuel pellets and the reduced water density in the DFC have been performed for a representative case using the 15x15F assembly class as the intact assembly, with voided guide tubes, a water density of 1.0 g/cc in the DFC and MPC, 2900 ppm soluble boron, and an enrichment of 5.0 wt% ^{235}U for the intact and damaged fuel and fuel debris. For this case, results are summarized in Table 6.4.13. For each condition, the table lists the highest maximum k_{eff}, including bias and calculational uncertainties, i.e. the point of optimum moderation. The results show that the fuel pellet diameter in the DFC has an insignificant effect on reactivity, and that reactivity decreases with decreasing water density. The latter demonstrates that replacing all cladding and other structural material with water is conservative even in the presence of soluble boron in the water. Therefore, a typical fuel pellet diameter and a water density of 1.0 in the DFCs are used for all further analyses. Two enrichment levels are analyzed, 4.1 wt% ^{235}U and 5.0 wt% ^{235}U, consistent with the analyses for intact fuel only. In any calculation, the same enrichment is used for the intact fuel and the damaged fuel and fuel debris. For both enrichment levels, analyses are performed with voided and filled guide tubes, each with water densities of 0.93 and 1.0 g/cm^3 in the MPC. In all cases, the water density inside the DFCs is assumed to be 1.0 g/cm^3, since this is the most reactive condition as shown in Table 6.4.13. Results are summarized in Table 6.4.14. For each group of assembly classes, the table shows the soluble boron level and the highest maximum k_{eff} for the various moderation conditions of the intact assembly. The highest maximum k_{eff} is the highest value of any of the hypothetical fuel debris configurations, i.e. various arrays of bare fuel rods. All maximum k_{eff} values are below the 0.95 regulatory limit. Conditions of damaged fuel such as assemblies with missing rods or collapsed assemblies were not analyzed in the MPC-32, since the results in Figure 6.4.14 clearly demonstrate that these conditions are bounded by the hypothetical model for fuel debris based on regular arrays of bare fuel rods.

6.4.5 Fuel Assemblies with Missing Rods

For fuel assemblies that are qualified for damaged fuel storage, missing and/or damaged fuel rods are acceptable. However, for fuel assemblies to meet the limitations of intact fuel assembly storage, missing fuel rods must be replaced with dummy rods that displace a volume of water that is equal to, or larger than, that displaced by the original rods.

6.4.6 Thoria Rod Canister

The Thoria Rod Canister is similar to a DFC with an internal separator assembly containing 18 intact fuel rods. The configuration is illustrated in Figure 6.4.15. The k_{eff} value for an MPC-68F filled with Thoria Rod Canisters is calculated to be 0.1813. This low reactivity is attributed to the relatively low content in ^{235}U (equivalent to UO_2 fuel with an enrichment of approximately 1.7 wt% ^{235}U), the large spacing between the rods (the pitch is approximately 1", the cladding OD is 0.412") and the absorption in the separator assembly. Together with the maximum k_{eff} values listed in Tables 6.1.7 and 6.1.8 this result demonstrates, that the k_{eff} for a Thoria Rod Canister loaded into the MPC-68 or the MPC-68F together with other approved fuel assemblies or DFCs will remain well below the regulatory requirement of $k_{eff} < 0.95$.

6.4.7 Sealed Rods replacing BWR Water Rods

Some BWR fuel assemblies contain sealed rods filled with a non-fissile material instead of water rods. Compared to the configuration with water rods, the configuration with sealed rods has a reduced amount of moderator, while the amount of fissile material is maintained. Thus, the reactivity of the configuration with sealed rods will be lower compared to the configuration with water rods. Any configuration containing sealed rods instead of water rods is therefore bounded by the analysis for the configuration with water rods and no further analysis is required to demonstrate the acceptability. Therefore, for all BWR fuel assemblies analyzed, it is permissible that water rods are replaced by sealed rods filled with a non-fissile material.

6.4.8 Non-fuel Hardware in PWR Fuel Assemblies

Non-fuel hardware such as Thimble Plugs (TPs), Burnable Poison Rod Assemblies (BPRAs), Control Rod Assemblies (CRAs), Axial Power Shaping Rods (APSRs) and similar devices are permitted for storage with all PWR fuel types. Non-fuel hardware is inserted in the guide tubes of the assemblies. For pure water, the reactivity of any PWR assembly with inserts is bounded by (i.e. lower than) the reactivity of the same assembly without the insert. This is due to the fact that the insert reduces the amount of moderator in the assembly, while the amount of fissile material remains unchanged. This conclusion is supported by the calculation listed in Table 6.2.4, which shows a significant reduction in reactivity as a result of voided guide tubes, i.e. the removal of the water from the guide tubes.

With the presence of soluble boron in the water, non-fuel hardware not only displaces water, but also the neutron absorber in the water. It is therefore possible that the insertion results in an increase of reactivity, specifically for higher soluble boron concentrations. As a bounding approach for the presence of non-fuel hardware, analyses were performed with empty (voided) guide tubes, i.e. any absorption of the hardware is neglected. If assemblies contain an instrument tube, this tube remains filled with borated water. Table 6.4.6 shows results for the variation in water density for cases with filled and voided guide tubes. These results show that the optimum moderator density depends on the soluble boron concentration, and on whether the guide tubes are filled or assumed empty. For the MPC-24 with 400 ppm and the MPC-32 with 1900 ppm, voiding the guide tubes results in a reduction of reactivity. All calculations for the MPC-24 and MPC-24E are therefore performed with water in the guide tubes. For the MPC-32 with 2600 ppm, the reactivity for voided guide tubes slightly exceeds the reactivity for filled guide tubes. However, this effect is not consistent across all assembly classes. Table 6.4.10, Table 6.4.11 and Table 6.4.14 show results with filled and voided guide tubes for all assembly classes in the MPC-32/32F at 4.1 wt% ^{235}U and 5.0 wt% ^{235}U. Some classes show an increase, other classes show a decrease as a result of voiding the guide tubes. Therefore, for the results presented in the Section 6.1, Table 6.1.5, Table 6.1.6 and Table 6.1.12, the maximum value for each class is chosen for each enrichment level.

In summary, from a criticality safety perspective, non-fuel hardware inserted into PWR assemblies are acceptable for all allowable PWR types, and, depending on the assembly class, can increase the safety margin.

6.4.9 Neutron Sources in Fuel Assemblies

Fuel assemblies containing start-up neutron sources are permitted for storage in the HI-STORM 100 System. The reactivity of a fuel assembly is not affected by the presence of a neutron source (other than by the presence of the material of the source, which is discussed later). This is true because in a system with a keff less than 1.0, any given neutron population at any time, regardless of its origin or size, will decrease over time. Therefore, a neutron source of any strength will not increase reactivity, but only the neutron flux in a system, and no additional criticality analyses are required. Sources are inserted as rods into fuel assemblies, i.e. they replace either a fuel rod or water rod (moderator). Therefore, the insertion of the material of the source into a fuel assembly will not lead to an increase of reactivity either.

6.4.10 Applicability of HI-STAR Analyses to HI-STORM 100 System

Calculations previously supplied to the NRC in applications for the HI-STAR 100 System (Docket Numbers 71-9261 and 72-1008) are directly applicable to the HI-STORM storage and HI-TRAC transfer casks. The MPC designs are identical. The cask systems differ only in the overpack shield material. The limiting condition for the HI-STORM 100 System is the fully flooded HI-TRAC transfer cask. As demonstrated by the comparative calculations presented in Tables 6.1.1 through 6.1.8, the shield material in the overpack (steel and lead for HI-TRAC, steel for HI-STAR) has a negligible impact on the eigenvalue of the cask systems. As a result, this analysis for the 125-ton HI-TRAC transfer cask is applicable to the 100-ton HI-TRAC transfer cask. In all cases, for the reference fuel assemblies, the maximum k_{eff} values are in good agreement and are conservatively less than the limiting k_{eff} value (0.95).

6.4.11 Fixed Neutron Absorber Material

The MPCs in the HI-STORM 100 System can be manufactured with one of two possible neutron absorber materials: Boral or Metamic. Both materials are made of aluminum and B_4C powder. Boral has an inner core consisting of B_4C and aluminum between two outer layers consisting of aluminum only. This configuration is explicitly modeled in the criticality evaluation and shown in Figures 6.3.1 through 6.3.3 for each basket. Metamic is a single layer material with a slightly higher overall thickness and the same credited ^{10}B loading (in g/cm^2) for each basket. The majority of the criticality evaluations documented in this chapter are performed using Boral as the fixed neutron absorber. For a selected number of bounding cases, analyses are also performed using Metamic instead of Boral. (Note that the Metamic cases use the same absorber thickness as the corresponding Boral case, instead of the slightly increased thickness for Metamic. This is acceptable since analyses of slight thickness increases for a fixed ^{10}B loading (in g/cm^2) indicate that such increases have a negligible effect on reactivity.) The results for these cases are listed in Table 6.4.15, together with the corresponding result using Boral and the difference between the two materials for each case. Individual cases show small differences for the two materials. However, the differences are mostly below two times the standard deviation (the standard deviation is about 0.0008 for all cases in Table 6.4.15), indicating that the results are statistically equivalent. Furthermore, the average difference is well below one standard deviation, and all cases are below the regulatory limit of 0.95. In some cases listed in Table 6.4.15, the reactivity difference between Metamic and Boral might be larger than expected for two equivalent materials. Also, for four out of the five cases with MPC-24 type baskets, Metamic shows the higher reactivity, which could potentially indicate a trend rather than a statistical variation. Therefore, in order to confirm that the materials are equivalent, a second set of calculations was performed for Metamic, which was statistically independent from the set shown in Table 6.4.15. This was achieved by selecting a different starting value for the random number generator in the Monte Carlo calculations. The second set also shows some individual variations of the differences, and a low average difference. However, there is no apparent trend regarding the MPC-24 type baskets compared to the MPC-32 and MPC-68, and the maximum positive reactivity difference for Metamic in an MPC-24 type basket is only 0.0005. Overall, the calculations demonstrate that the two fixed neutron absorber materials are identical from a criticality perspective. All results obtained for Boral are therefore directly applicable to Metamic and no further evaluations using Metamic are required.

6.4.12 Annular Fuel Pellets

Typically, PWR fuel assemblies are designed with solid fuel pellets throughout the entire active fuel length. However, some PWR assemblies contain annular fuel pellets in the top and bottom 6 to 8 inches of the active fuel length. This changes the fuel to water ratio in these areas, which could have an effect on reactivity. However, the top and bottom of the active length are areas with high neutron leakage, and changes in these areas typically have no significant effect on reactivity. Studies with up to 12 inches of annular pellets at the top and bottom, with various pellet IDs confirm this, i.e., shown no significant reactivity effects, even if the annular region of the pellet is flooded with pure water. All calculations for PWR fuel assemblies are therefore performed with solid fuel pellets along the entire length of the active fuel region, and the results are directly applicable to those PWR assemblies with annular fuel pellets.

Table 6.4.1

MAXIMUM REACTIVITIES WITH REDUCED WATER DENSITIES FOR CASK ARRAYS†

	Water Density		**MCNP4a Maximum k_{eff} ††**	
Case Number	**Internal**	**External**	**MPC-24 (17x17A01 @ 4.0%)**	**MPC-68 (8x8C04 @ 4.2%)**
1	100%	single cask	0.9368	0.9348
2	100%	100%	0.9354	0.9339
3	100%	70%	0.9362	0.9339
4	100%	50%	0.9352	0.9347
5	100%	20%	0.9372	0.9338
6	100%	10%	0.9380	0.9336
7	100%	5%	0.9351	0.9333
8	100%	0%	0.9342	0.9338
9	70%	0%	0.8337	0.8488
10	50%	0%	0.7426	0.7631
11	20%	0%	0.5606	0.5797
12	10%	0%	0.4834	0.5139
13	5%	0%	0.4432	0.4763
14	10%	100%	0.4793	0.4946

† For an infinite square array of casks with 60cm spacing between cask surfaces.

†† Maximum k_{eff} includes the bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

Table 6.4.2

REACTIVITY EFFECTS OF PARTIAL CASK FLOODING

MPC-24 (17x17A01 @ 4.0% ENRICHMENT) (no soluble boron)			
Flooded Condition (% Full)	Vertical Orientation	Flooded Condition (% Full)	Horizontal Orientation
25	0.9157	25	0.8766
50	0.9305	50	0.9240
75	0.9330	75	0.9329
100	0.9368	100	0.9368
MPC-68 (8x8C04 @ 4.2% ENRICHMENT)			
Flooded Condition (% Full)	Vertical Orientation	Flooded Condition (% Full)	Horizontal Orientation
25	0.9132	23.5	0.8586
50	0.9307	50	0.9088
75	0.9312	76.5	0.9275
100	0.9348	100	0.9348
MPC-32 (15x15F @ 5.0 % ENRICHMENT) 2600ppm Soluble Boron			
Flooded Condition (% Full)	Vertical Orientation	Flooded Condition (% Full)	Horizontal Orientation
25	0.8927	31.25	0.9213
50	0.9215	50	0.9388
75	0.9350	68.75	0.9401
100	0.9445	100	0.9445

Notes:

1. All values are maximum k_{eff} which include bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

Table 6.4.3

REACTIVITY EFFECT OF FLOODING THE PELLET-TO-CLAD GAP

Pellet-to-Clad Condition	MPC-24 17x17A01 4.0% Enrichment	MPC-68 8x8C04 4.2% Enrichment
dry	0.9295	0.9279
flooded with unborated water	0.9368	0.9348

Notes:

1. All values are maximum k_{eff} which includes bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

Table 6.4.4

REACTIVITY EFFECT OF PREFERENTIAL FLOODING OF THE DFCs

DFC Configuration	Preferential Flooding	Fully Flooded
MPC-68 or MPC-68F with 68 DFCs (Assembly Classes 6x6A/B/C, 7x7A and 8x8A)	0.6560	0.7857
MPC-68 or MPC-68FF with 16 DFCs (All BWR Assembly Classes)	0.6646	0.9328
MPC-24E or MPC-24EF with 4 DFCs (All PWR Assembly Classes)	0.7895	0.9480
MPC-32 or MPC-32 with 8 DFCs (All PWR Assembly Classes)	0.7213	0.9378

Notes:

1. All values are maximum k_{eff} which includes bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

Table 6.4.5

MAXIMUM k_{eff} VALUES† IN THE DAMAGED FUEL CONTAINER

Condition	**MCNP4a Maximum†† k_{eff}**	
	DFC Dimensions: ID 4.93" THK. 0.12"	**DFC Dimensions: ID 4.81" THK. 0.11"**
<u>6x6 Fuel Assembly</u>		
6x6 Intact Fuel	0.7086	0.7016
w/32 Rods Standing	0.7183	0.7117
w/28 Rods Standing	0.7315	0.7241
w/24 Rods Standing	0.7086	0.7010
w/18 Rods Standing	0.6524	0.6453
Collapsed to 8x8 array	0.7845	0.7857
Dispersed Powder	0.7628	0.7440
<u>7x7 Fuel Assembly</u>		
7x7 Intact Fuel	0.7463	0.7393
w/41 Rods Standing	0.7529	0.7481
w/36 Rods Standing	0.7487	0.7444
w/25 Rods Standing	0.6718	0.6644

† These calculations were performed with a planar-average enrichment of 3.0% and a ^{10}B loading of 0.0067 g/cm^2, which is 75% of a minimum ^{10}B loading of 0.0089 g/cm^2. The minimum ^{10}B loading in the MPC-68F is 0.010 g/cm^2. Therefore, the listed maximum k_{eff} values are conservative

†† Maximum k_{eff} includes bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

Table 6.4.6

MAXIMUM k_{eff} VALUES WITH REDUCED BORATED WATER DENSITIES

Internal Water Density† in g/cm³	**Maximum k_{eff}**				
	MPC-24 (400ppm) @ 5.0 %	**MPC-32 (1900ppm) @ 4.1 %**		**MPC-32 (2600ppm) @ 5.0 %**	
Guide Tubes	filled	filled	void	filled	void
1.005	NC††	0.9403	0.9395	NC	0.9481
1.00	0.9314	0.9411	0.9400	0.9445	0.9483
0.99	NC	0.9393	0.9396	0.9438	0.9462
0.98	0.9245	0.9403	0.9376	0.9447	0.9465
0.97	NC	0.9397	0.9391	0.9453	0.9476
0.96	NC	NC	NC	0.9446	0.9466
0.95	0.9186	0.9380	0.9384	0.9451	0.9468
0.94	NC	NC	NC	0.9445	0.9467
0.93	0.9130	0.9392	0.9352	0.9465	0.9460
0.92	NC	NC	NC	0.9458	0.9450
0.91	NC	NC	NC	0.9447	0.9452
0.90	0.9061	0.9384	NC	0.9449	0.9454
0.80	0.8774	0.9322	NC	0.9431	0.9390
0.70	0.8457	0.9190	NC	0.9339	0.9259
0.60	0.8095	0.8990	NC	0.9194	0.9058
0.40	0.7225	0.8280	NC	0.8575	0.8410
0.20	0.6131	0.7002	NC	0.7421	0.7271
0.10	0.5486	0.6178	NC	0.6662	0.6584

† External moderator is modeled at 0%. This is consistent with the results demonstrated in Table 6.4.1.

