Table 2.II.1.6

Burnup and Cooling Time Fuel Qualification Requirements for MPC-32M

Cell Decay Heat Load Limit (kW)	Polynomial Coefficients, see Paragraph 2.II.1.5.2			
	A	B	C	D
≤ 0.83	6.57083E-14	-4.02593E-09	1.47107E-04	8.01647E-01
0.83 < decay heat ≤ 1.25	4.11020E-14	-4.62813E-09	2.17444E-04	-5.55545E-01
1.25 < decay heat ≤ 1.46	1.21147E-14	-1.08013E-09	8.66361E-05	4.04455E-01
1.46 < decay heat ≤ 1.81	3.82652E-15	-2.38729E-10	4.75134E-05	6.36443E-01
1.81 < decay heat ≤ 3.26	3.76103E-16	4.83486E-11	1.74805E-05	6.53455E-01

SUPPLEMENT 5.II: SHIELDING EVALUATION

5.II.0 Introduction

This supplement provides shielding evaluations for a number of design variations of the HI-STORM 100 System showing that using these variations, together with the qualified content for these variations, the system is in compliance with the applicable regulatory requirements. The following design variations are addressed:

- HI-STORM 100S Version E, HI-TRAC Version MS, and MPC-32M. These are variations of the HI-STORM 100, HI-TRAC and MPC-32 addressed in the main part of this chapter, with characteristics described in Supplement 1.II.
    - The analyses using the MPC-32M canister are also shown to bound all other canisters listed in the main part of this chapter, for both the HI-STORM 100S Version E and HI-TRAC Version MS. All those other canisters are therefore also qualified to be loaded into those systems.
    - The MPC-32M uses highly flexible thermal loading patterns to allow extensive optimization of the content. This is appropriately considered in defining the radiological fuel limits in Supplement 2.II, and in the dose evaluations in this supplement.
- Additionally, this supplement addresses two additional versions of baskets analyzed in the main part of this chapter, namely the MPC-32 Version 1 (version of the MPC-32), and MPC-68 Version 1 (version of the MPC-68). These are qualified for all systems, based on a comparison of the design features as it applies to shielding evaluations.

All shielding analyses in this supplement were performed with MCNP5-1.51 [5.II.2], which is the same code as that used for the evaluation of the HI-STORM 100 System with MPC-68M in Supplement 5.III. The source terms were determined by the TRITON/ORIGAMI sequence from SCALE 6.2.1 [5.II.3], consistent with other approved Holtec applications [5.II.4].

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 5.II.1 through 5.II.6 correspond to Sections 5.1 through 5.6. Information in the main body of Chapter 5 that remains applicable is not repeated here, but referenced accordingly.

5.II.1 Discussion and Results

Following is a discussion on all the designs addressed in this supplement focusing on the differences to the versions presented in the main part of this chapter as it is relevant for shielding performance and corresponding compliance. This informs which results are presented in this section and in Section 5.II.4.

- HI-STORM 100S Version E: The HI-STORM 100S Version E cask is an enhanced version of HI-STORM 100S Version B with a number of improvements, such as a new design of the inlet and outlet vent systems to improve thermal performance, and increased density of the shielding concrete in the overpack body and top lid. From a shielding perspective, the principal features are the same as for the versions in the main part of this chapter, but it requires new calculational models reflecting the design details.

- HI-TRAC MS: The HI-TRAC Version MS (acronym for **m**aximum **s**hielding) cask is designed to provide maximum shielding to the plant personnel engaged in conducting short-term operations and facilitate ALARA transfer of a loaded MPC to or from the storage module. The HI-TRAC Version MS is anatomically similar to HI-TRAC 100 and HI-TRAC 125 cask models analyzed in the main part of Chapter 5 of this FSAR. However, instead of having fixed weights and dimensions, the thickness of the lead cylinder and the water jacket, as well as the cavity height, can be varied to optimize shielding by taking full advantage of the lifting capacity at an individual site, something not possible with the fixed-weight versions described in the main part of this chapter. In that sense, it is essentially a smaller diameter version of the HI-TRAC VW, specifically Version V, transfer cask in the HI-STORM FW FSAR [5.II.1]. The bounding condition from a dose perspective would be the version with the minimum lead and water thicknesses.

- MPC-32M: The MPC-32M is a variation of the MPC-32 addressed in the main part of this chapter, with the basket made from Metamic-HT instead of steel, in the same way that the MPC-68M addressed in Supplement 5.III is a variation of the MPC-68. For the same content, the shielding performance of the Metamic versions (MPC-32M) would be similar to that of the original version (MPC-32). However, based on the better thermal performance of the basket material, the MPC-32M is qualified for more extensive thermal loading patterns. In alignment with this, corresponding limits for burnups and cooling times are defined for the content in Supplement 2.II.

