Criticality

The MPC provides criticality control for all design basis normal, off-normal, and postulated accident conditions, as discussed in Section 6.1. The effective neutron multiplication factor is limited to $k_{eff} < 0.95$ for fresh (unirradiated) fuel with optimum water moderation and close reflection, including all biases, uncertainties, and manufacturing tolerances.

Criticality control is maintained by the geometric spacing of the fuel assemblies and the spatially distributed B-10 isotope in the Metamic-HT fuel basket, and for the PWR MPC model, the additional soluble boron in the MPC water or use of burnup credit. The minimum specified boron concentration in the purchasing specification for Metamic-HT must be met in every lot of the material manufactured. The guaranteed B-10 value in the neutron absorber, assured by the manufacturing process, is further reduced by 10% (90% credit is taken for the Metamic-HT) to accord with NUREG/CR-5661. No credit is taken for fuel burnup or integral poisons such as gadolinia in BWR fuel. For PWR fuel, ~~T~~the soluble boron concentration requirements ~~(for PWR fuel only)~~ or burnup requirements based on the initial enrichment of the fuel assemblies are delineated in Section 2.1 consistent with the criticality analysis described in Chapter 6.

Confinement

The MPC provides for confinement of all radioactive materials for all design basis normal, off-normal, and postulated accident conditions. As discussed in Section 7.1, the HI-STORM FW MPC design meets the guidance in Interim Staff Guidance (ISG)-18 so that leakage of radiological matter from the confinement boundary is non-credible. Therefore, no confinement dose analysis is required or performed. The confinement function of the MPC is verified through pressure testing, helium leak testing of the MPC shell, base plate, and lid material along with the shell to base plate and shell to shell seam welds, and a rigorous weld examination regimen executed in accordance with the acceptance test program in Chapter 10.

Operations

There are no radioactive effluents that result from storage or transfer operations. Effluents generated during MPC loading are handled by the plant's radioactive waste system and procedures.

Generic operating procedures for the HI-STORM FW System are provided in Chapter 9. Detailed operating procedures will be developed by the licensee using the information provided in Chapter 9 along with the site-specific requirements that comply with the 10CFR50 Technical Specifications for the plant, and the HI-STORM FW System Certificate of Compliance (CoC).

Acceptance Tests and Maintenance

The acceptance criteria and maintenance program to be applied to the MPC are described in Chapter 10. The operational controls and limits to be applied to the MPC are discussed in reasonably conservative dose rates. The reference assemblies given in Table 1.0.4 are the predominant assemblies used in the industry.

The design basis dose rates can be met by a variety of burnup levels and cooling times. Table 2.1.1 provides the acceptable ranges of burnup, enrichment and cooling time for all of the authorized fuel assembly array/classes. Table 2.1.5 and Figures 2.1.3 and 2.1.4 provide the axial distribution for the radiological source terms for PWR and BWR fuel assemblies based on the axial burnup distribution. The axial burnup distributions are representative of fuel assemblies with the design basis burnup levels considered. These distributions are used for analyses only, and do not provide a criteria for fuel assembly acceptability for storage in the HI-STORM FW System.

Non-fuel hardware, as defined in the Glossary, has been evaluated and is also authorized for storage in the PWR MPCs as specified in Table 2.1.1.

2.1.7 Criticality Parameters for Design Basis SNF

Criticality control during loading of the MPC-37 is achieved through either meeting the soluble boron limits in Table 2.1.6 OR verifying that the assemblies meet the minimum burnup requirements in Table 2.1.7.

For those spent fuel assemblies that need to meet the burnup requirements specified in Table 2.1.7, a burnup verification shall be performed in accordance with either Method A OR Method B described below.

Method A: Burnup Verification Through Quantitative Burnup Measurement

For each assembly in the MPC-37 where burnup credit is required, the minimum burnup is determined from the burnup requirement applicable to the loading configuration chosen for the cask (see Table 2.1.7). A measurement is then performed that confirms that the fuel assembly burnup exceeds this minimum burnup. The measurement technique may be calibrated to the reactor records for a representative set of assemblies. The assembly burnup value to be compared with the minimum required burnup should be the measured burnup value as adjusted by reducing the value by a combination of the uncertainties in the calibration method and the measurement itself.