†† NC: Not Calculated

Table 6.4.7

MAXIMUM k_{eff} VALUES FOR INTACT BWR FUEL ASSEMBLIES WITH A MAXIMUM PLANAR AVERAGE ENRICHMENT OF 3.7 wt% ^{235}U

Fuel Assembly Class	**Maximum k_{eff}**
6x6A	0.8287
6x6C	0.8436
7x7A	0.8399
7x7B	0.9109
8x8A	0.8102
8x8B	0.9131
8x8C	0.9115
8x8D	0.9125
8x8E	0.9049
8x8F	0.9233
9x9A	0.9111
9x9B	0.9134
9x9C	0.9103
9x9D	0.9096
9x9E	0.9237
9x9F	0.9237
9x9G	0.9005
10x10A	0.9158
10x10B	0.9156
10x10C	0.9152
10x10D	0.9182
10x10E	0.8970

Table 6.4.8

MAXIMUM k_{eff} VALUES IN THE GENERIC BWR DAMAGED FUEL CONTAINER FOR A MAXIMUM INITIAL ENRICHMENT OF 4.0 wt% ^{235}U FOR DAMAGED FUEL AND 3.7 wt% ^{235}U FOR INTACT FUEL

Model Configuration inside the DFC	**Maximum k_{eff}**
Intact Assemblies (4 assemblies analyzed)	0.9241
Assemblies with missing rods (7 configurations analyzed)	0.9240
Assemblies with distributed enrichment (4 configurations analyzed)	0.9245
Collapsed Assemblies (6 configurations analyzed)	0.9258
Regular Arrays of Bare Fuel Rods (31 configurations analyzed)	0.9328

Table 6.4.9

MAXIMUM k_{eff} VALUES IN THE MPC-24E/EF WITH THE GENERIC PWR DAMAGED FUEL CONTAINER FOR A MAXIMUM INITIAL ENRICHMENT OF 4.0 wt% ^{235}U AND NO SOLUBLE BORON.

Model Configuration inside the DFC	**Maximum k_{eff}**
Intact Assemblies (2 assemblies analyzed)	0.9340
Assemblies with missing rods (4 configurations analyzed)	0.9350
Collapsed Assemblies (6 configurations analyzed)	0.9360
Regular Arrays of Bare Fuel Rods (36 configurations analyzed)	0.9480

Table 6.4.10

MAXIMUM k_{eff} VALUES WITH FILLED AND VOIDED GUIDE TUBES FOR THE MPC-32 AT 5.0 wt% ENRICHMENT

Fuel Class	**Minimum Soluble Boron Content (ppm)**	**MPC-32 @ 5.0 %**			
		Guide Tubes Filled,		**Guide Tubes Voided,**	
		1.0 g/cm^3	**0.93 g/cm^3**	**1.0 g/cm^3**	**0.93 g/cm^3**
14x14A	1900	0.8984	0.9000	0.8953	0.8943
14x14B	1900	0.9210	0.9214	0.9164	0.9118
14x14C	1900	0.9371	0.9376	0.9480	0.9421
14x14D	1900	0.9050	0.9027	0.8947	0.8904
15x15A	2500	0.9210	0.9223	0.9230	0.9210
15x15B	2500	0.9402	0.9420	0.9429	0.9421
15x15C	2500	0.9258	0.9292	0.9307	0.9293
15x15D	2600	0.9426	0.9419	0.9466	0.9440
15x15E	2600	0.9394	0.9415	0.9434	0.9442
15x15F	2600	0.9445	0.9465	0.9483	0.9460
15x15G	2500	0.9228	0.9244	0.9251	0.9243
15X15H	2600	0.9271	0.9301	0.9317	0.9333
16X16A	1900	0.9460	0.9450	0.9474	0.9434
17x17A	2600	0.9105	0.9145	0.9160	0.9161
17x17B	2600	0.9345	0.9358	0.9371	0.9356
17X17C	2600	0.9417	0.9431	0.9437	0.9430

Table 6.4.11

MAXIMUM k_{eff} VALUES WITH FILLED AND VOIDED GUIDE TUBES FOR THE MPC-32 AT 4.1 wt% ENRICHMENT

Fuel Class	**Minimum Soluble Boron Content (ppm)**	**MPC-32 @ 4.1 %**			
		Guide Tubes Filled		**Guide Tubes Voided**	
		1.0 g/cm^3	**0.93 g/cm^3**	**1.0 g/cm^3**	**0.93 g/cm^3**
14x14A	1300	0.9041	0.9029	0.8954	0.8939
14x14B	1300	0.9257	0.9205	0.9128	0.9074
14x14C	1300	0.9402	0.9384	0.9423	0.9365
14x14D	1300	0.8970	0.8943	0.8836	0.8788
15x15A	1800	0.9199	0.9206	0.9193	0.9134
15x15B	1800	0.9397	0.9387	0.9385	0.9347
15x15C	1800	0.9266	0.9250	0.9264	0.9236
15x15D	1900	0.9375	0.9384	0.9380	0.9329
15x15E	1900	0.9348	0.9340	0.9365	0.9336
15x15F	1900	0.9411	0.9392	0.9400	0.9352
15x15G	1800	0.9147	0.9128	0.9125	0.9062
15X15H	1900	0.9267	0.9274	0.9276	0.9268
16X16A	1300	0.9468	0.9425	0.9433	0.9384
17x17A	1900	0.9105	0.9111	0.9106	0.9091
17x17B	1900	0.9309	0.9307	0.9297	0.9243
17X17C	1900	0.9355	0.9347	0.9350	0.9308

Table 6.4.12

MAXIMUM k_{eff} VALUES IN THE MPC-24E/24EF WITH THE GENERIC PWR DAMAGED FUEL CONTAINER FOR A MAXIMUM INITIAL ENRICHMENT OF 5.0 wt% ^{235}U AND 600 PPM SOLUBLE BORON.

Water Density inside the DFC	**Bare Fuel Pellet Diameter**	**Maximum k_{eff}**
1.00	minimum	0.9185
1.00	typical	0.9181
1.00	maximum	0.9171
0.95	typical	0.9145
0.90	typical	0.9125
0.60	typical	0.9063
0.10	typical	0.9025
0.02	typical	0.9025

Table 6.4.13

MAXIMUM k_{eff} VALUES IN THE MPC-32/32F WITH THE GENERIC PWR DAMAGED FUEL CONTAINER FOR A MAXIMUM INITIAL ENRICHMENT OF 5.0 wt% ^{235}U, 2900 PPM SOLUBLE BORON AND THE 15x15F ASSEMBLY CLASS AS INTACT ASSEMBLY.

Water Density inside the DFC	**Bare Fuel Pellet Diameter**	**Maximum k_{eff}**
1.00	minimum	0.9374
1.00	typical	0.9372
1.00	maximum	0.9373
0.95	typical	0.9369
0.90	typical	0.9365
0.60	typical	0.9308
0.10	typical	0.9295
0.02	typical	0.9283

Table 6.4.14

BOUNDING MAXIMUM k_{eff} VALUES FOR THE MPC-32 AND MPC-32F WITH UP TO 8 DFCs UNDER VARIOUS MODERATION CONDITIONS.

Fuel Assembly Class of Intact Fuel	Initial Enrichment (wt% ^{235}U)	Minimum Soluble Boron Content (ppm)	Maximum k_{eff}			
			Filled Guide Tubes		Voided Guide Tubes	
			1.0 g/cm^3	0.93 g/cm^3	1.0 g/cm^3	0.93 g/cm^3
14x14A through 14x14D	4.1	1500	0.9277	0.9283	0.9336	0.9298
	5.0	2300	0.9139	0.9180	0.9269	0.9262
15x15A, B, C, G	4.1	1900	0.9345	0.9350	0.9350	0.9326
	5.0	2700	0.9307	0.9346	0.9347	0.9365
15x15D, E, F, H	4.1	2100	0.9322	0.9336	0.9340	0.9329
	5.0	2900	0.9342	0.9375	0.9385	0.9397
16x16A	4.1	1500	0.9322	0.9321	0.9335	0.9302
	5.0	2300	0.9198	0.9239	0.9289	0.9267
17x17A, B, C	4.1	2100	0.9284	0.9290	0.9294	0.9285
	5.0	2900	0.9308	0.9338	0.9355	0.9367

Table 6.4.15

COMPARISON OF MAXIMUM k_{eff} VALUES FOR DIFFERENT FIXED NEUTRON ABSORBER MATERIALS

Case	**Maximum k_{eff}**		**Reactivity Difference**
	BORAL	**METAMIC**	
MPC-68, Intact Assemblies	0.9457	0.9452	-0.0005
MPC-68, with 16 DFCs	0.9328	0.9315	-0.0013
MPC-68F with 68 DFCs	0.8021	0.8019	-0.0002
MPC-24, 0ppm	0.9478	0.9491	+0.0013
MPC-24, 400ppm	0.9447	0.9457	+0.0010
MPC-24E, Intact Assemblies, 0ppm	0.9468	0.9494	+0.0026
MPC-24E, Intact Assemblies, 300ppm	0.9399	0.9410	+0.0011
MPC-24E, with 4 DFCs, 0ppm	0.9480	0.9471	-0.0009
MPC-32, Intact Assemblies, 1900ppm	0.9411	0.9397	-0.0014
MPC-32, Intact Assemblies, 2600ppm	0.9483	0.9471	-0.0012
Average Difference			**+0.0001**

DELETED

FIGURE 6.4.1

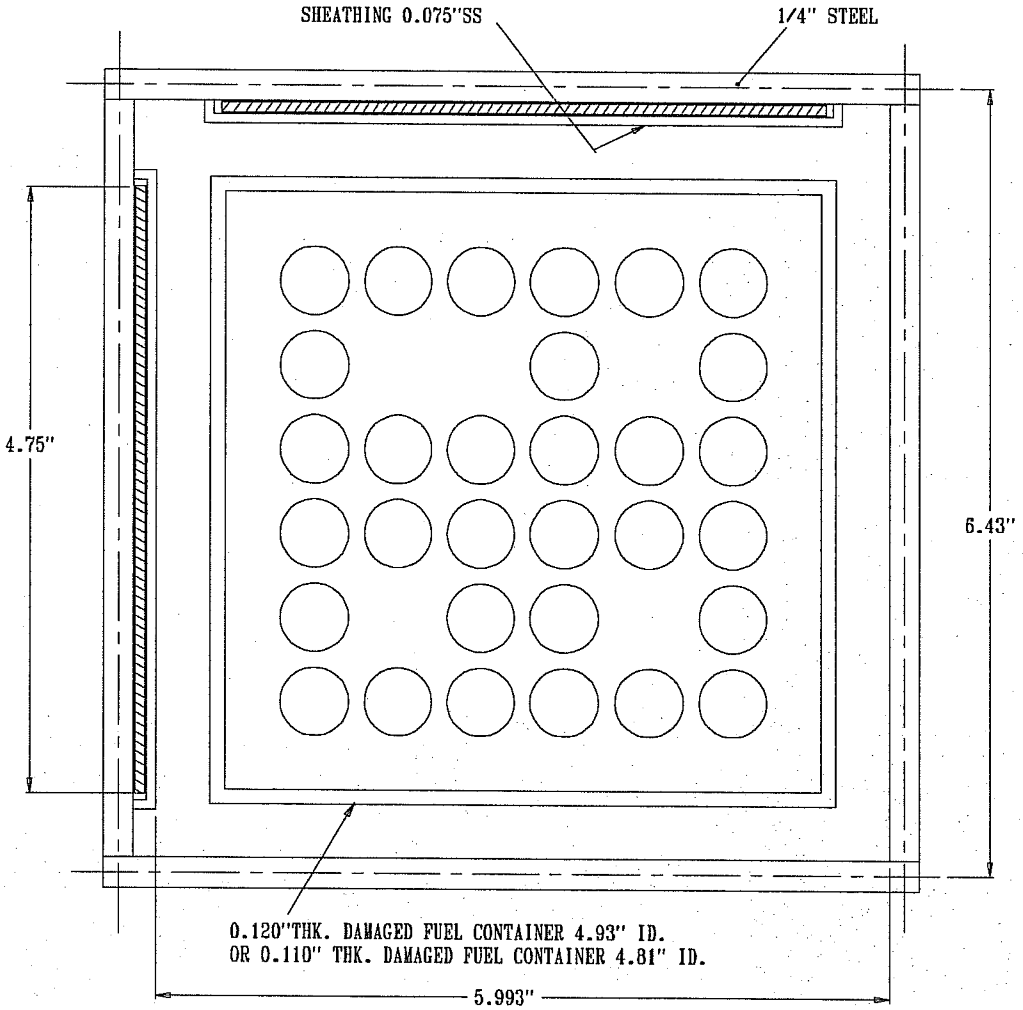

FIGURE 6.4.2; FAILED FUEL CALCULATION MODEL (PLANAR CROSS-SECTION) WITH 6X6 ARRAY WITH 4 MISSING RODS IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

NOTE: THESE DIMENSIONS WERE CONSERVATIVELY USED FOR CRITICALITY ANALYSES.

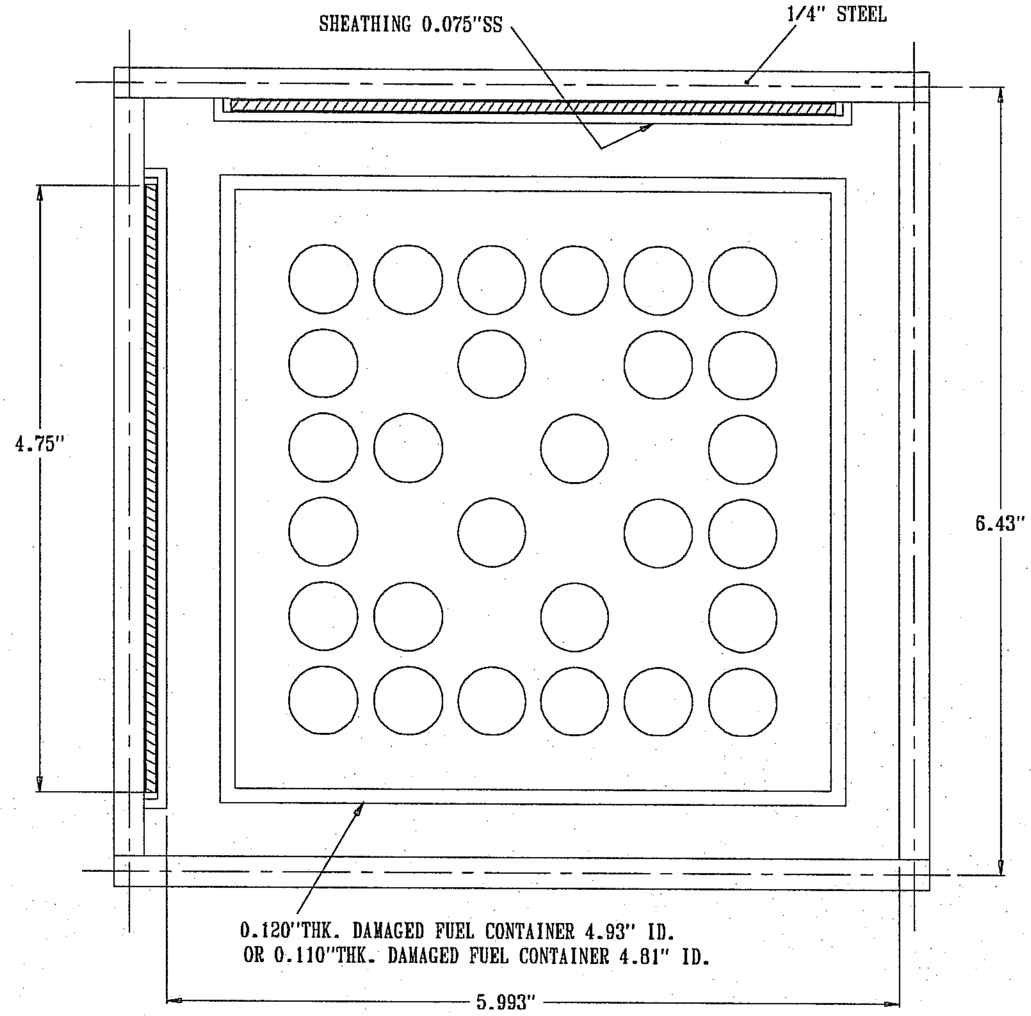

FIGURE 6.4.3; FAILED FUEL CALCULATION MODEL (PLANAR CROSS-SECTION) WITH 6X6 ARRAY WITH 8 MISSING RODS IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

NOTE: THESE DIMENSIONS WERE CONSERVATIVELY USED FOR CRITICALITY ANALYSES.

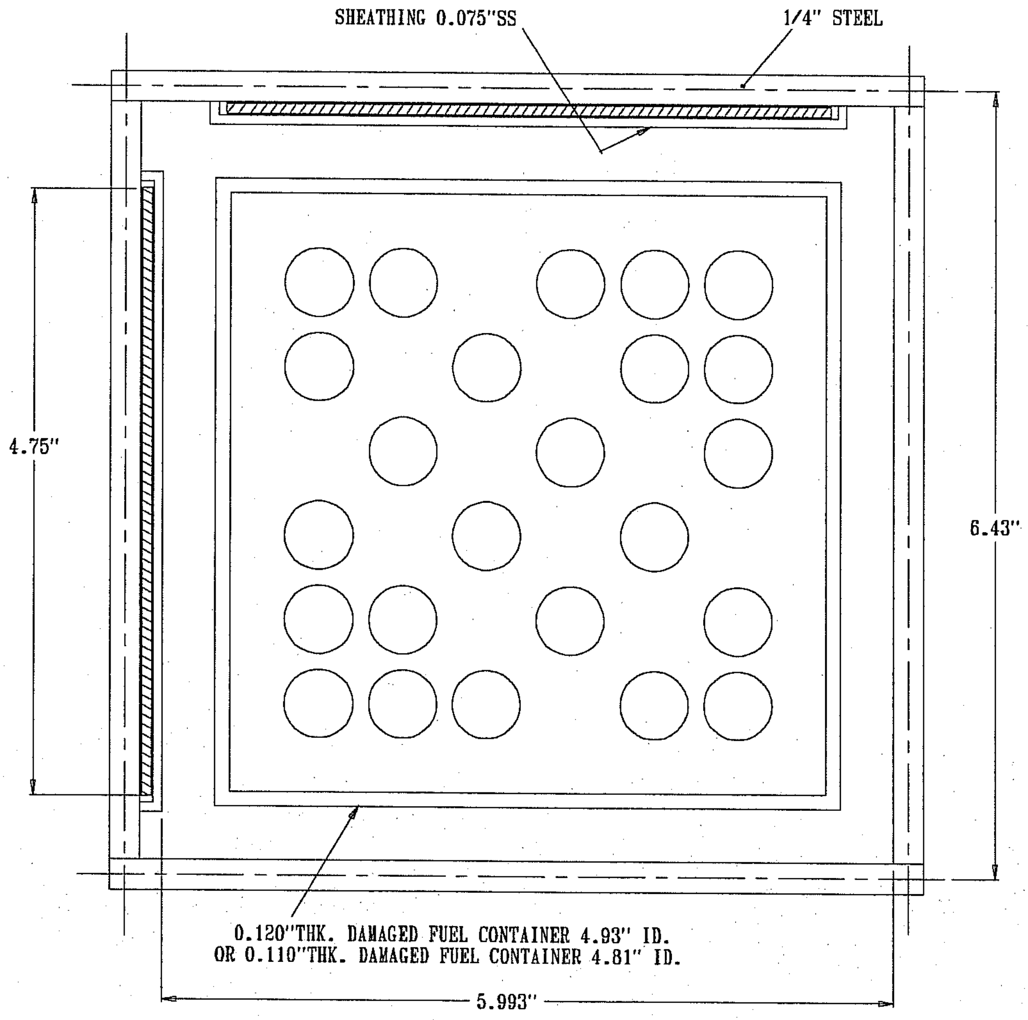

FIGURE 6.4.4; FAILED FUEL CALCULATION MODEL (PLANAR CROSS-SECTION) WITH 6X6 ARRAY WITH 12 MISSING RODS IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

NOTE: THESE DIMENSIONS WERE CONSERVATIVELY USED FOR CRITICALITY ANALYSES.