- MPC-32 Version 1 and MPC-68 Version 1: These are variations of the MPC-32 and MPC-68 presented in the main part of this chapter. They still contain a steel basket, but with slightly thinner basket walls, and aluminum shims between the basket and the enclosure shell. The evaluations presented in Section 5.4 indicate that the main impact of the basket design details is on photon dose rates, and that this effect is limited to the outer basket walls, due to the high self-shielding of the fuel itself. The difference in wall thickness is less than 1/8 of an inch. That is offset by the presence of the aluminum shims around the basket, adding about 3/4 of an inch of aluminum. Hence overall, the same or an even better shielding performance is expected for these two versions. Based on this comparison, these variations are qualified, without any further analysis.

To identify and present limiting (bounding) dose rates, the following approaches are used:

[PROPRIETARY INFORMATION WITHHELD IN ACCORDANCE WITH 10 CFR 2.390]

[PROPRIETARY INFORMATION WITHHELD IN ACCORDANCE WITH 10 CFR 2.390]

5.II.1.1 Normal and Off-Normal Operations

As discussed in Subsection 5.1.1, none of the off-normal conditions have any impact on the shielding analysis, and this is also applicable to the systems described in this supplement, since the principal designs are the same. Therefore, off-normal and normal conditions are identical for the purpose of the shielding evaluation.

Table 5.II.1.1 provides the maximum dose rates adjacent to and one meter from the HI-STORM 100S Version E overpack with MPC-32M during normal conditions.

Table 5.II.1.2 presents the annual dose to an individual from a single HI-STORM 100S Version E cask and various storage cask arrays, assuming an 8760 hour annual occupancy at the dose point location. The minimum distance required for the corresponding dose is also listed.

Table 5.II.1.3 provides dose rates adjacent to and one meter from the HI-TRAC Version MS with MPC-32M using the discrete loading pattern in Table 5.II.2.5. The dose rates correspond to the normal condition in which the MPC is dry and the HI-TRAC water jacket is filled with water. The dose rates in this table are calculated for the limiting content of the MPC-32M, and shielding thickness of the HI-TRAC MS that lead to dose rates on the outside of the HI-TRAC that are consistent with the dose rate limit set for that location. For dose rates under other conditions see Section 5.II.4.

The analyses summarized in this supplement demonstrate that the HI-STORM 100 System, including the HI-STORM Version E storage cask, the HI-TRAC Version MS transfer cask and MPC-32M, are capable of meeting the 10CFR72.104 limits and support ALARA practices.

5.II.1.2 Accident Conditions

The discussions in Subsection 5.1.2 remain fully applicable for the HI STORM 100 System components evaluated in this supplement, except that dose rates are re-calculated for the HI-TRAC Version MS cask with the MPC-32M with the most limiting content. Results for this case are summarized in Table 5.II.1.4 at 1 and 100 meters from the HI-TRAC Version MS cask with the lower bound lead and water jacket thicknesses under accident conditions. Consistent with Subsection 5.1.2, it is conservatively assumed that the neutron shield (water) is completely lost and replaced by a void under the accident condition. The normal condition dose rates are provided for reference, but note that bounding content for normal and accident conditions may not be identical, since both are determined to maximize dose rates under the respective condition. Also note that the dose rate under normal conditions are different from those in Table 5.II.1.3, since minimum shielding thicknesses are assumed here.

Overall, the results show that under bounding conditions, the requirements form 10CFR72.106 will always be met at 100 m from the ISFSI. Additional site specific evaluations for accident conditions are therefore not required.

Table 5.II.1.1

DOSE RATES ADJACENT TO AND AT ONE METER FROM HI-STORM 100S VERSION E OVERPACK FOR NORMAL CONDITIONS MPC-32M

Dose Point[1] Location	Fuel Gammas[2] (mrem/hr)	^{60}Co Gammas (mrem/hr)	Neutrons (mrem/hr)	Totals (mrem/hr)	Totals with BPRAs (mrem/hr)
ADJACENT TO OVERPACK					
1	176.00	369.99	14.90	560.89	576.52
2	125.86	0.11	0.41	126.38	134.75
3	76.82	37.95	9.97	124.73	159.67
4	8.98	1.50	0.29	10.77	12.83
ONE METER FROM OVERPACK					
1	44.24	6.26	0.27	50.77	53.40
2	58.26	21.70	0.77	80.73	85.33
3	19.34	5.76	1.14	26.24	32.10
4	2.80	0.54	0.14	3.48	4.12

[1] Refer to Figures 5.II.3-1 AND 5.II.3-3.
[2] Gammas generated by neutron capture are included with fuel gammas.