Method B: Burnup Verification Through an Administrative Procedure and Qualitative Measurements

Depending on the location in the basket, assemblies loaded into a specific MPC-37 can either be fresh, or have to meet a single minimum burnup value. The assembly burnup value to be compared with the minimum required burnup should be the reactor record burnup value as adjusted by reducing the value by the uncertainties in the reactor record value. An administrative procedure shall be established that prescribes the following steps, which shall be performed for each cask loading:

- Based on a review of the reactor records, all assemblies in the spent fuel pool that have a burnup that is below the minimum required burnup of the loading curve for the cask to be loaded are identified.
- After the cask loading, but before the release for shipment of the cask, the presence and location of all those identified assemblies is verified, except for those assemblies that have been loaded as fresh assemblies into the cask.

Additionally, for all assemblies to be loaded that are required to meet a minimum burnup, a measurement shall be performed that verifies that the assembly is not a fresh assembly.
~~The criticality analyses for the MPC-37 are performed with credit taken for soluble boron in the MPC water during wet loading and unloading operations. Table 2.1.6 provides the required soluble boron concentrations for this MPC.~~

2.1.8 Summary of Authorized Contents

Tables 2.1.1 through 2.1.3 specify the limits for spent fuel and non-fuel hardware authorized for storage in the HI-STORM FW System. The limits in these tables are derived from the safety analyses described in the following chapters of this FSAR.

Table 2.1.1

MATERIAL TO BE STORED

PARAMETER	VALUE	
	MPC-37	MPC-89
Fuel Type	Uranium oxide undamaged fuel assemblies, damaged fuel assemblies, and fuel debris meeting the limits in Table 2.1.2 for the applicable array/class.	Uranium oxide undamaged fuel assemblies, damaged fuel assemblies, with or without channels, fuel debris meeting the limits in Table 2.1.3 for the applicable array/class.
Cladding Type	ZR (see Glossary for definition)	ZR (see Glossary for definition)
Maximum Initial Rod Enrichment	Depending on soluble boron levels or burnup credit and assembly array/class as specified in Table 2.1.6 and Table 2.1.7.	≤ 5.0 wt. % U-235
Post-irradiation cooling time and average burnup per assembly	Minimum Cooling Time: 3 years Maximum Assembly Average Burnup: 68.2 GWd/mtU	Minimum Cooling Time: 3 years Maximum Assembly Average Burnup: 65 GWd/mtU
Non-fuel hardware post-irradiation cooling time and burnup	Minimum Cooling Time: 3 years Maximum Burnup†: - BPRAs, WABAs and vibration suppressors: 60 GWd/mtU - TPDs, NSAs, APSRs, RCCAs, CRAs, CEAs, water displacement guide tube plugs and orifice rod assemblies: 630 GWd/mtU - ITTRs: not applicable	N/A
Decay heat per fuel storage location	Regionalized Loading: See Table 1.2.3	Regionalized Loading: See Table 1.2.4

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† Burnups for non-fuel hardware are to be determined based on the burnup and uranium mass of the fuel assemblies in which the component was inserted during reactor operation. Burnup not applicable for ITTRs since installed post-irradiation.

Table 2.1.6

Soluble Boron Requirements for MPC-37 Wet Loading and Unloading Operations

Array/Class	**All Undamaged Fuel Assemblies**		**One or More Damaged Fuel Assemblies and/or Fuel Debris**	
	Maximum Initial Enrichment $\leq$ 4.0 wt% ^{235}U (ppmb)	Maximum Initial Enrichment 5.0 wt% ^{235}U (ppmb)	Maximum Initial Enrichment $\leq$ 4.0 wt% ^{235}U (ppmb)	Maximum Initial Enrichment 5.0 wt% ^{235}U (ppmb)
All 14x14 and 16x16	1,000	1,6~~5~~00	1,300	1,800
All 15x15 and 17x17	1,500	2,000	1,800	2,300

Note:

1. For maximum initial enrichments between 4.0 wt% and 5.0 wt% ^{235}U, the minimum soluble boron concentration may be determined by linear interpolation between the minimum soluble boron concentrations at 4.0 wt% and 5.0 wt% ^{235}U.