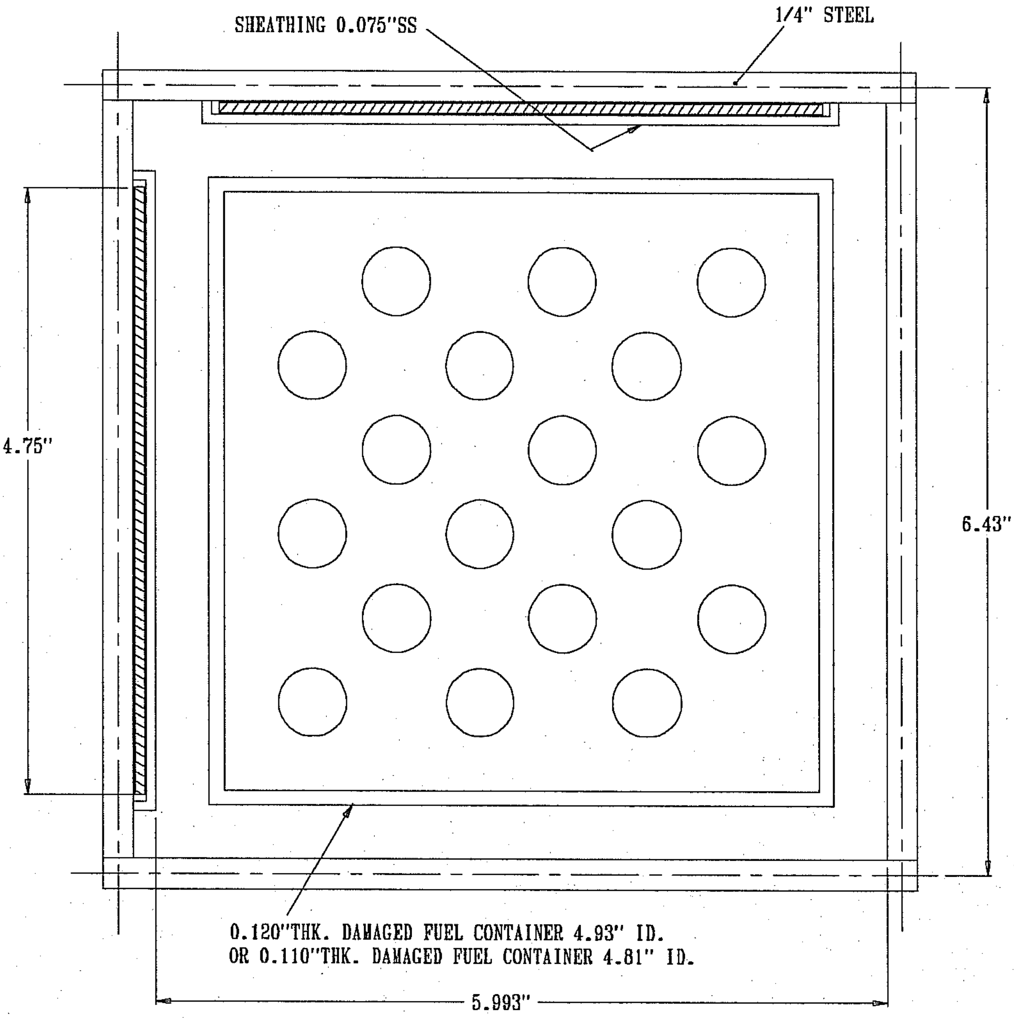

FIGURE 6.4.5; FAILED FUEL CALCULATION MODEL (PLANAR CROSS-SECTION) WITH 6X6 ARRAY WITH 18 MISSING RODS IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

NOTE: THESE DIMENSIONS WERE CONSERVATIVELY USED FOR CRITICALITY ANALYSES.

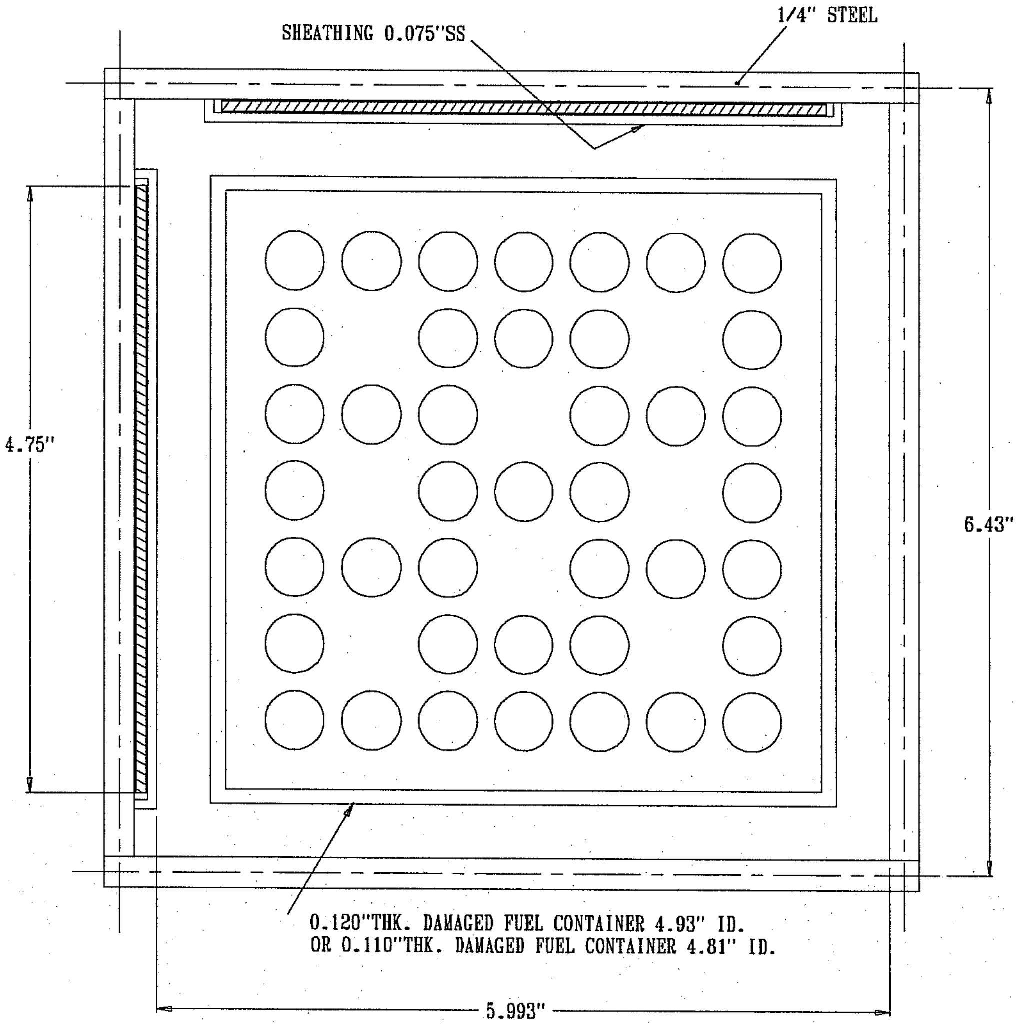

FIGURE 6.4.6; FAILED FUEL CALCULATION MODEL (PLANAR CROSS-SECTION) WITH 7X7 ARRAY WITH 8 MISSING RODS IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

NOTE: THESE DIMENSIONS WERE CONSERVATIVELY USED FOR CRITICALITY ANALYSES.

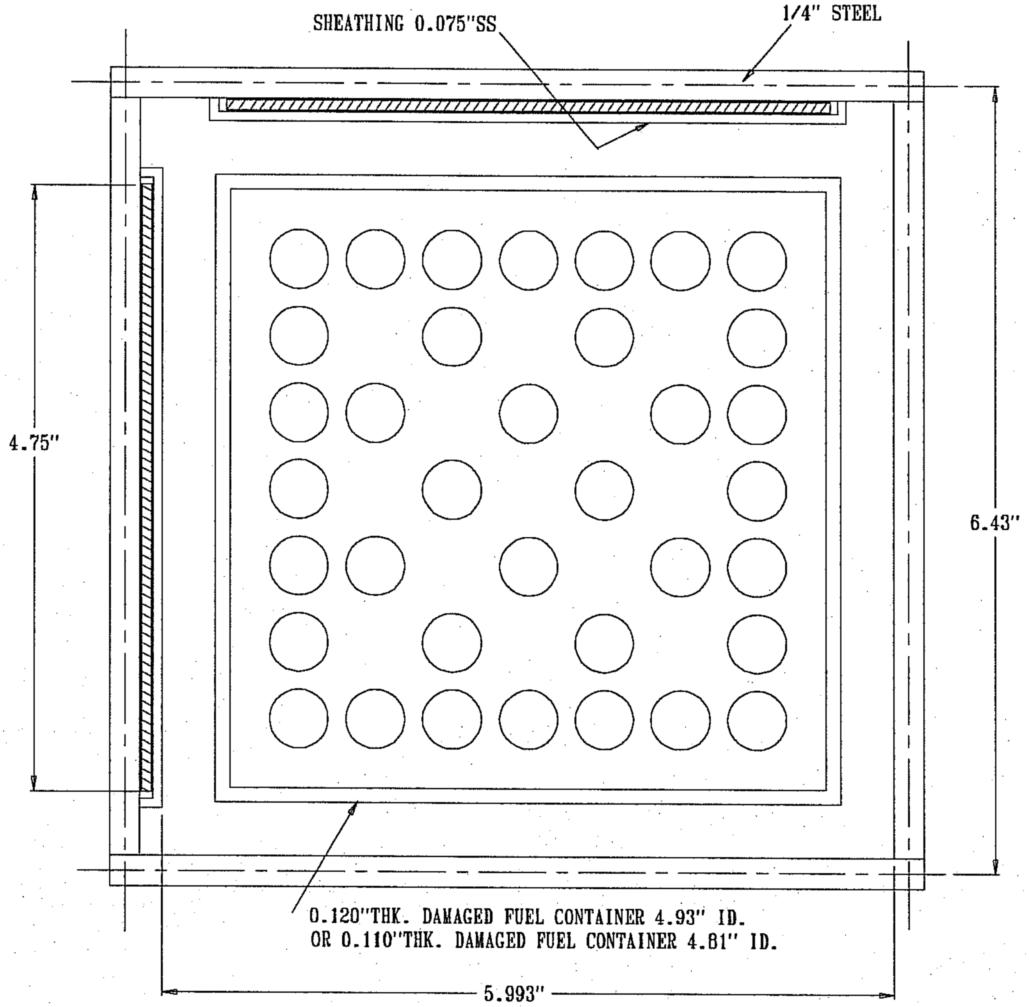

FIGURE 6.4.7; FAILED FUEL CALCULATION MODEL (PLANAR CROSS-SECTION) WITH 7X7 ARRAY WITH 13 MISSING RODS IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

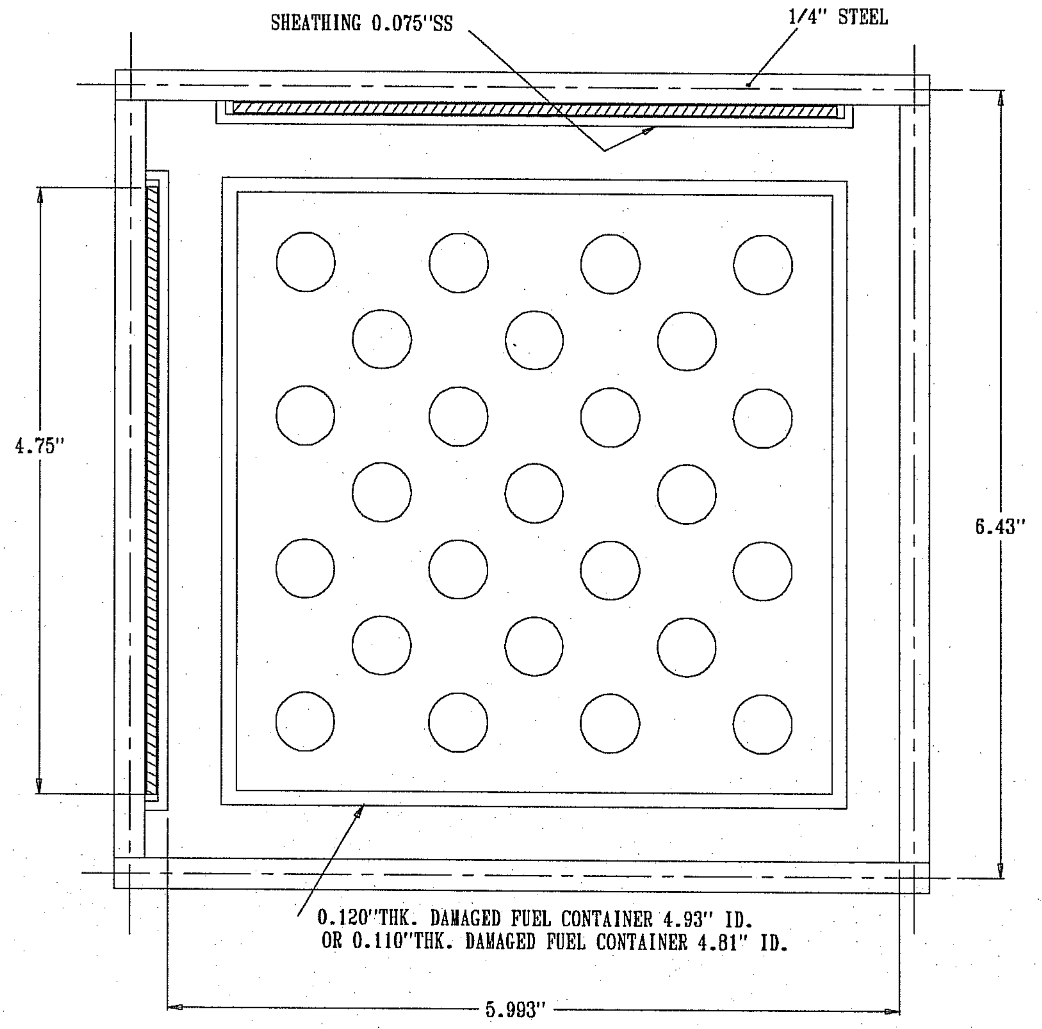

FIGURE 6.4.8; FAILED FUEL CALCULATION MODEL (PLANAR CROSS-SECTION) WITH 7X7 ARRAY WITH 24 MISSING RODS IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

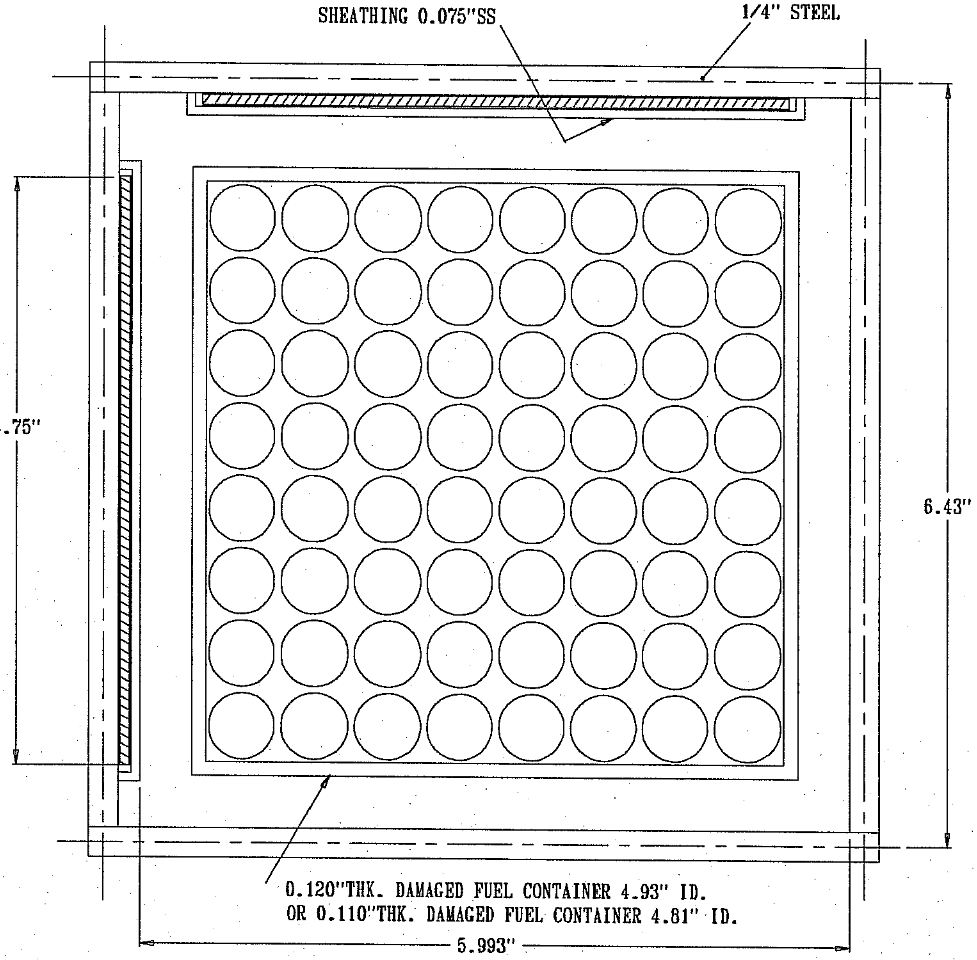

FIGURE 6.4.9; FAILED FUEL CALCULATION MODEL (PLANAR CROSS-SECTION) WITH DAMAGED FUEL COLLAPSED INTO 8X8 ARRAY IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