Table 5.II.1.3

DOSE RATES FROM HI-TRAC VERSION MS FOR NORMAL CONDITIONS MPC-32M

Dose Point[1] Location	Fuel Gammas[2] (mrem/hr)	^{60}Co Gammas (mrem/hr)	Neutrons (mrem/hr)	Totals (mrem/hr)	Totals with BPRAs (mrem/hr)
ADJACENT TO HI-TRAC					
1	421.86	742.68	552.69	1717.23	1747.02
2	3099.24	1.20	541.55	3641.98	3933.75
3	13.03	18.13	33.36	64.52	79.79
4	3577.56	1700.91	424.89	5703.37	7223.70
5	1102.35	6403.49	4778.83	12284.67	12556.38
ONE METER FROM HI-TRAC					
1	414.47	220.60	83.81	718.87	757.64
2	1074.43	7.80	136.26	1218.49	1322.90
3	168.23	63.16	25.91	257.30	323.34
4	435.50	482.66	192.11	1110.28	1529.98

[1] Refer to Figure 5.II.3-4.
[2] Gammas generated by neutron capture are included with fuel gammas.

Table 5.II.1.4

DOSE RATES FROM HI-TRAC VERSION MS FOR ACCIDENT CONDITIONS MPC-32M

Dose Point[1] Location	Fuel Gammas[2] (mrem/hr)	^{60}Co Gammas (mrem/hr)	Neutrons (mrem/hr)	Totals (mrem/hr)	Totals with BPRAs (mrem/hr)
ONE METER FROM HI-TRAC					
2 (Accident Condition)	4551.12	49.33	3874.88	8475.32	9099.17
2 (Normal Condition[3])	3652.37	30.07	162.06	3844.50	4243.24
100 METERS FROM HI-TRAC					
2 (Accident Condition)	1.65	0.18	1.48	3.30	3.66

[1] Refer to Figure 5.II.3-4.
[2] Gammas generated by neutron capture are included with fuel gammas.
[3] For minimum shielding thicknesses, see Subsection 5.II.1.2.

5.II.2 Source Specification

The neutron and gamma source terms were calculated with the TRITON / ORIGAMI modules of the SCALE 6.2.1 code package [5.II.3]. These have already been used for other Holtec applications [5.II.4]. This is an improved approach compared to the SAS2H / ORIGEN-S sequence from SCALE 4.3, using predefined assembly libraries and a 252-energy group structure. Nevertheless, unless otherwise noted in the following subsections, the discussions and conclusions in Section 5.2 remain applicable to the evaluations in this supplement. These codes also calculate decay heat values, which are used to inform the loading curves defined for the MPC-32M.

5.II.2.1 Design Basis Assembly

In order to perform a bounding analysis, a design basis fuel assembly must be chosen. In accordance with the discussions in Subsection 5.2.5, the design basis zircaloy clad fuel assemblies B&W 15x15 and GE 7x7 are used for all PWR and BWR calculations, respectively. Tables 5.II.2.1 and 5.II.2.2 provide the gamma and neutron source term for the design basis fuel, calculated using the TRITON / ORIGAMI modules of the SCALE 6.2.1 code package, for the same burnup and cooling time values that were presented in Section 5.2. Table 5.II.2.3 shows the corresponding fuel hardware activation.

5.II.2.2 Fuel Specifications and Limits

This subsection only addresses fuel specifications and limitations for the MPC-32M. Fuel specifications for all other canisters are specified in Section 5.1, Table 5.III.1 and Table 5.III.2

5.II.2.2.1 Design Basis Burnup and Cooling Times

Burnup and cooling time limits are specified in Supplement 2.II for each basket cell through a loading curve that defines the minimum cooling time as a function of the assembly burnup. However, not every cell may be necessarily assigned a unique loading curve

[PROPRIETARY INFORMATION WITHHELD IN ACCORDANCE WITH 10 CFR 2.390]

[PROPRIETARY INFORMATION WITHHELD IN ACCORDANCE WITH 10 CFR 2.390]

These patterns of loading curves, using the corresponding sets of burnup and cooling times, qualify all fuel configurations from a dose perspective as informed by the thermal patterns.

5.II.2.2.2 Fuel Enrichment

As discussed in Subsection 5.2.2, enrichments have a significant impact on neutron dose rates, with lower enrichments resulting in higher neutron dose rates for the same burnup and cooling time. For assemblies with higher burnups (where the neutron contribution to the total dose rate is higher) and/or locations that are more neutron dominated, the enrichment would therefore be important in order to present dose rates in a conservative way. However, it would be impractical and excessively conservative to perform all calculations at bounding low enrichment, since low enrichments are generally only found in lower burned assemblies. Therefore, a conservatively low enrichment value is selected for each burnup. This selection is based on industry information on more than 130,000 PWR assemblies. For the selection, the fuel assemblies are sorted into burnup bins (i.e., 0 5, 5-10 … 70-75 GWd/mtU). The bins do not overlap, so for the burnup bin of 5-10 GWd/mtU, the data set includes the enrichments for the fuel assemblies with the burnup from 5,000 MWd/mtU to 9,999 MWd/mtU. Then, in each burnup bin, the enrichments are sorted from low to high, and the enrichment value that bounds 99% of the assemblies in that bin (from below) is used for calculations for assemblies with the burnup of this bin. The enrichment values determined that way are provided in Table 5.II.2.4, and, as a visual together with all the data analyzed, are also shown in Figure 5.II.2-2. These are used in all dose analyzes presented in this Supplement for the MPC-32M.