~~1.~~2. If burnup credit is used (as described in Section 2.1.7), these soluble boron requirements do not apply.

TABLE 2.1.7

POYNOMIAL FUNCTIONS FOR THE MINIMUM BURNUP AS A FUNCTION OF INITIAL ENRICHMENT

Assembly Classes	**Configuration**[**]	**Cooling Time, years**	**Minimum Burnup (GWd/mtU) as a Function of the Initial Enrichment (wt% ^{235}U)**
15x15B, C, D, E, F, H, I and 17x17A, B, C, D, E	Uniform	3.0	f(x) = -7.9224e-02 * x^3 -7.6419e-01 * x^2 +2.2411e+01 * x^1 -4.1183e+01
		7.0	f(x) = +1.3212e-02 * x^3 -1.6850e+00 * x^2 +2.4595e+01 * x^1 -4.2603e+01
	Regionalized	3.0	f(x) = +3.6976e-01 * x^3 -5.8233e+00 * x^2 +4.0599e+01 * x^1 -5.8346e+01
		7.0	f(x) = +3.3423e-01 * x^3 -5.1647e+00 * x^2 +3.6549e+01 * x^1 -5.2348e+01
16x16A, B, C	Uniform	3.0	f(x) = -1.0361e+00 * x^3 +1.1386e+01 * x^2 -2.9174e+01 * x^1 +2.0850e+01
		7.0	f(x) = -9.6572e-01 * x^3 +1.0484e+01 * x^2 -2.5982e+01 * x^1 +1.7515e+01
	Regionalized	~~3.0~~	~~f(x) = -2.1456e-01 * x^3 +2.4668e+00 * x^2 +2.1381e+00 * x^1 -1.2560e+01~~
		~~7.0~~	~~f(x) = -5.9154e-01 * x^3 +5.8403e+00 * x^2 -6.9339e+00 * x^1 -4.7951e+00~~
		Combined[††]	f(x) = -4.9680e-01 * x^3 +4.9471e+00 * x^2 -4.2373e+00 * x^1 -7.3936e+00

[**] Uniform configuration refers to Configuration 1 in Table 2.1.8. Regionalized configuration refers to Configuration 2, 3, and 4 in Table 2.1.8.

[††] The combined cooling time loading curve is applicable for fuel with above 3 years cooling time.

TABLE 2.1.8
BURNUP CREDIT CONFIGURATIONS

Configuration	Description
Configuration 1	Spent UNDAMAGED fuel assemblies are placed in all positions of the basket
Configuration 2	Fresh UNDAMAGED fuel assemblies are placed in locations 3-4, 3-5, 3-12, and 3-13 (see Figure 2.1.1); spent UNDAMAGED fuel assemblies are placed in the remaining positions
Configuration 3	Damaged Fuel Containers (DFCs) with spent DAMAGED fuel assemblies are placed in locations 3-1, 3-3, 3-4, 3-5, 3-6, 3-7, 3-10, 3-11, 3-12, 3-13, 3-14, and 3-16 (see Figure 2.1.1); spent UNDAMAGED fuel assemblies are placed in the remaining positions
Configuration 4	DFCs with fresh FUEL DEBRIS are placed in locations 3-1, 3-7, 3-10, and 3-16 with locations 2-1, 2-5, 2-8, and 2-12 (see Figure 2.1.1) empty; spent UNDAMAGED fuel assemblies are placed in the remaining positions