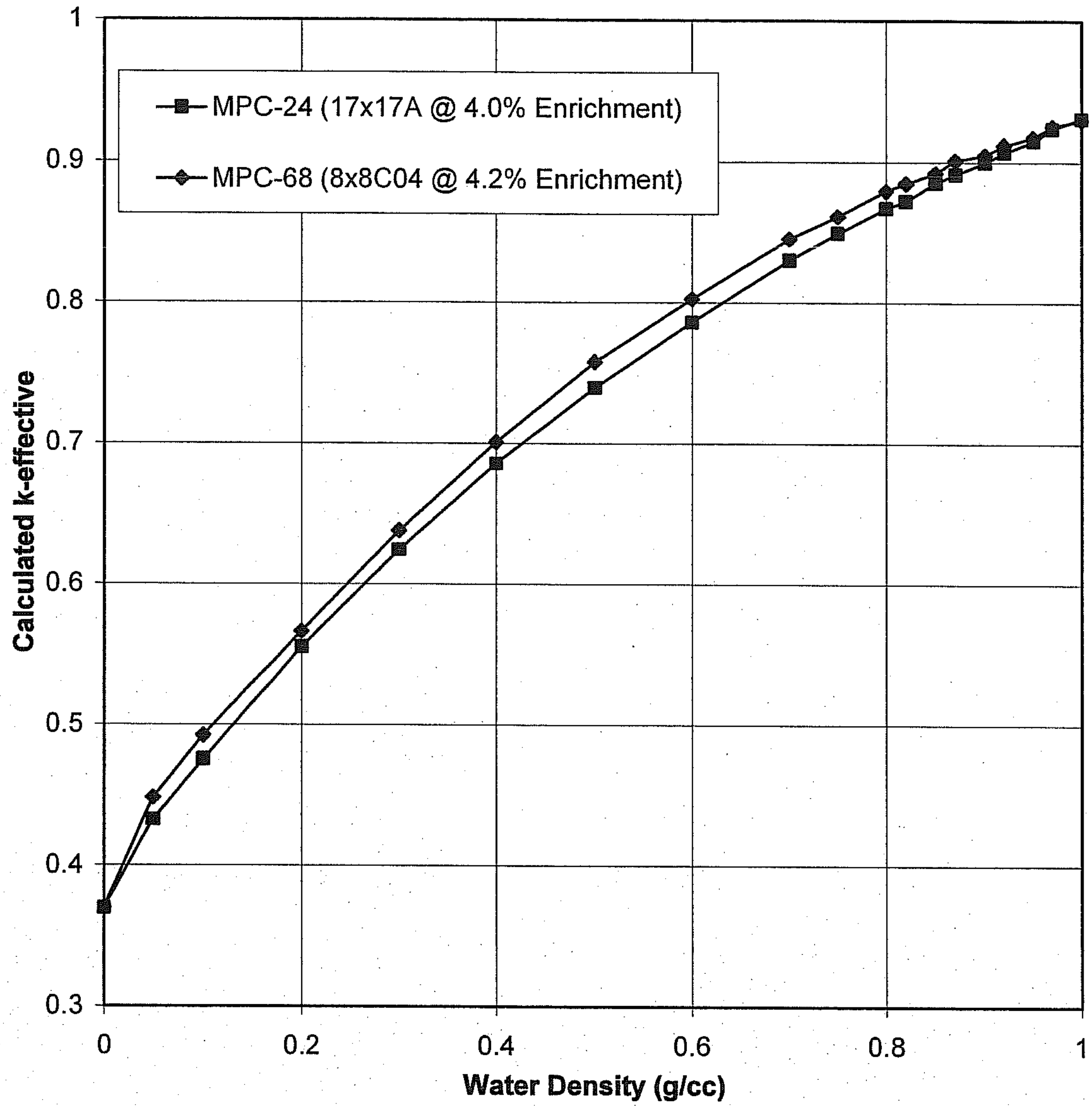

FIGURE 6.4.10; CALCULATED K-EFFECTIVE AS A FUNCTION OF INTERNAL MODERATOR DENSITY

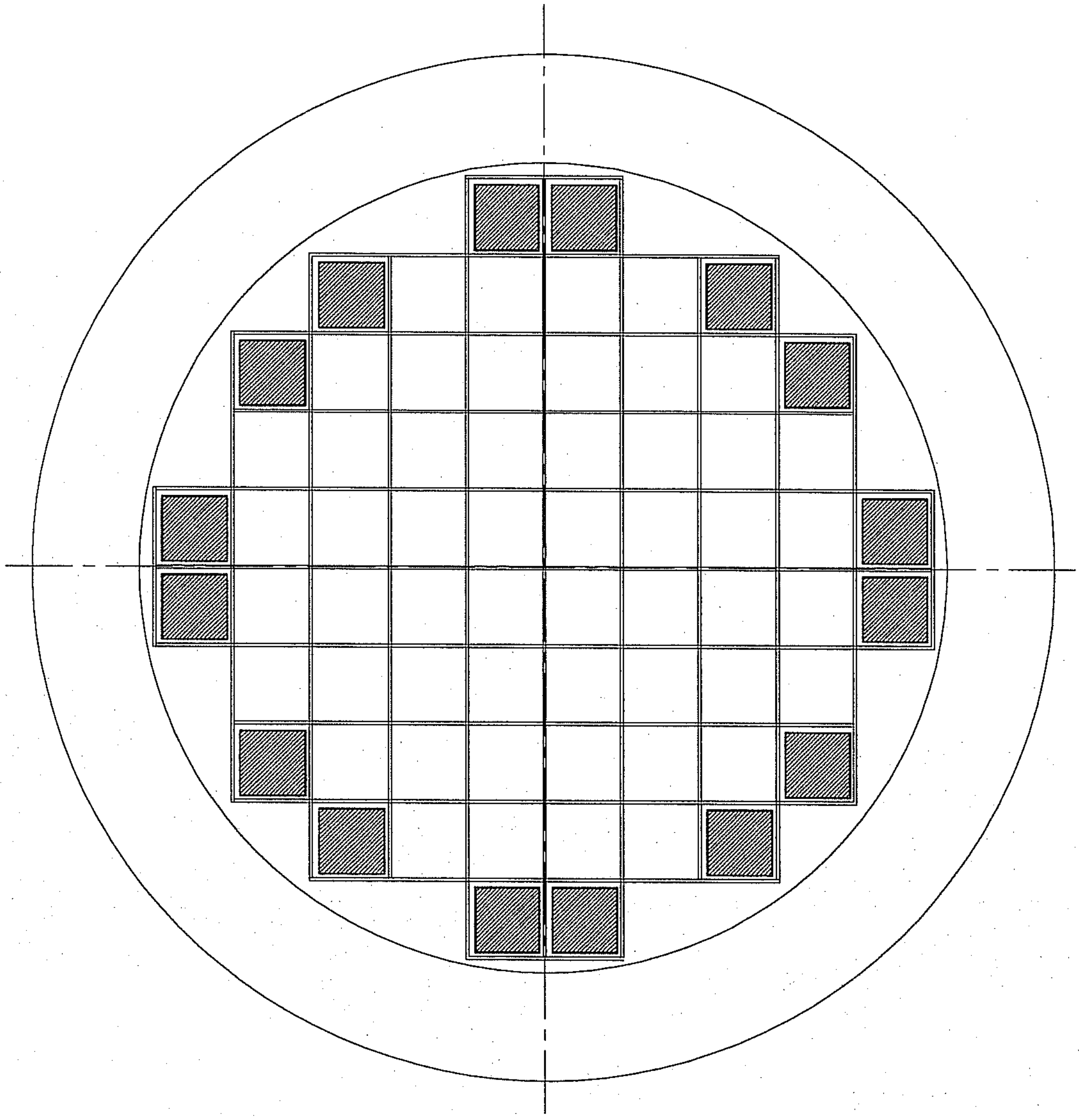

FIGURE 6.4.11; LOCATIONS OF THE DAMAGED FUEL CONTAINER IN THE MPC-68 AND MPC-68FF

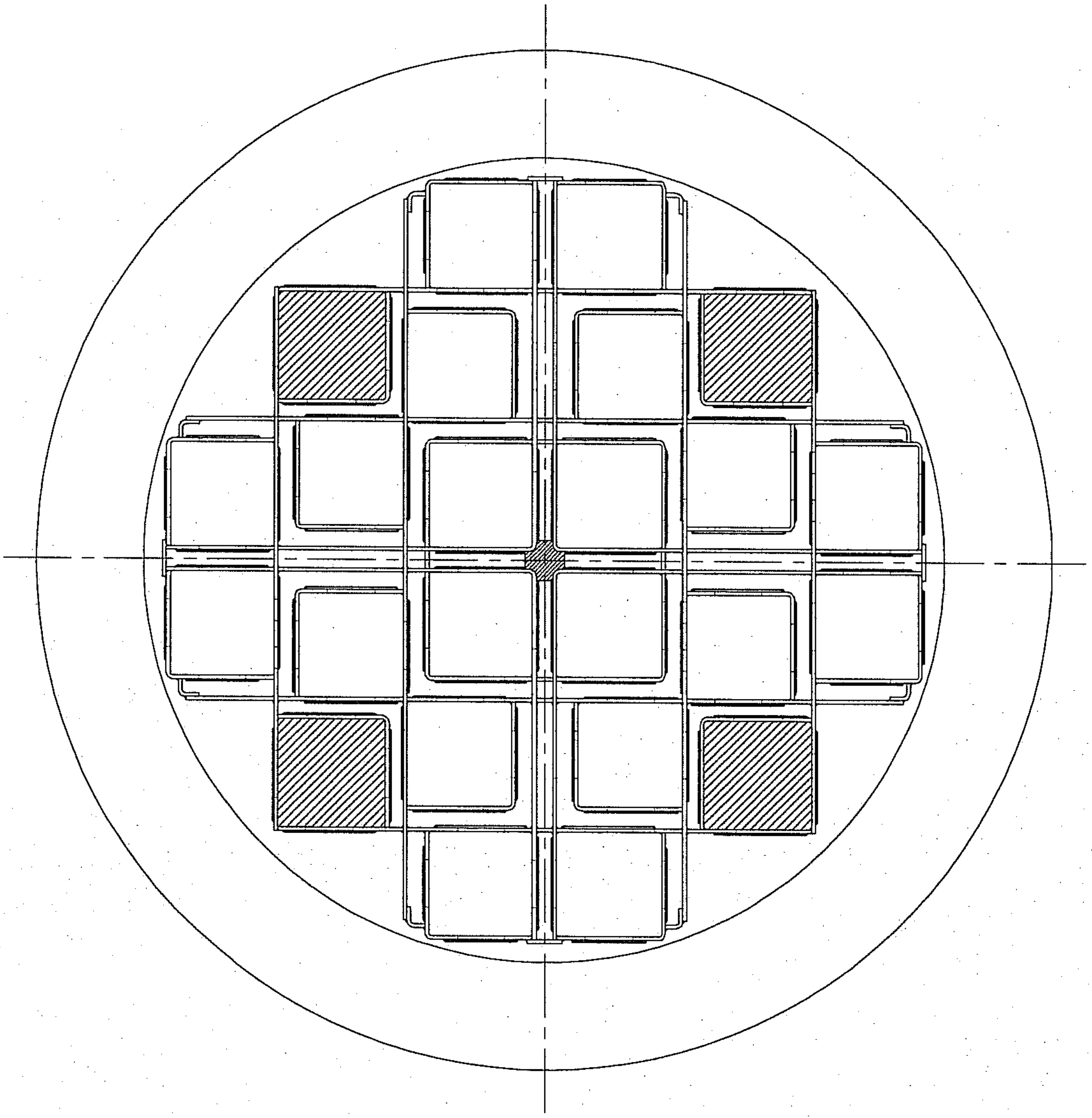

FIGURE 6.4.12; LOCATIONS OF THE DAMAGED FUEL CONTAINERS IN THE MPC 24E

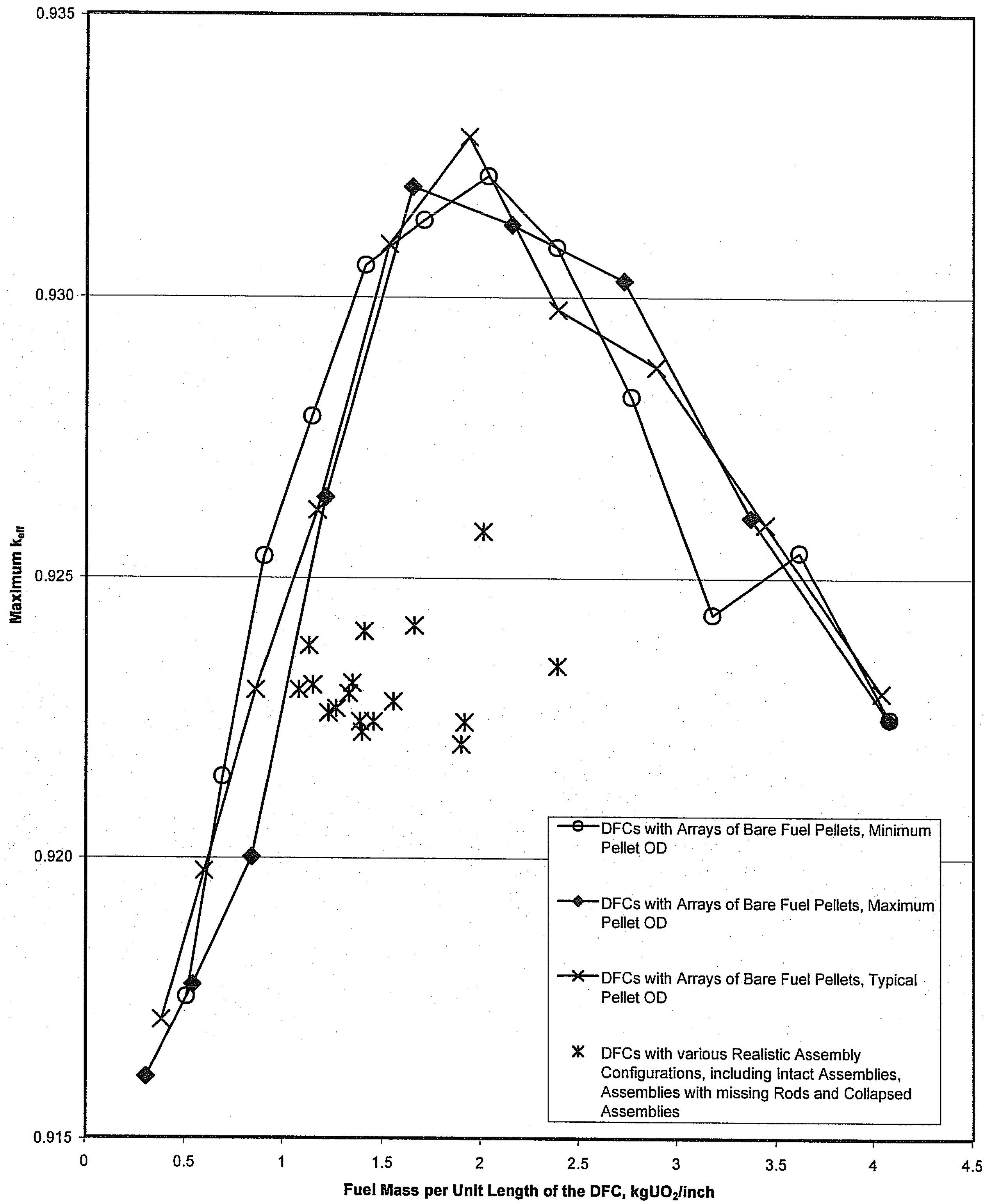

Figure 6.4.13: Maximum keff for the MPC-68 with Generic BWR Damaged Fuel Container, Initial Enrichment of 4.0 wt% for Damaged and 3.7 wt% for Intact Fuel.

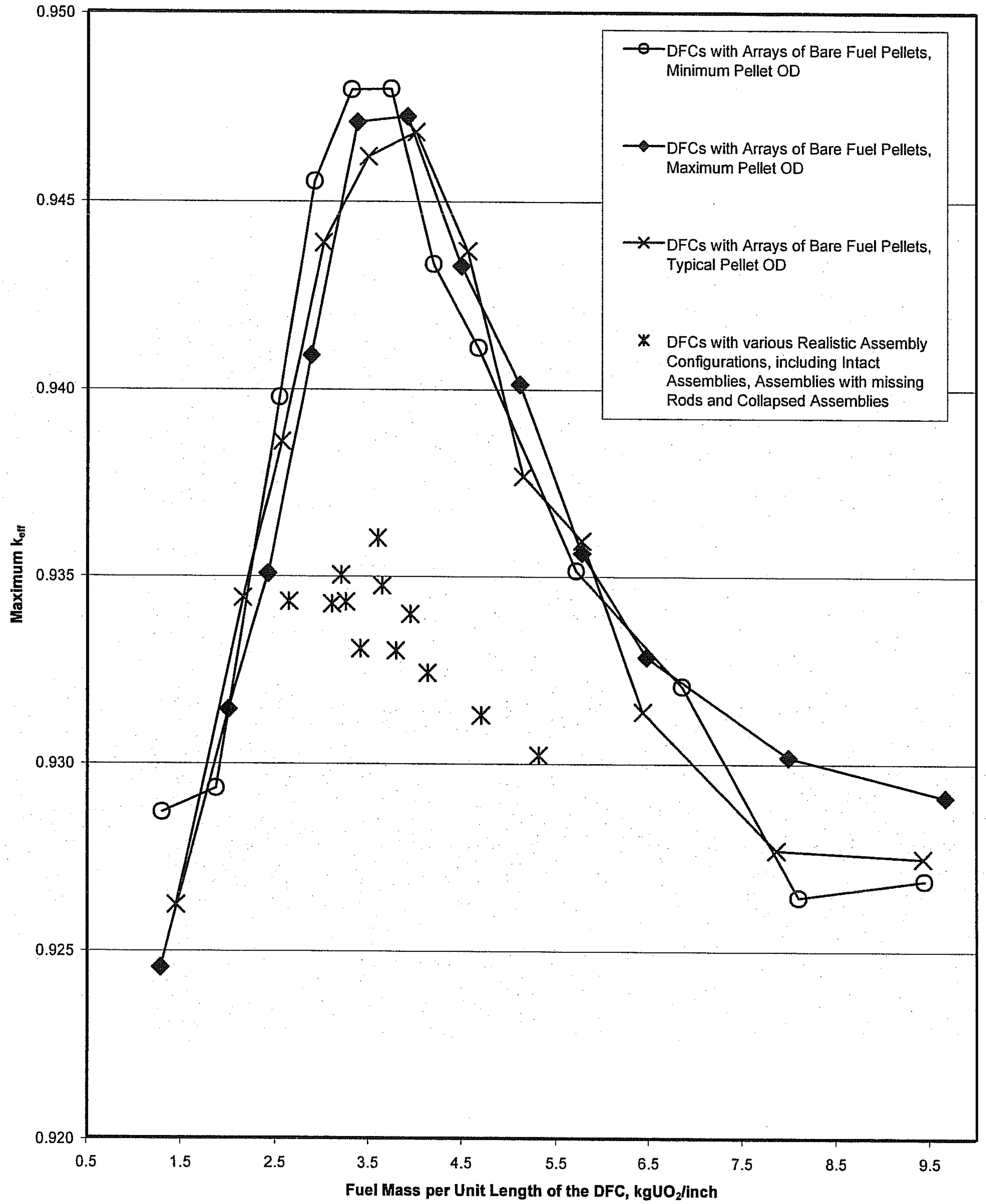

Figure 6.4.14: Maximum keff for the MPC-24E with Generic PWR Damaged Fuel Container, Initial Enrichment of 4.0 wt% for Damaged and Intact Fuel.

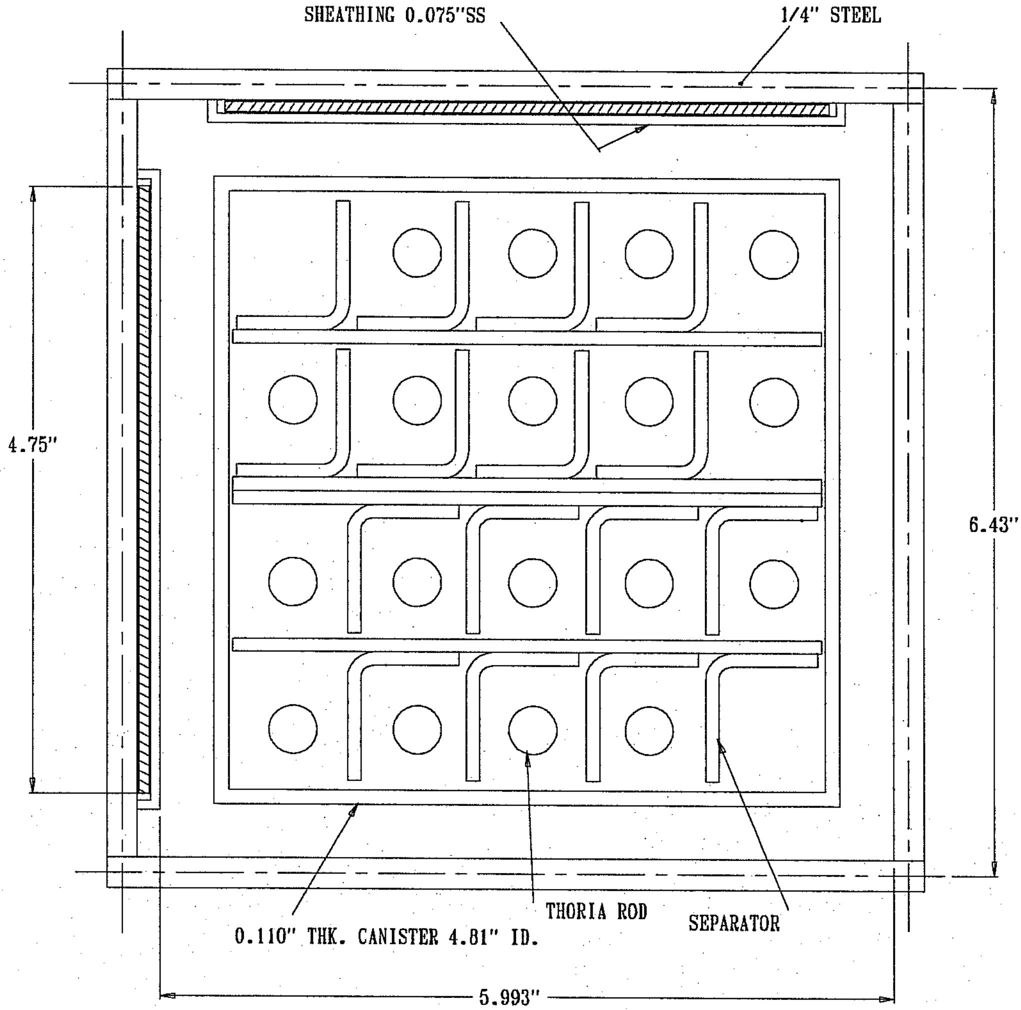

FIGURE 6.4.15; THORIA ROD CANISTER (PLANAR CROSS-SECTION) WITH 18 THORIA RODS IN THE MPC-68 BASKET (SEE CHAPTER 1 FOR TRUE BASKET DIMENSIONS)

Table 6.2.2 (page 3 of 4)
PWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Guide Tubes	Guide Tube OD	Guide Tube ID	Guide Tube Thickness
15x15B Assembly Class											
15x15B01	Zr	0.563	204	0.422	0.0245	0.3660	150	21	0.533	0.499	0.0170
15x15B02	Zr	0.563	204	0.422	0.0245	0.3660	150	21	0.546	0.512	0.0170
15x15B03	Zr	0.563	204	0.422	0.0243	0.3660	150	21	0.533	0.499	0.0170
15x15B04	Zr	0.563	204	0.422	0.0243	0.3659	150	21	0.545	0.515	0.0150
15x15B05	Zr	0.563	204	0.422	0.0242	0.3659	150	21	0.545	0.515	0.0150
15x15B06	Zr	0.563	204	0.420	0.0240	0.3671	150	21	0.544	0.514	0.0150
15x15C Assembly Class											
15x15C01	Zr	0.563	204	0.424	0.0300	0.3570	150	21	0.544	0.493	0.0255
15x15C02	Zr	0.563	204	0.424	0.0300	0.3570	150	21	0.544	0.511	0.0165
15x15C03	Zr	0.563	204	0.424	0.0300	0.3565	150	21	0.544	0.511	0.0165
15x15C04	Zr	0.563	204	0.417	0.0300	0.3565	150	21	0.544	0.511	0.0165
15x15D Assembly Class											
15x15D01	Zr	0.568	208	0.430	0.0265	0.3690	150	17	0.530	0.498	0.0160
15x15D02	Zr	0.568	208	0.430	0.0265	0.3686	150	17	0.530	0.498	0.0160
15x15D03	Zr	0.568	208	0.430	0.0265	0.3700	150	17	0.530	0.499	0.0155
15x15D04	Zr	0.568	208	0.430	0.0250	0.3735	150	17	0.530	0.500	0.0150
15x15E Assembly Class											
15x15E01	Zr	0.568	208	0.428	0.0245	0.3707	150	17	0.528	0.500	0.0140
15x15F Assembly Class											
15x15F01	Zr	0.568	208	0.428	0.0230	0.3742	150	17	0.528	0.500	0.0140

Table 6.2.2 (page 4 of 4)
PWR FUEL CHARACTERISTICS AND ASSEMBLY CLASS DEFINITIONS
(all dimensions are in inches)

Fuel Assembly Designation	Clad Material	Pitch	Number of Fuel Rods	Cladding OD	Cladding Thickness	Pellet Diameter	Active Fuel Length	Number of Guide Tubes	Guide Tube OD	Guide Tube ID	Guide Tube Thickness
15x15G Assembly Class											
15x15G01	SS	0.563	204	0.422	0.0165	0.3825	144	21	0.543	0.514	0.0145
15x15H Assembly Class											
15x15H01	Zr	0.568	208	0.414	0.0220	0.3622	150	17	0.528	0.500	0.0140
16x16A Assembly Class											
16x16A01	Zr	0.506	236	0.382	0.0250	0.3255	150	5	0.980	0.900	0.0400
16x16A02	Zr	0.506	236	0.382	0.0250	0.3250	150	5	0.980	0.900	0.0400
17x17A Assembly Class											
17x17A01	Zr	0.496	264	0.360	0.0225	0.3088	150	25	0.474	0.442	0.0160
17x17A02	Zr	0.496	264	0.360	0.0250	0.3030	150	25	0.480	0.448	0.0160
17x17B Assembly Class											
17x17B01	Zr	0.496	264	0.374	0.0225	0.3225	150	25	0.482	0.450	0.0160
17x17B02	Zr	0.496	264	0.374	0.0225	0.3225	150	25	0.474	0.442	0.0160
17x17B03	Zr	0.496	264	0.376	0.0240	0.3215	150	25	0.480	0.448	0.0160
17x17B04	Zr	0.496	264	0.372	0.0205	0.3232	150	25	0.427	0.399	0.0140
17x17B05	Zr	0.496	264	0.374	0.0240	0.3195	150	25	0.482	0.450	0.0160
17x17B06	Zr	0.496	264	0.372	0.0205	0.3232	150	25	0.480	0.452	0.0140
17x17C Assembly Class											
17x17C01	Zr	0.502	264	0.379	0.0240	0.3232	150	25	0.472	0.432	0.0200
17x17C02	Zr	0.502	264	0.377	0.0220	0.3252	150	25	0.472	0.432	0.0200

Table 6.2.3
REACTIVITY EFFECT OF ASSEMBLY PARAMETER VARIATIONS for BWR Fuel in the MPC-68
(all dimensions are in inches)

Fuel Assembly/ Parameter Variation	reactivity effect	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	water rod thickness	channel thickness
8x8C04 (GE8x8R)	reference	0.9307	0.0007	0.483	0.419	0.032	0.410	0.030	0.100
increase pellet OD (+0.001)	+0.0005	0.9312	0.0007	0.483	0.419	0.032	0.411	0.030	0.100
decrease pellet OD (-0.001)	-0.0008	0.9299	0.0009	0.483	0.419	0.032	0.409	0.030	0.100
increase clad ID (+0.004)	+0.0027	0.9334	0.0007	0.483	0.423	0.030	0.410	0.030	0.100
decrease clad ID (-0.004)	-0.0034	0.9273	0.0007	0.483	0.415	0.034	0.410	0.030	0.100
increase clad OD (+0.004)	-0.0041	0.9266	0.0008	0.487	0.419	0.034	0.410	0.030	0.100
decrease clad OD (-0.004)	+0.0023	0.9330	0.0007	0.479	0.419	0.030	0.410	0.030	0.100
increase water rod thickness (+0.015)	-0.0019	0.9288	0.0008	0.483	0.419	0.032	0.410	0.045	0.100
decrease water rod thickness (-0.015)	+0.0001	0.9308	0.0008	0.483	0.419	0.032	0.410	0.015	0.100
remove water rods (i.e., replace the water rod tubes with water)	+0.0021	0.9328	0.0008	0.483	0.419	0.032	0.410	0.000	0.100
remove channel	-0.0039	0.9268	0.0009	0.483	0.419	0.032	0.410	0.030	0.000
increase channel thickness (+0.020)	+0.0005	0.9312	0.0007	0.483	0.419	0.032	0.410	0.030	0.120
reduced active length (120 Inches)	-0.0007	0.9300	0.0007	0.483	0.419	0.032	0.410	0.030	0.100
reduced active length (90 Inches)	-0.0043	0.9264	0.0007	0.483	0.419	0.032	0.410	0.030	0.100

Table 6.2.4
REACTIVITY EFFECT OF ASSEMBLY PARAMETER VARIATIONS in PWR Fuel in the MPC 24 with 400ppm soluble boron concentration
(all dimensions are in inches)

Fuel Assembly/ Parameter Variation	reactivity effect	calculated k_{eff}	standard deviation	cladding OD	Cladding ID	cladding thickness	pellet OD	guide tube thickness
15x15F (15x15 B&W, 5.0% E)	reference	0.9271	0.0005	0.4280	0.3820	0.0230	0.3742	0.0140
increase pellet OD (+0.001)	-0.0008	0.9263	0.0004	0.4280	0.3820	0.0230	0.3752	0.0140
decrease pellet OD (-0.001)	-0.0002	0.9269	0.0005	0.4280	0.3820	0.0230	0.3732	0.0140
increase clad ID (+0.004)	+0.0040	0.9311	0.0005	0.4280	0.3860	0.0210	0.3742	0.0140
decrease clad ID (-0.004)	-0.0033	0.9238	0.0004	0.4280	0.3780	0.0250	0.3742	0.0140
increase clad OD (+0.004)	-0.0042	0.9229	0.0004	0.4320	0.3820	0.0250	0.3742	0.0140
decrease clad OD (-0.004)	+0.0035	0.9306	0.0005	0.4240	0.3820	0.0210	0.3742	0.0140
increase guide tube thickness (+0.004)	-0.0008	0.9263	0.0005	0.4280	0.3820	0.0230	0.3742	0.0180
decrease guide tube thickness (-0.004)	+0.0006	0.9277	0.0004	0.4280	0.3820	0.0230	0.3742	0.0100
remove guide tubes (i.e., replace the guide tubes with water)	+0.0028	0.9299	0.0004	0.4280	0.3820	0.0230	0.3742	0.000
voided guide tubes	-0.0318	0.8953	0.0005	0.4280	0.3820	0.0230	0.3742	0.0140

Table 6.2.5
REACTIVITY EFFECT OF ASSEMBLY PARAMETER VARIATIONS in PWR Fuel in the MPC-32 with 2600ppm soluble boron concentration
(all dimensions are in inches)

Fuel Assembly/ Parameter Variation	reactivity effect	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	guide tube thickness
15x15F (15x15 B&W, 5.0% E)	reference	0.9389	0.0004	0.4280	0.3820	0.0230	0.3742	0.0140
increase pellet OD (+0.001)	+0.0019	0.9408	0.0004	0.4280	0.3820	0.0230	0.3752	0.0140
decrease pellet OD (-0.001)	0.0000	0.9389	0.0004	0.4280	0.3820	0.0230	0.3732	0.0140
increase clad ID (+0.004)	+0.0015	0.9404	0.0004	0.4280	0.3860	0.0210	0.3742	0.0140
decrease clad ID (-0.004)	-0.0015	0.9374	0.0004	0.4280	0.3780	0.0250	0.3742	0.0140
increase clad OD (+0.004)	-0.0002	0.9387	0.0004	0.4320	0.3820	0.0250	0.3742	0.0140
decrease clad OD (-0.004)	+0.0007	0.9397	0.0004	0.4240	0.3820	0.0210	0.3742	0.0140
increase guide tube thickness (+0.004)	-0.0003	0.9387	0.0004	0.4280	0.3820	0.0230	0.3742	0.0180
decrease guide tube thickness (-0.004)	-0.0005	0.9384	0.0004	0.4280	0.3820	0.0230	0.3742	0.0100
remove guide tubes (i.e., replace the guide tubes with water)	-0.0005	0.9385	0.0004	0.4280	0.3820	0.0230	0.3742	0.000
voided guide tubes	+0.0039	0.9428	0.0004	0.4280	0.3820	0.0230	0.3742	0.0140

Table 6.2. 6
MAXIMUM K_{EFF} VALUES FOR THE 14X14A ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

14x14A (4.6% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.02 g/cm^2) 179 fuel rods, 17 guide tubes, pitch=0.556, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
14x14A01	0.9295	0.9252	0.0008	0.400	0.3514	0.0243	0.3444	150	0.017
14x14A02	0.9286	0.9242	0.0008	0.400	0.3514	0.0243	0.3444	150	0.019
14x14A03	0.9296	0.9253	0.0008	0.400	0.3514	0.0243	0.3444	150	0.017
Dimensions Listed for Authorized Contents				0.400 (min.)	0.3514 (max.)		0.3444 (max.)	150 (max.)	0.017 (min.)
bounding dimensions (14x14A03)	0.9296	0.9253	0.0008	0.400	0.3514	0.0243	0.3444	150	0.017

Table 6.2.7
MAXIMUM K_{EFF} VALUES FOR THE 14X14B ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

14x14B (4.6% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.02 g/cm^2) 179 fuel rods, 17 guide tubes, pitch=0.556, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
14x14B01	0.9159	0.9117	0.0007	0.422	0.3734	0.0243	0.3659	150	0.017
14x14B02	0.9169	0.9126	0.0008	0.417	0.3580	0.0295	0.3505	150	0.017
14x14B03	0.9110	0.9065	0.0009	0.424	0.3640	0.0300	0.3565	150	0.017
14x14B04	0.9084	0.9039	0.0009	0.426	0.3640	0.0310	0.3565	150	0.017
Dimensions Listed for Authorized Contents				0.417 (min.)	0.3734 (max.)		0.3659 (max.)	150 (max.)	0.017 (min.)
bounding dimensions (B14x14B01)	0.9228	0.9185	0.0008	0.417	0.3734	0.0218	0.3659	150	0.017

Table 6.2.8
MAXIMUM K_{EFF} VALUES FOR THE 14X14C ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

14x14C (4.6% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.02 g/cm^2) 176 fuel rods, 5 guide tubes, pitch=0.580, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	Cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
14x14C01	0.9258	0.9215	0.0008	0.440	0.3840	0.0280	0.3765	150	0.040
14x14C02	0.9265	0.9222	0.0008	0.440	0.3840	0.0280	0.3770	150	0.040
14x14C03	0.9287	0.9242	0.0009	0.440	0.3880	0.0260	0.3805	150	0.038
Dimensions Listed for Authorized Contents				0.440 (min.)	0.3880 (max.)		0.3805 (max.)	150 (max.)	0.038 (min.)
bounding dimensions (14x14C03)	0.9287	0.9242	0.0009	0.440	0.3880	0.0260	0.3805	150	0.038

Table 6.2.9
MAXIMUM K_{EFF} VALUES FOR THE 14X14D ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

14x14D (4.0% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.02 g/cm^2) 180 fuel rods, 16 guide tubes, pitch=0.556, SS clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	Cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
14x14D01	0.8507	0.8464	0.0008	0.422	0.3890	0.0165	0.3835	144	0.0145
Dimensions Listed for Authorized Contents				0.422 (min.)	0.3890 (max.)		0.3835 (max.)	144 (max.)	0.0145 (min.)