SUPPLEMENT 6.I

CRITICALITY EVALUATION OF MPC-37 WITH THE BURNUP CREDIT

6.I.0 INTRODUCTION

This supplement is solely focused on providing an evaluation of criticality safety of HI-STORM FW with MPC-37 using the burnup credit approach instead of the soluble boron credit approach, discussed in Section 6.1. The evaluation presented herein supplements those evaluations of HI-STORM FW system contained in the main part of Chapter 6 of this FSAR. The HI-STORM FW design structures and components, limiting fuel characteristics, analysis methodologies, modeling assumptions, etc. utilized in the safety evaluation are based on those used in the main body of Chapter 6, unless otherwise noted in the following sections. Specifically, the actinide and fission product burnup credit, based on the latest USNRC Interim Staff Guidance (ISG-8 Rev. 3), is used for the MPC-37 basket. The results of this evaluation demonstrate that the effective neutron multiplication factor (k_{eff}) of the HI-STORM FW system with MPC-37, 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, which is in conformance with the principles established in 10CFR72.124 [6.I.0.1], NUREG-1536 [6.I.0.2], and NUREG-0800 Section 9.1.2 [6.I.0.3].

6.I.1 DISCUSSION AND RESULTS

6.I.1.1 Design Features

Criticality safety of HI-STORM FW with MPC-37 and burnup credit depends on the following principal design features:

- The inherent geometry of the fuel basket design within the MPC;
- The incorporation of permanent fixed neutron-absorbing material in the fuel basket structure. The baskets are completely manufactured from Metamic-HT, an aluminum and B_4C composite material. All assemblies are therefore completely surrounded by neutron absorbing material;
- An administrative limit on the maximum average enrichment for PWR fuel;
- An administrative limit on the minimum average assembly burnup for PWR fuel. The burnup credit methodology is described in detail in Appendix 6.I.B of this supplement, and implements an actinides and fission products approach; and

The number and permissible location of DFCs is provided in Figure 2.1.1 and the licensing drawing in Section 1.5, respectively. The following basket loading configurations are available for use in MPC-37 with the burnup credit approach:

- Configuration 1: Spent undamaged fuel assemblies are placed in all positions of the basket;
- Configuration 2: Fresh undamaged fuel assemblies are placed in one region (4 cells) at the periphery of the basket; spent undamaged fuel assemblies are placed in the remaining positions;
- Configuration 3: Damaged Fuel Containers (DFCs) with the spent damaged fuel assemblies are placed in one region (12 cells) at the periphery of the basket; spent undamaged fuel assemblies are placed in the remaining positions;
- Configuration 4: DFCs with fresh fuel debris are placed in one region (4 cells) at the periphery of the basket with the adjacent cells kept empty; spent undamaged fuel assemblies are placed in the remaining positions.

The basket loading configurations, discussed above, are graphically shown in Section 6.I.C.4.

Confirmation of the criticality safety of the HI-STORM FW system was accomplished with the three-dimensional Monte Carlo code MCNP5 [6.I.1.1]. 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.I.1.2]. Benchmark calculations were made and summarized in Appendix 6.I.A to compare the primary code package (MCNP5) with experimental data, using critical experiments selected to encompass, insofar as practical, the design parameters of HI-STORM FW.

The design basis criticality safety calculations are performed for a single unreflected, internally flooded cask. The results of the calculations, conservatively evaluated for the worst combination of manufacturing tolerances (as identified in Section 6.3), and including the calculational bias, uncertainties, and calculational statistics, are listed in Table 6.I.1.1. For each fuel assembly class, Tables 6.I.1.1 lists the bounding maximum k_{eff} value, the associated maximum allowable enrichment, and the minimum required assembly average burnup. The unreflected cask condition is acceptable since this configuration is shown to yield results that are statistically equivalent to the results for the corresponding reflected cask (see Subparagraph 6.4.2.1.1). The maximum enrichment and minimum burnup acceptance criteria are defined in Chapter 2.

In summary, the evaluation presented in this supplement shows that the maximum k_{eff} value, including all applicable biases and uncertainties is below 0.95 for all normal, off-normal and accident conditions. This demonstrates that the HI-STORM FW system with MPC-37 and PWR burnup credit is in full compliance with the criticality requirements of 10CFR72 and NUREG-1536. The maximum k_{eff} value for misloading conditions is below the limit of 0.98 recommended in ISG-8 Rev. 3 (see Appendix 6.I.D).

[Remainder of Supplement Proprietary Information Withheld in Accordance with 10 CFR 2.390]