Table 6.2.10
MAXIMUM K_{EFF} VALUES FOR THE 14X14E ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

14x14E (5.0% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.02 g/cm^2) 173 fuel rods, 0 guide tubes, pitch=0.453 and 0.441, SS clad†									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length††	guide tube thickness
14x14E01	0.7598	0.7555	0.0008	0.3415	0.3175 0.2845 0.3015	0.0120 0.0285 0.0200	0.3130 0.2800 0.2970	102	0.0000
14x14E02	0.7627	0.7586	0.0007	0.3415	0.3175	0.0120	0.3130	102	0.0000
14x14E03	0.6952	0.6909	0.0008	0.3415	0.2845	0.0285	0.2800	102	0.0000
Dimensions Listed for Authorized Contents				0.3415 (min.)	0.3175 (max.)		0.3130 (max.)	102 (max.)	0.0000 (min.)
Bounding dimensions (14x14E02)	0.7627	0.7586	0.0007	0.3415	0.3175	0.0120	0.3130	102	0.0000

† This is the IP-1 fuel assembly at Indian Point. This assembly is a 14x14 assembly with 23 fuel rods omitted to allow passage of control rods between assemblies. Fuel rod dimensions are bounding for each of the three types of rods found in the IP-1 fuel assembly.

†† Calculations were conservatively performed for a fuel length of 150 inches.

Table 6.2.11
MAXIMUM K_{EFF} VALUES FOR THE 15X15A ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

15x15A (4.1% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.02 g/cm^2) 204 fuel rods, 21 guide tubes, pitch=0.550, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
15x15A01	0.9204	0.9159	0.0009	0.418	0.3660	0.0260	0.3580	150	0.0165
Dimensions Listed for Authorized Contents				0.418 (min.)	0.3660 (max.)		0.3580 (max.)	150 (max.)	0.0165 (min.)

Table 6.2.12
MAXIMUM K_{EFF} VALUES FOR THE 15X15B ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

15x15B (4.1% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.02 g/cm^2) 204 fuel rods, 21 guide tubes, pitch=0.563, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
15x15B01	0.9369	0.9326	0.0008	0.422	0.3730	0.0245	0.3660	150	0.017
15x15B02	0.9338	0.9295	0.0008	0.422	0.3730	0.0245	0.3660	150	0.017
15x15B03	0.9362	0.9318	0.0008	0.422	0.3734	0.0243	0.3660	150	0.017
15x15B04	0.9370	0.9327	0.0008	0.422	0.3734	0.0243	0.3659	150	0.015
15x15B05	0.9356	0.9313	0.0008	0.422	0.3736	0.0242	0.3659	150	0.015
15x15B06	0.9366	0.9324	0.0007	0.420	0.3720	0.0240	0.3671	150	0.015
Dimensions Listed for Authorized Contents				0.420 (min.)	0.3736 (max.)		0.3671 (max.)	150 (max.)	0.015 (min.)
bounding dimensions (B15x15B01)	0.9388	0.9343	0.0009	0.420	0.3736	0.0232	0.3671	150	0.015

Table 6.2.13
MAXIMUM K_{EFF} VALUES FOR THE 15X15C ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

15x15C (4.1% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.02 g/cm^2) 204 fuel rods, 21 guide tubes, pitch=0.563, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
15x15C01	0.9255	0.9213	0.0007	0.424	0.3640	0.0300	0.3570	150	0.0255
15x15C02	0.9297	0.9255	0.0007	0.424	0.3640	0.0300	0.3570	150	0.0165
15x15C03	0.9297	0.9255	0.0007	0.424	0.3640	0.0300	0.3565	150	0.0165
15x15C04	0.9311	0.9268	0.0008	0.417	0.3570	0.0300	0.3565	150	0.0165
Dimensions Listed for Authorized Contents				0.417 (min.)	0.3640 (max.)		0.3570 (max.)	150 (max.)	0.0165 (min.)
bounding dimensions (B15x15C01)	0.9361	0.9316	0.0009	0.417	0.3640	0.0265	0.3570	150	0.0165

Table 6.2.14
MAXIMUM K_{EFF} VALUES FOR THE 15X15D ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

15x15D (4.1% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.02 g/cm^2) 208 fuel rods, 17 guide tubes, pitch=0.568, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
15x15D01	0.9341	0.9298	0.0008	0.430	0.3770	0.0265	0.3690	150	0.0160
15x15D02	0.9367	0.9324	0.0008	0.430	0.3770	0.0265	0.3686	150	0.0160
15x15D03	0.9354	0.9311	0.0008	0.430	0.3770	0.0265	0.3700	150	0.0155
15x15D04	0.9339	0.9292	0.0010	0.430	0.3800	0.0250	0.3735	150	0.0150
Dimensions Listed for Authorized Contents				0.430 (min.)	0.3800 (max.)		0.3735 (max.)	150 (max.)	0.0150 (min.)
bounding dimensions (15x15D04)	0.9339†	0.9292	0.0010	0.430	0.3800	0.0250	0.3735	150	0.0150

† The k_{eff} value listed for the 15x15D02 case is higher than that for the case with the bounding dimensions. Therefore, the 0.9367 (15x15D02) value is listed in Table 6.1.1 as the maximum.

Table 6.2.15
MAXIMUM K_{EFF} VALUES FOR THE 15X15E ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

15x15E (4.1% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.02 g/cm^2) 208 fuel rods, 17 guide tubes, pitch=0.568, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
15x15E01	0.9368	0.9325	0.0008	0.428	0.3790	0.0245	0.3707	150	0.0140
Dimensions Listed for Authorized Contents				0.428 (min.)	0.3790 (max.)		0.3707 (max.)	150 (max.)	0.0140 (min.)

Table 6.2.16
MAXIMUM K_{EFF} VALUES FOR THE 15X15F ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

15x15F (4.1% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.02 g/cm^2) 208 fuel rods, 17 guide tubes, pitch=0.568, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
15x15F01	0.9395†	0.9350	0.0009	0.428	0.3820	0.0230	0.3742	150	0.0140
Dimensions Listed for Authorized Contents				0.428 (min.)	0.3820 (max.)		0.3742 (max.)	150 (max.)	0.0140 (min.)

† KENO5a verification calculation resulted in a maximum k_{eff} of 0.9383.

Table 6.2.17
MAXIMUM K_{EFF} VALUES FOR THE 15X15G ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

15x15G (4.0% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.02 g/cm^2) 204 fuel rods, 21 guide tubes, pitch=0.563, SS clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
15x15G01	0.8876	0.8833	0.0008	0.422	0.3890	0.0165	0.3825	144	0.0145
Dimensions Listed for Authorized Contents				0.422 (min.)	0.3890 (max.)		0.3825 (max.)	144 (max.)	0.0145 (min.)

Table 6.2.18
MAXIMUM K_{EFF} VALUES FOR THE 15X15H ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

15x15H (3.8% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.02 g/cm^2) 208 fuel rods, 17 guide tubes, pitch=0.568, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
15x15H01	0.9337	0.9292	0.0009	0.414	0.3700	0.0220	0.3622	150	0.0140
Dimensions Listed for Authorized Contents				0.414 (min.)	0.3700 (max.)		0.3622 (max.)	150 (max.)	0.0140 (min.)

Table 6.2.19
MAXIMUM K_{EFF} VALUES FOR THE 16X16A ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

16x16A (4.6% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.02 g/cm^2) 236 fuel rods, 5 guide tubes, pitch=0.506, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
16x16A01	0.9287	0.9244	0.0008	0.382	0.3320	0.0250	0.3255	150	0.0400
16x16A02	0.9263	0.9221	0.0007	0.382	0.3320	0.0250	0.3250	150	0.0400
Dimensions Listed for Authorized Contents				0.382 (min.)	0.3320 (max.)		0.3255 (max.)	150 (max.)	0.0400 (min.)
bounding dimensions (16x16A01)	0.9287	0.9244	0.0008	0.382	0.3320	0.0250	0.3255	150	0.0400

Table 6.2.20
MAXIMUM K_{EFF} VALUES FOR THE 17X17A ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

17x17A (4.0% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.02 g/cm^2) 264 fuel rods, 25 guide tubes, pitch=0.496, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
17x17A01	0.9368	0.9325	0.0008	0.360	0.3150	0.0225	0.3088	150	0.016
17x17A02	0.9329	0.9286	0.0008	0.360	0.3100	0.0250	0.3030	150	0.016
Dimensions Listed for Authorized Contents				0.360 (min.)	0.3150 (max.)		0.3088 (max.)	150 (max.)	0.016 (min.)
bounding dimensions (17x17A01)	0.9368	0.9325	0.0008	0.360	0.3150	0.0225	0.3088	150	0.016

Table 6.2.21
MAXIMUM K_{EFF} VALUES FOR THE 17X17B ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

17x17B (4.0% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.02 g/cm^2) 264 fuel rods, 25 guide tubes, pitch=0.496, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	Cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
17x17B01	0.9288	0.9243	0.0009	0.374	0.3290	0.0225	0.3225	150	0.016
17x17B02	0.9290	0.9247	0.0008	0.374	0.3290	0.0225	0.3225	150	0.016
17x17B03	0.9243	0.9199	0.0008	0.376	0.3280	0.0240	0.3215	150	0.016
17x17B04	0.9324	0.9279	0.0009	0.372	0.3310	0.0205	0.3232	150	0.014
17x17B05	0.9266	0.9222	0.0008	0.374	0.3260	0.0240	0.3195	150	0.016
17x17B06	0.9311	0.9268	0.0008	0.372	0.3310	0.0205	0.3232	150	0.014
Dimensions Listed for Authorized Contents				0.372 (min.)	0.3310 (max.)		0.3232 (max.)	150 (max.)	0.014 (min.)
bounding dimensions (17x17B06)	0.9311†	0.9268	0.0008	0.372	0.3310	0.0205	0.3232	150	0.014

† The k_{eff} value listed for the 17x17B04 case is higher than that for the case with the bounding dimensions. Therefore, the 0.9324 (17x17B04) value is listed in Table 6.1.1 as the maximum.

Table 6.2.22
MAXIMUM K_{EFF} VALUES FOR THE 17X17C ASSEMBLY CLASS IN THE MPC-24
(all dimensions are in inches)

17x17C (4.0% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.02 g/cm^2) 264 fuel rods, 25 guide tubes, pitch=0.502, Zr clad									
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	guide tube thickness
17x17C01	0.9293	0.9250	0.0008	0.379	0.3310	0.0240	0.3232	150	0.020
17x17C02	0.9336	0.9293	0.0008	0.377	0.3330	0.0220	0.3252	150	0.020
Dimensions Listed for Authorized Contents				0.377 (min.)	0.3330 (max.)		0.3252 (max.)	150 (max.)	0.020 (min.)
bounding dimensions (17x17C02)	0.9336	0.9293	0.0008	0.377	0.3330	0.0220	0.3252	150	0.020

Table 6.2.23
MAXIMUM K_{EFF} VALUES FOR THE 7X7B ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF
(all dimensions are in inches)

7x7B (4.2% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 49 fuel rods, 0 water rods, pitch=0.738, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
7x7B01	0.9372	0.9330	0.0007	0.5630	0.4990	0.0320	0.4870	150	n/a	0.080
7x7B02	0.9301	0.9260	0.0007	0.5630	0.4890	0.0370	0.4770	150	n/a	0.102
7x7B03	0.9313	0.9271	0.0008	0.5630	0.4890	0.0370	0.4770	150	n/a	0.080
7x7B04	0.9311	0.9270	0.0007	0.5700	0.4990	0.0355	0.4880	150	n/a	0.080
7x7B05	0.9350	0.9306	0.0008	0.5630	0.4950	0.0340	0.4775	150	n/a	0.080
7x7B06	0.9298	0.9260	0.0006	0.5700	0.4990	0.0355	0.4910	150	n/a	0.080
Dimensions Listed for Authorized Contents				0.5630 (min.)	0.4990 (max.)		0.4910 (max.)	150 (max.)	n/a	0.120 (max.)
bounding dimensions (B7x7B01)	0.9375	0.9332	0.0008	0.5630	0.4990	0.0320	0.4910	150	n/a	0.102
bounding dimensions with 120 mil channel (B7x7B02)	0.9386	0.9344	0.0007	0.5630	0.4990	0.0320	0.4910	150	n/a	0.120

Table 6.2.24
MAXIMUM K_{EFF} VALUES FOR THE 8X8B ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF
(all dimensions are in inches)

8x8B (4.2% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 63 or 64 fuel rods†, 1 or 0 water rods†, pitch† = 0.636-0.642, Zr clad												
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	Fuel rods	Pitch	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
8x8B01	0.9310	0.9265	0.0009	63	0.641	0.4840	0.4140	0.0350	0.4050	150	0.035	0.100
8x8B02	0.9227	0.9185	0.0007	63	0.636	0.4840	0.4140	0.0350	0.4050	150	0.035	0.100
8x8B03	0.9299	0.9257	0.0008	63	0.640	0.4930	0.4250	0.0340	0.4160	150	0.034	0.100
8x8B04	0.9236	0.9194	0.0008	64	0.642	0.5015	0.4295	0.0360	0.4195	150	n/a	0.100
Dimensions Listed for Authorized Contents				63 or 64	0.636-0.642	0.4840 (min.)	0.4295 (max.)		0.4195 (max.)	150 (max.)	0.034	0.120 (max.)
bounding (pitch=0.636) (B8x8B01)	0.9346	0.9301	0.0009	63	0.636	0.4840	0.4295	0.02725	0.4195	150	0.034	0.120
bounding (pitch=0.640) (B8x8B02)	0.9385	0.9343	0.0008	63	0.640	0.4840	0.4295	0.02725	0.4195	150	0.034	0.120
bounding (pitch=0.642) (B8x8B03)	0.9416	0.9375	0.0007	63	0.642	0.4840	0.4295	0.02725	0.4195	150	0.034	0.120

† This assembly class was analyzed and qualified for a small variation in the pitch and a variation in the number of fuel and water rods.

Table 6.2.25
MAXIMUM K_{EFF} VALUES FOR THE 8X8C ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF
(all dimensions are in inches)

8x8C (4.2% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 62 fuel rods, 2 water rods, pitch† = 0.636-0.641, Zr clad											
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	pitch	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
8x8C01	0.9315	0.9273	0.0007	0.641	0.4840	0.4140	0.0350	0.4050	150	0.035	0.100
8x8C02	0.9313	0.9268	0.0009	0.640	0.4830	0.4190	0.0320	0.4100	150	0.030	0.000
8x8C03	0.9329	0.9286	0.0008	0.640	0.4830	0.4190	0.0320	0.4100	150	0.030	0.800
8x8C04	0.9348††	0.9307	0.0007	0.640	0.4830	0.4190	0.0320	0.4100	150	0.030	0.100
8x8C05	0.9353	0.9312	0.0007	0.640	0.4830	0.4190	0.0320	0.4100	150	0.030	0.120
8x8C06	0.9353	0.9312	0.0007	0.640	0.4830	0.4190	0.0320	0.4110	150	0.030	0.100
8x8C07	0.9314	0.9273	0.0007	0.640	0.4830	0.4150	0.0340	0.4100	150	0.030	0.100
8x8C08	0.9339	0.9298	0.0007	0.640	0.4830	0.4190	0.0320	0.4100	150	0.034	0.100
8x8C09	0.9301	0.9260	0.0007	0.640	0.4930	0.4250	0.0340	0.4160	150	0.034	0.100
8x8C10	0.9317	0.9275	0.0008	0.640	0.4830	0.4150	0.0340	0.4100	150	0.030	0.120
8x8C11	0.9328	0.9287	0.0007	0.640	0.4830	0.4150	0.0340	0.4100	150	0.030	0.120
8x8C12	0.9285	0.9242	0.0008	0.636	0.4830	0.4190	0.0320	0.4110	150	0.030	0.120
Dimensions Listed for Authorized Contents				0.636-0.641	0.4830 (min.)	0.4250 (max.)		0.4160 (max.)	150 (max.)	0.000 (min.)	0.120 (max.)
bounding (pitch=0.636) (B8x8C01)	0.9357	0.9313	0.0009	0.636	0.4830	0.4250	0.0290	0.4160	150	0.000	0.120
bounding (pitch=0.640) (B8x8C02)	0.9425	0.9384	0.0007	0.640	0.4830	0.4250	0.0290	0.4160	150	0.000	0.120
Bounding (pitch=0.641) (B8x8C03)	0.9418	0.9375	0.0008	0.641	0.4830	0.4250	0.0290	0.4160	150	0.000	0.120

† This assembly class was analyzed and qualified for a small variation in the pitch.
†† KENO5a verification calculation resulted in a maximum k_{eff} of 0.9343.

Table 6.2.26
MAXIMUM K_{EFF} VALUES FOR THE 8X8D ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF
(all dimensions are in inches)

8x8D (4.2% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 60-61 fuel rods, 1-4 water rods†, pitch=0.640, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	Cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
8x8D01	0.9342	0.9302	0.0006	0.4830	0.4190	0.0320	0.4110	150	0.03/0.025	0.100
8x8D02	0.9325	0.9284	0.0007	0.4830	0.4190	0.0320	0.4110	150	0.030	0.100
8x8D03	0.9351	0.9309	0.0008	0.4830	0.4190	0.0320	0.4110	150	0.025	0.100
8x8D04	0.9338	0.9296	0.0007	0.4830	0.4190	0.0320	0.4110	150	0.040	0.100
8x8D05	0.9339	0.9294	0.0009	0.4830	0.4190	0.0320	0.4100	150	0.040	0.100
8x8D06	0.9365	0.9324	0.0007	0.4830	0.4190	0.0320	0.4110	150	0.040	0.120
8x8D07	0.9341	0.9297	0.0009	0.4830	0.4190	0.0320	0.4110	150	0.040	0.080
8x8D08	0.9376	0.9332	0.0009	0.4830	0.4230	0.0300	0.4140	150	0.030	0.080
Dimensions Listed for Authorized Contents				0.4830 (min.)	0.4230 (max.)		0.4140 (max.)	150 (max.)	0.000 (min.)	0.120 (max.)
bounding dimensions (B8x8D01)	0.9403	0.9363	0.0007	0.4830	0.4230	0.0300	0.4140	150	0.000	0.120

† Fuel assemblies 8x8D01 through 8x8D03 have 4 water rods that are similar in size to the fuel rods, while assemblies 8x8D04 through 8x8D07 have 1 large water rod that takes the place of the 4 water rods. Fuel assembly 8x8D08 contains 3 water rods that are similar in size to the fuel rods.

Table 6.2.27
MAXIMUM K_{EFF} VALUES FOR THE 8X8E ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF
(all dimensions are in inches)

8x8E (4.2% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 59 fuel rods, 5 water rods, pitch=0.640, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
8x8E01	0.9312	0.9270	0.0008	0.4930	0.4250	0.0340	0.4160	150	0.034	0.100
Dimensions Listed for Authorized Contents				0.4930 (min.)	0.4250 (max.)		0.4160 (max.)	150 (max.)	0.034 (min.)	0.100 (max.)

Table 6.2.28
MAXIMUM K_{EFF} VALUES FOR THE 8X8F ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF
(all dimensions are in inches)

8x8F (4.0% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 64 fuel rods, 4 rectangular water cross segments dividing the assembly into four quadrants, pitch=0.609, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
8x8F01	0.9411	0.9366	0.0009	0.4576	0.3996	0.0290	0.3913	150	0.0315	0.055
Dimensions Listed for Authorized Contents				0.4576 (min.)	0.3996 (max.)		0.3913 (max.)	150 (max.)	0.0315 (min.)	0.055 (max.)

Table 6.2.29
MAXIMUM K_{EFF} VALUES FOR THE 9X9A ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF
(all dimensions are in inches)

9x9A (4.2% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 74/66 fuel rods†, 2 water rods, pitch=0.566, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
9x9A01 (axial segment with all rods)	0.9353	0.9310	0.0008	0.4400	0.3840	0.0280	0.3760	150	0.030	0.100
9x9A02 (axial segment with only the full length rods)	0.9388	0.9345	0.0008	0.4400	0.3840	0.0280	0.3760	150	0.030	0.100
9x9A03 (actual three-dimensional representation of all rods)	0.9351	0.9310	0.0007	0.4400	0.3840	0.0280	0.3760	150/90	0.030	0.100
9x9A04 (axial segment with only the full length rods)	0.9396	0.9355	0.0007	0.4400	0.3840	0.0280	0.3760	150	0.030	0.120
Dimensions Listed for Authorized Contents				0.4400 (min.)	0.3840 (max.)		0.3760 (max.)	150 (max.)	0.000 (min.)	0.120 (max.)
bounding dimensions (axial segment with only the full length rods) (B9x9A01)	0.9417	0.9374	0.0008	0.4400	0.3840	0.0280	0.3760	150	0.000	0.120

† This assembly class contains 66 full length rods and 8 partial length rods. In order to eliminate a requirement on the length of the partial length rods, separate calculations were performed for the axial segments with and without the partial length rods.

Table 6.2.30
MAXIMUM K_{EFF} VALUES FOR THE 9X9B ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF
(all dimensions are in inches)

9x9B (4.2% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 72 fuel rods, 1 water rod (square, replacing 9 fuel rods), pitch=0.569 to 0.572†, Zr clad											
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	pitch	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
9x9B01	0.9380	0.9336	0.0008	0.569	0.4330	0.3807	0.0262	0.3737	150	0.0285	0.100
9x9B02	0.9373	0.9329	0.0009	0.569	0.4330	0.3810	0.0260	0.3737	150	0.0285	0.100
9x9B03	0.9417	0.9374	0.0008	0.572	0.4330	0.3810	0.0260	0.3737	150	0.0285	0.100
Dimensions Listed for Authorized Contents				0.572	0.4330 (min.)	0.3810 (max.)		0.3740 (max.)	150 (max.)	0.000 (min.)	0.120 (max.)
bounding dimensions (B9x9B01)	0.9436	0.9394	0.0008	0.572	0.4330	0.3810	0.0260	0.3740††	150	0.000	0.120

† This assembly class was analyzed and qualified for a small variation in the pitch.
†† This value was conservatively defined to be larger than any of the actual pellet diameters.

Table 6.2.31
MAXIMUM K_{EFF} VALUES FOR THE 9X9C ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF
(all dimensions are in inches)

9x9C (4.2% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 80 fuel rods, 1 water rods, pitch=0.572, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
9x9C01	0.9395	0.9352	0.0008	0.4230	0.3640	0.0295	0.3565	150	0.020	0.100
Dimensions Listed for Authorized Contents				0.4230 (min.)	0.3640 (max.)		0.3565 (max.)	150 (max.)	0.020 (min.)	0.100 (max.)

Table 6.2.32
MAXIMUM K_{EFF} VALUES FOR THE 9X9D ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF
(all dimensions are in inches)

9x9D (4.2% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 79 fuel rods, 2 water rods, pitch=0.572, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
9x9D01	0.9394	0.9350	0.0009	0.4240	0.3640	0.0300	0.3565	150	0.0300	0.100
Dimensions Listed for Authorized Contents				0.4240 (min.)	0.3640 (max.)		0.3565 (max.)	150 (max.)	0.0300 (min.)	0.100 (max.)

Table 6.2.33
MAXIMUM K_{EFF} VALUES FOR THE 9X9E ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF

(all dimensions are in inches)

9x9E (4.0% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 76 fuel rods, 5 water rods, pitch=0.572, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
9x9E01	0.9334	0.9293	0.0007	0.4170	0.3640	0.0265	0.3530	150	0.0120	0.120
9x9E02	0.9401	0.9359	0.0008	0.4170 0.4430	0.3640 0.3860	0.0265 0.0285	0.3530 0.3745	150	0.0120	0.120
Dimensions Listed for Authorized Contents†				0.4170 (min.)	0.3640 (max.)		0.3530 (max.)	150 (max.)	0.0120 (min.)	0.120 (max.)
bounding dimensions (9x9E02)	0.9401	0.9359	0.0008	0.4170 0.4430	0.3640 0.3860	0.0265 0.0285	0.3530 0.3745	150	0.0120	0.120

† This fuel assembly, also known as SPC 9x9-5, contains fuel rods with different cladding and pellet diameters which do not bound each other. To be consistent in the way fuel assemblies are listed for the authorized contents, two assembly classes (9x9E and 9x9F) are required to specify this assembly. Each class contains the actual geometry (9x9E02 and 9x9F02), as well as a hypothetical geometry with either all small rods (9x9E01) or all large rods (9x9F01). The Authorized Contents lists the small rod dimensions for class 9x9E and the large rod dimensions for class 9x9F, and a note that both classes are used to qualify the assembly. The analyses demonstrate that all configurations, including the actual geometry, are acceptable.

Table 6.2.34
MAXIMUM K_{EFF} VALUES FOR THE 9X9F ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF

(all dimensions are in inches)

9x9F (4.0% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 76 fuel rods, 5 water rods, pitch=0.572, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
9x9F01	0.9307	0.9265	0.0007	0.4430	0.3860	0.0285	0.3745	150	0.0120	0.120
9x9F02	0.9401	0.9359	0.0008	0.4170 0.4430	0.3640 0.3860	0.0265 0.0285	0.3530 0.3745	150	0.0120	0.120
Dimensions Listed for Authorized Contents†				0.4430 (min.)	0.3860 (max.)		0.3745 (max.)	150 (max.)	0.0120 (min.)	0.120 (max.)
bounding dimensions (9x9F02)	0.9401	0.9359	0.0008	0.4170 0.4430	0.3640 0.3860	0.0265 0.0285	0.3530 0.3745	150	0.0120	0.120

† This fuel assembly, also known as SPC 9x9-5, contains fuel rods with different cladding and pellet diameters which do not bound each other. To be consistent in the way fuel assemblies are listed for the authorized contents, two assembly classes (9x9E and 9x9F) are required to specify this assembly. Each class contains the actual geometry (9x9E02 and 9x9F02), as well as a hypothetical geometry with either all small rods (9x9E01) or all large rods (9x9F01). The Authorized Contents lists the small rod dimensions for class 9x9E and the large rod dimensions for class 9x9F, and a note that both classes are used to qualify the assembly. The analyses demonstrate that all configurations, including the actual geometry, are acceptable.

Table 6.2.35
MAXIMUM K_{EFF} VALUES FOR THE 9X9G ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF
(all dimensions are in inches)

9x9G (4.2% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 72 fuel rods, 1 water rod (square, replacing 9 fuel rods), pitch=0.572, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
9x9G01	0.9309	0.9265	0.0008	0.4240	0.3640	0.0300	0.3565	150	0.0320	0.120
Dimensions Listed for Authorized Contents				0.4240 (min.)	0.3640 (max.)		0.3565 (max.)	150 (max.)	0.0320 (min.)	0.120 (max.)

Table 6.2.36
MAXIMUM K_{EFF} VALUES FOR THE 10X10A ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF

(all dimensions are in inches)

10x10A (4.2% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 92/78 fuel rods†, 2 water rods, pitch=0.510, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
10x10A01 (axial segment with all rods)	0.9377	0.9335	0.0008	0.4040	0.3520	0.0260	0.3450	155	0.030	0.100
10x10A02 (axial segment with only the full length rods)	0.9426	0.9386	0.0007	0.4040	0.3520	0.0260	0.3450	155	0.030	0.100
10x10A03 (actual three-dimensional representation of all rods)	0.9396	0.9356	0.0007	0.4040	0.3520	0.0260	0.3450	155/90	0.030	0.100
Dimensions Listed for Authorized Contents				0.4040 (min.)	0.3520 (max.)		0.3455 (max.)	150†† (max.)	0.030 (min.)	0.120 (max.)
bounding dimensions (axial segment with only the full length rods) (B10x10A01)	0.9457†††	0.9414	0.0008	0.4040	0.3520	0.0260	0.3455‡	155	0.030	0.120

† This assembly class contains 78 full-length rods and 14 partial-length rods. In order to eliminate the requirement on the length of the partial length rods, separate calculations were performed for axial segments with and without the partial length rods.

†† Although the analysis qualifies this assembly for a maximum active fuel length of 155 inches, the specification for the authorized contents limits the active fuel length to 150 inches. This is due to the fact that the fixed neutron absorber panels are 156 inches in length.

††† KENO5a verification calculation resulted in a maximum k_{eff} of 0.9453.

‡ This value was conservatively defined to be larger than any of the actual pellet diameters.

Table 6.2.37
MAXIMUM K_{EFF} VALUES FOR THE 10X10B ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF
(all dimensions are in inches)

10x10B (4.2% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 91/83 fuel rods†, 1 water rods (square, replacing 9 fuel rods), pitch=0.510, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
10x10B01 (axial segment with all rods)	0.9384	0.9341	0.0008	0.3957	0.3480	0.0239	0.3413	155	0.0285	0.100
10x10B02 (axial segment with only the full length rods)	0.9416	0.9373	0.0008	0.3957	0.3480	0.0239	0.3413	155	0.0285	0.100
10x10B03 (actual three-dimensional representation of all rods)	0.9375	0.9334	0.0007	0.3957	0.3480	0.0239	0.3413	155/90	0.0285	0.100
Dimensions Listed for Authorized Contents				0.3957 (min.)	0.3480 (max.)		0.3420 (max.)	150†† (max.)	0.000 (min.)	0.120 (max.)
bounding dimensions (axial segment with only the full length rods) (B10x10B01)	0.9436	0.9395	0.0007	0.3957	0.3480	0.0239	0.3420†††	155	0.000	0.120

† This assembly class contains 83 full length rods and 8 partial length rods. In order to eliminate a requirement on the length of the partial length rods, separate calculations were performed for the axial segments with and without the partial length rods.

†† Although the analysis qualifies this assembly for a maximum active fuel length of 155 inches, the specification for the authorized contents limits the active fuel length to 150 inches. This is due to the fact that the fixed neutron absorber panels are 156 inches in length.

††† This value was conservatively defined to be larger than any of the actual pellet diameters.

Table 6.2.38
MAXIMUM K_{EFF} VALUES FOR THE 10X10C ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF

(all dimensions are in inches)

10x10C (4.2% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 96 fuel rods, 5 water rods (1 center diamond and 4 rectangular), pitch=0.488, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
10x10C01	0.9433	0.9392	0.0007	0.3780	0.3294	0.0243	0.3224	150	0.031	0.055
Dimensions Listed for Authorized Contents				0.3780 (min.)	0.3294 (max.)		0.3224 (max.)	150 (max.)	0.031 (min.)	0.055 (max.)

Table 6.2.39
MAXIMUM K_{EFF} VALUES FOR THE 10X10D ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF

(all dimensions are in inches)

10x10D (4.0% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 100 fuel rods, 0 water rods, pitch=0.565, SS clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
10x10D01	0.9376	0.9333	0.0008	0.3960	0.3560	0.0200	0.350	83	n/a	0.080
Dimensions Listed for Authorized Contents				0.3960 (min.)	0.3560 (max.)		0.350 (max.)	83 (max.)	n/a	0.080 (max.)

Table 6.2.40
MAXIMUM K_{EFF} VALUES FOR THE 10X10E ASSEMBLY CLASS IN THE MPC-68 and MPC-68FF

(all dimensions are in inches)

10x10E (4.0% Enrichment, fixed neutron absorber ^{10}B minimum loading of 0.0279 g/cm^2) 96 fuel rods, 4 water rods, pitch=0.557, SS clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
10x10E01	0.9185	0.9144	0.0007	0.3940	0.3500	0.0220	0.3430	83	0.022	0.080
Dimensions Listed for Authorized Contents				0.3940 (min.)	0.3500 (max.)		0.3430 (max.)	83 (max.)	0.022 (min.)	0.080 (max.)

Table 6.2.41
MAXIMUM K_{EFF} VALUES FOR THE 6X6A ASSEMBLY CLASS IN THE MPC-68F and MPC-68FF
(all dimensions are in inches)

6x6A (3.0% Enrichment†, fixed neutron absorber ^{10}B minimum loading of 0.0067 g/cm^2) 35 or 36 fuel rods††, 1 or 0 water rods††, pitch††=0.694 to 0.710, Zr clad												
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	pitch	fuel rods	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
6x6A01	0.7539	0.7498	0.0007	0.694	36	0.5645	0.4945	0.0350	0.4940	110	n/a	0.060
6x6A02	0.7517	0.7476	0.0007	0.694	36	0.5645	0.4925	0.0360	0.4820	110	n/a	0.060
6x6A03	0.7545	0.7501	0.0008	0.694	36	0.5645	0.4945	0.0350	0.4820	110	n/a	0.060
6x6A04	0.7537	0.7494	0.0008	0.694	36	0.5550	0.4850	0.0350	0.4820	110	n/a	0.060
6x6A05	0.7555	0.7512	0.0008	0.696	36	0.5625	0.4925	0.0350	0.4820	110	n/a	0.060
6x6A06	0.7618	0.7576	0.0008	0.696	35	0.5625	0.4925	0.0350	0.4820	110	0.0	0.060
6x6A07	0.7588	0.7550	0.0005	0.700	36	0.5555	0.4850	0.03525	0.4780	110	n/a	0.060
6x6A08	0.7808	0.7766	0.0007	0.710	36	0.5625	0.5105	0.0260	0.4980	110	n/a	0.060
Dimensions Listed for Authorized Contents				0.710 (max.)	35 or 36	0.5550 (min.)	0.5105 (max.)	0.02225	0.4980 (max.)	120 (max.)	0.0	0.060 (max.)
bounding dimensions (B6x6A01)	0.7727	0.7685	0.0007	0.694	35	0.5550	0.5105	0.02225	0.4980	120	0.0	0.060
bounding dimensions (B6x6A02)	0.7782	0.7738	0.0008	0.700	35	0.5550	0.5105	0.02225	0.4980	120	0.0	0.060
bounding dimensions (B6x6A03)	0.7888	0.7846	0.0007	0.710	35	0.5550	0.5105	0.02225	0.4980	120	0.0	0.060

† Although the calculations were performed for 3.0%, the enrichment is limited in the specification for the authorized contents to 2.7%.
†† This assembly class was analyzed and qualified for a small variation in the pitch and a variation in the number of fuel and water rods.

Table 6.2.42
MAXIMUM K_{EFF} VALUES FOR THE 6X6B ASSEMBLY CLASS IN THE MPC-68F and MPC-68FF
(all dimensions are in inches)

6x6B (3.0% Enrichment†, fixed neutron absorber ^{10}B minimum loading of 0.0067 g/cm^2) 35 or 36 fuel rods†† (up to 9 MOX rods), 1 or 0 water rods††, pitch††=0.694 to 0.710, Zr clad												
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	pitch	fuel rods	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
6x6B01	0.7604	0.7563	0.0007	0.694	36	0.5645	0.4945	0.0350	0.4820	110	n/a	0.060
6x6B02	0.7618	0.7577	0.0007	0.694	36	0.5625	0.4925	0.0350	0.4820	110	n/a	0.060
6x6B03	0.7619	0.7578	0.0007	0.696	36	0.5625	0.4925	0.0350	0.4820	110	n/a	0.060
6x6B04	0.7686	0.7644	0.0008	0.696	35	0.5625	0.4925	0.0350	0.4820	110	0.0	0.060
6x6B05	0.7824	0.7785	0.0006	0.710	35	0.5625	0.4925	0.0350	0.4820	110	0.0	0.060
Dimensions Listed for Authorized Contents				0.710 (max.)	35 or 36	0.5625 (min.)	0.4945 (max.)		0.4820 (max.)	120 (max.)	0.0	0.060 (max.)
bounding dimensions (B6x6B01)	0.7822†††	0.7783	0.0006	0.710	35	0.5625	0.4945	0.0340	0.4820	120	0.0	0.060

Note:

1. These assemblies contain up to 9 MOX pins. The composition of the MOX fuel pins is given in Table 6.3.4.

† The ^{235}U enrichment of the MOX and UO_2 pins is assumed to be 0.711% and 3.0%, respectively.

†† This assembly class was analyzed and qualified for a small variation in the pitch and a variation in the number of fuel and water rods.

††† The k_{eff} value listed for the 6x6B05 case is slightly higher than that for the case with the bounding dimensions. However, the difference (0.0002) is well within the statistical uncertainties, and thus, the two values are statistically equivalent (within 1σ). Therefore, the 0.7824 value is listed in Tables 6.1.7 and 6.1.8 as the maximum.

Table 6.2.43
MAXIMUM K_{EFF} VALUES FOR THE 6X6C ASSEMBLY CLASS IN THE MPC-68F and MPC-68FF

(all dimensions are in inches)

6x6C (3.0% Enrichment†, fixed neutron absorber ^{10}B minimum loading of 0.0067 g/cm^2) 36 fuel rods, 0 water rods, pitch=0.740, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
6x6C01	0.8021	0.7980	0.0007	0.5630	0.4990	0.0320	0.4880	77.5	n/a	0.060
Dimensions Listed for Authorized Contents				0.5630 (min.)	0.4990 (max.)		0.4880 (max.)	77.5 (max.)	n/a	0.060 (max.)

† Although the calculations were performed for 3.0%, the enrichment is limited in the specification for the authorized contents to 2.7%.

Table 6.2.44
MAXIMUM K_{EFF} VALUES FOR THE 7X7A ASSEMBLY CLASS IN THE MPC-68F and MPC-68FF

(all dimensions are in inches)

7x7A (3.0% Enrichment†, fixed neutron absorber ^{10}B minimum loading of 0.0067 g/cm^2) 49 fuel rods, 0 water rods, pitch=0.631, Zr clad										
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
7x7A01	0.7974	0.7932	0.0008	0.4860	0.4204	0.0328	0.4110	80	n/a	0.060
Dimensions Listed for Authorized Contents				0.4860 (min.)	0.4204 (max.)		0.4110 (max.)	80 (max.)	n/a	0.060 (max.)

† Although the calculations were performed for 3.0%, the enrichment is limited in the specification for the authorized contents to 2.7%.

Table 6.2.45
MAXIMUM K_{EFF} VALUES FOR THE 8X8A ASSEMBLY CLASS IN THE MPC-68F and MPC-68FF

(all dimensions are in inches)

8x8A (3.0% Enrichment†, fixed neutron absorber ^{10}B minimum loading of 0.0067 g/cm^2) 63 or 64 fuel rods††, 0 water rods, pitch=0.523, Zr clad											
Fuel Assembly Designation	maximum k_{eff}	calculated k_{eff}	standard deviation	fuel rods	cladding OD	cladding ID	cladding thickness	pellet OD	fuel length	water rod thickness	channel thickness
8x8A01	0.7685	0.7644	0.0007	64	0.4120	0.3620	0.0250	0.3580	110	n/a	0.100
8x8A02	0.7697	0.7656	0.0007	63	0.4120	0.3620	0.0250	0.3580	120	n/a	0.100
Dimensions Listed for Authorized Contents				63	0.4120 (min.)	0.3620 (max.)		0.3580 (max.)	120 (max.)	n/a	0.100 (max.)
bounding dimensions (8x8A02)	0.7697	0.7656	0.0007	63	0.4120	0.3620	0.0250	0.3580	120	n/a	0.100

† Although the calculations were performed for 3.0%, the enrichment is limited in the specification for the authorized contents to 2.7%.
†† This assembly class was analyzed and qualified for a variation in the number of fuel rods.

Table 6.2.46

SPECIFICATION OF THE THORIA ROD CANISTER AND THE THORIA RODS

Canister ID	4.81"
Canister Wall Thickness	0.11"
Separator Assembly Plates Thickness	0.11"
Cladding OD	0.412"
Cladding ID	0.362"
Pellet OD	0.358"
Active Length	110.5"
Fuel Composition	1.8% UO_2 and 98.2% ThO_2
Initial Enrichment	93.5 wt% ^{235}U for 1.8% of the fuel
Maximum k_{eff}	0.1813
Calculated k_{eff}	0.1779
Standard Deviation	0.0004

6.3 MODEL SPECIFICATION

6.3.1 Description of Calculational Model

Figures 6.3.1, 6.3.1.a, 6.3.2 and 6.3.3 show representative horizontal cross sections of the four types of cells used in the calculations, and Figures 6.3.4 through 6.3.6 illustrate the basket configurations used. Four different MPC fuel basket designs were evaluated as follows:

- a 24 PWR assembly basket
- an optimized 24 PWR assembly basket (24E / 24EF)
- a 32 PWR assembly basket
- a 68 BWR assembly basket.

For all four basket designs, the same techniques and the same level of detail are used in the calculational models.

Full three-dimensional calculations were used, assuming the axial configuration shown in Figure 6.3.7. Although the fixed neutron absorber panels are 156 inches in length, which is much longer than the active fuel length (maximum of 150 inches), they are assumed equal to or less than the active fuel length in the calculations. As shown on the Drawings in Section 1.5, 16 of the 24 periphery fixed neutron absorber panels on the MPC-24 and MPC-24E/EF have reduced width (i.e., 6.25 inches wide as opposed to 7.5 inches). However, the calculational models for these baskets conservatively assume all of the periphery fixed neutron absorber panels are 6.25 inches in width. Note that Figures 6.3.1 through 6.3.3 show Boral as the fixed neutron absorber. The effect of using Metamic as fixed neutron absorber is discussed in Subsection 6.4.11.

The off-normal and accident conditions defined in Chapter 2 and considered in Chapter 11 have no adverse effect on the design conditions important to criticality safety (see Subsection 6.4.2.5), and thus from a criticality standpoint, the normal, off-normal, and accident conditions are identical and do not require individual models.

The calculational model explicitly defines the fuel rods and cladding, the guide tubes (or water rods for BWR assemblies), the water-gaps and fixed neutron absorber panels on the stainless steel walls of the storage cells. Under the conditions of storage, when the MPC is dry, the resultant reactivity with the design basis fuel is very low ($k_{eff} < 0.52$). For the flooded condition (loading and unloading), pure, unborated water was assumed to be present in the fuel rod pellet-to-clad gaps. Appendix 6.D provides sample input files for two of the MPC basket designs (MPC-68 and MPC-24) in the HI-STORM 100 System.

The water thickness above and below the fuel is intentionally maintained less than or equal to the actual water thickness. This assures that any positive reactivity effect of the steel in the MPC is conservatively included. Furthermore, the water above and below the fuel is modeled as unborated water, even when borated water is present in the fuel region.

As indicated in Figures 6.3.1 through 6.3.3 and in Tables 6.3.1 and 6.3.2, calculations were made with dimensions assumed to be at their most conservative value with respect to criticality. CASMO-3 and MCNP4a were used to determine the direction of the manufacturing tolerances, which produced the most adverse effect on criticality. After the directional effect (positive effect with an increase in reactivity; or negative effect with a decrease in reactivity) of the manufacturing tolerances was determined, the criticality analyses were performed using the worst case tolerances in the direction which would increase reactivity.

CASMO-3 was used for one of each of the two principal basket designs, i.e. for the flux trap design MPC-24 and for the non-fluxtrap design MPC-68. The effects are shown in Table 6.3.1 which also identifies the approximate magnitude of the tolerances on reactivity. Generally, the conclusions in Table 6.3.1 are directly applicable to the MPC-24E/EF and the MPC-32. Exceptions are the conclusions for the water temperature and void percentage, which are not directly applicable to the MPC-32 due to the presence of high soluble boron concentrations in this canister. This condition is addressed in Section 6.4.2.1 where the optimum moderation is determined for the MPC-32.

Additionally, MCNP4a calculations are performed to evaluate the tolerances of the various basket dimensions of the MPC-68, MPC-24 and MPC-32 in further detail. The various basket dimensions are inter-dependent, and therefore cannot be individually varied (i.e., reduction in one parameter requires a corresponding reduction or increase in another parameter). Thus, it is not possible to determine the reactivity effect of each individual dimensional tolerance separately. However, it is possible to determine the reactivity effect of the dimensional tolerances by evaluating the various possible dimensional combinations. To this end, an evaluation of the various possible dimensional combinations was performed using MCNP4a. Calculated k_{eff} results (which do not include the bias, uncertainties, or calculational statistics), along with the actual dimensions, for a number of dimensional combinations are shown in Table 6.3.2 for the reference PWR and BWR assemblies. Each of the basket dimensions are evaluated for their minimum, nominal and maximum values from the Drawings of section 1.5. For PWR MPC designs, the reactivity effect of tolerances with soluble boron present in the water is additionally determined. Due to the close similarity between the MPC-24 and MPC-24E, the basket dimensions are only evaluated for the MPC-24, and the same dimensional assumptions are applied to both MPC designs.

Based on the MCNP4a and CASMO-3 calculations, the conservative dimensional assumptions listed in Table 6.3.3 were determined. Because the reactivity effect (positive or negative) of the manufacturing tolerances are not assembly dependent, these dimensional assumptions were employed for the criticality analyses.

As demonstrated in this section, design parameters important to criticality safety are: fuel enrichment, the inherent geometry of the fuel basket structure, the fixed neutron absorbing panels and the soluble boron concentration in the water during loading/unloading operations. As shown in Chapter 11, none of these parameters are affected during any of the design basis off-normal or accident conditions involving handling, packaging, transfer or storage.

The MPC-32 criticality model uses a sheathing thickness of 0.075 inches, whereas the actual MPC-32 design uses a sheathing thickness of 0.035 inches. For the minimum cell pitch of 9.158 inches, the thicker sheathing results in a slightly smaller cell ID of 8.69 inches (minimum), compared to 8.73 inches (minimum) for the thinner sheathing. To demonstrate that the dimensions used in the criticality model are acceptable and conservative, calculations were performed for both sheathing thicknesses and the results are compared in Table 6.3.5. To bound various soluble boron levels, two comparisons were performed. The first comparison uses the bounding case for the MPC-32 (see Table 6.1.6), which is for assembly class 15x15F at 5 wt% ^{235}U and a soluble boron level of 2600 ppm. To bound lower soluble boron levels, the second comparison uses the same assembly class (15x15F), 0 ppm soluble boron (i.e. pure water), and an arbitrary enrichment of 1.7 wt% ^{235}U. In both comparisons, the results of the 0.075 inch sheathing are slightly higher, i.e. more conservative, than the results for 0.035 inch sheathing, although the differences are within the statistical uncertainties. Using a sheathing thickness of 0.075 inches in the criticality models of the MPC-32 is therefore acceptable, and potentially more conservative, than using the actual value of 0.035 inches. This validates the choice of the dimensional assumptions for the MPC-32 shown in Table 6.3.3, which are used for all further MPC-32 criticality calculations, unless otherwise noted.

6.3.2 Cask Regional Densities

Composition of the various components of the principal designs of the HI-STORM 100 System are listed in Table 6.3.4.

The HI-STORM 100 System is designed such that the fixed neutron absorber will remain effective for a storage period greater than 20 years, and there are no credible means to lose it. A detailed physical description, historical applications, unique characteristics, service experience, and manufacturing quality assurance of fixed neutron absorber are provided in Section 1.2.1.3.1.

The continued efficacy of the fixed neutron absorber is assured by acceptance testing, documented in Section 9.1.5.3, to validate the ^{10}B (poison) concentration in the fixed neutron absorber. To demonstrate that the neutron flux from the irradiated fuel results in a negligible depletion of the poison material over the storage period, an MCNP4a calculation of the number of neutrons absorbed in the ^{10}B was performed. The calculation conservatively assumed a constant neutron source for 50 years equal to the initial source for the design basis fuel, as determined in Section 5.2, and shows that the fraction of ^{10}B atoms destroyed is only 2.6E-09 in 50 years. Thus, the reduction in ^{10}B concentration in the fixed neutron absorber by neutron absorption is negligible. In addition, the results presented in Subsection 3.4.4.3.1.8 demonstrate that the sheathing, which affixes the fixed neutron absorber panel, remains in place during all credible accident conditions, and thus, the fixed neutron absorber panel remains permanently fixed. Therefore, in accordance with 10CFR72.124(b), there is no need to provide a surveillance or monitoring program to verify the continued efficacy of the neutron absorber.

6.3.3 Eccentric Positioning of Assemblies in Fuel Storage Cells

Up to and including Revision 1 of this FSAR, all criticality calculations were performed with fuel assemblies centered in the fuel storage locations since the effect of credible eccentric fuel positioning was judged to be not significant. Starting in Revision 2 of this FSAR, the potential reactivity effect of eccentric positioning of assemblies in the fuel storage locations is accounted for in a conservatively bounding fashion, as described further in this subsection, for all new or changed conditions. The calculations in this subsection serve to determine for which of these conditions the eccentric positioning of assemblies in the fuel storage locations results in a higher maximum k_{eff} value than the centered positioning. For the cases where the eccentric positioning results in a higher maximum k_{eff} value, the eccentric positioning is used for all corresponding cases reported in the summary tables in Section 6.1 and the results tables in Section 6.4. All other calculations throughout this chapter, such as studies to determine bounding fuel dimensions, bounding basket dimensions, or bounding moderation conditions, are performed with assemblies centered in the fuel storage locations.

To conservatively account for eccentric fuel positioning in the fuel storage cells, three different configurations are analyzed, and the results are compared to determine the bounding configuration:

- Cell Center Configuration: All assemblies centered in their fuel storage cell; same configuration that is used in Section 6.2 and Section 6.3.1;
- Basket Center Configuration: All assemblies in the basket are moved as close to the center of the basket as permitted by the basket geometry; and
- Basket Periphery Configuration: All assemblies in the basket are moved furthest away from the basket center, and as close to the periphery of the basket as possible.

It should be noted that the two eccentric configurations are hypothetical, since there is no known physical effect that could move all assemblies within a basket consistently to the center or periphery. Instead, the most likely configuration would be that all assemblies are moved in the same direction when the cask is in a horizontal position, and that assemblies are positioned randomly when the cask is in a vertical position. Further, it is not credible to assume that any such configuration could exist by chance. Even if the probability for a single assembly placed in the corner towards the basket center would be 1/5 (i.e. assuming only the center and four corner positions in each cell, all with equal probability), then the probability that all assemblies would be located towards the center would be $(1/5)^{24}$ or approximately 10^{-17} for the MPC-24, $(1/5)^{32}$ or approximately 10^{-23} for the MPC-32, and $(1/5)^{68}$ or approximately 10^{-48} for the MPC-68. However, since the configurations listed above bound all credible configurations, they are conservatively used in the analyses.

In Table 6.3.6, results are presented for all conditions that were introduced in Revision 2 of this FSAR, namely results for the MPC-24E/EF with intact and damaged fuel at 5 wt% ^{235}U, for the MPC-32 with soluble boron levels lower than 2600 ppm for 5 wt% ^{235}U and lower than 1900 ppm for 4.1 wt% ^{235}U, and for the MPC-32 with intact and damaged fuel. The table shows the maximum k_{eff} value for centered and the two eccentric configurations for each condition, and the difference in k_{eff} between the centered and eccentric positioning. The results and conclusions are summarized as follows:

- In all cases, moving the assemblies to the periphery of the basket results in a reduction in reactivity, compared to the cell centered position.
- For the MPC-24E/EF, moving the assemblies and DFCs towards the center of the basket also results in a minor reduction. The cell centered configuration is therefore bounding for this condition and is used in the design basis calculations reported in Section 6.1 and Section 6.4.
- For the MPC-32 cases listed in Table 6.3.6, the maximum reactivity is shown for the basket center configuration. However, for some of the cases with intact and damaged fuel in the MPC-32, the cell centered configuration results in a higher maximum reactivity. Therefore, both the cell centered and basket centered configuration are analyzed for the MPC-32 design basis calculation, and the higher results are listed in the tables in Section 6.1. and 6.4. This applies to the cases with intact and damaged fuel, and to cases with intact fuel only and soluble boron levels lower than 2600 ppm for 5 wt% ^{235}U and lower than 1900 ppm for 4.1 wt% ^{235}U.