Given that the considered baskets contain a relatively large number of assemblies, selecting the minimum enrichment for each assembly this way is considered reasonably conservative. The typical content of the basket would have most assemblies well above the lower bound enrichment assumed in the analyses, so even if a small number of assemblies would fall below the assumed minimum, the effect on dose rates would be negligible or inconsequential. Furthermore, the site-specific shielding analyses will consider actual or bounding fuel enrichment. Therefore, an explicit lower enrichment limit is not considered necessary.

5.II.2.3 Non-Fuel Hardware

This subsection only addresses non-fuel hardware in MPC-32M. The non-fuel hardware in other canisters is discussed in Sections 5.2 and 5.4 of the main part of the chapter.

The same non-fuel hardware, discussed in Subsection 5.2.4, i.e. BPRAs, TPDs, CRAs, and APSRs, are permitted for storage in MPC-32M as an integral part of a PWR fuel assembly, following the requirements provided in Subsection 2.1.9 and Section 2.II.1.

Additionally, in order to qualify non-fuel hardware with lower cooling times, the following conditions are considered:

- BPRA and TPD are analyzed with a minimum cooling time of 1 year, independent of the burnup (i.e. up to 60 GWd/mtU and 225 GWd/mtU). Table 5.II.2.6 shows the corresponding ^{60}Co activities for BPRAs and TPDs in each region of the fuel assembly;
- CRA and APSR are analyzed with the minimum cooling time of 2 years, independent of the burnup (i.e. up to 630 GWd/mtU). Tables 5.II.2.7 and 5.II.2.8 present the source terms, including decay heat, that were calculated for the CRAs and APSRs, respectively. As discussed in Paragraph 5.2.4.2, the only significant source from the activation of inconel or steel is Co-60 and the other significant source is from the activation of AgInCd (0.3-1.0 MeV);
- NSAs with the minimum cooling time of 1 year are also permitted for storage in MPC-32M. As discussed in Paragraph 5.2.7.1, the total activation of steel and inconel in NSAs (^{60}Co source) is bounded by the total activation of a BPRA, while the neutron source itself is either very short-lived, which results in a complete decay by the time of storage, or long-lived, where the cooling time decrease to 1 year has a small effect. Hence the justification in Subsection 5.2.7 remains fully applicable.

Subsection 5.II.4.3 discusses the effect on dose rate of the insertion of non-fuel hardware with the lower cooling times into MPC-32M.

Table 5.II.2.5 (Page 1 of 2)

DESIGN BASIS BURNUP, ENRICHMENT AND COOLING TIMES COMBINATIONS CONSIDERED FOR MPC-32M

Applicability	**Burnup (MWd/mtU)**	**Enrichment (wt% ^{235}U)**	**Calculated Cooling Time[1] (years)**	**Cooling Time Assumed in Dose Analysis (years)**	**Decay Heat Limit (kW)**
Zone 2 for Discrete Configuration, Lower Heat Load Region for Regionalized Configuration	5000	1.1	1.44	1.4	0.83
	10000	1.1	1.94	1.8	
	20000	1.6	2.66	2.6	
	30000	2.4	3.37	3.0	
	40000	3.0	4.45	4.0	
	50000	3.6	6.31	6.0	
	60000	3.9	9.33	9.0	
	70000	4.2	13.90	13.0	
Uniform Loading	5000	1.1	0.42	1.0	1.25
	10000	1.1	1.20	1.0	
	20000	1.6	2.27	2.2	
	30000	2.4	2.91	2.8	
	40000	3.0	3.37	3.0	
	50000	3.6	3.88	3.5	
	60000	3.9	4.71	4.5	
	70000	4.2	6.09	6.0	
Zone 1 for Discrete Configuration	5000	1.1	0.81	1.0	1.46
	10000	1.1	1.17	1.0	
	20000	1.6	1.80	1.8	
	30000	2.4	2.36	2.2	
	40000	3.0	2.92	2.8	
	50000	3.6	3.55	3.5	
	60000	3.9	4.33	4.0	
	70000	4.2	5.33	5.0	

[1] Cooling times are calculated following the methodology in Paragraph 2.II.1.5.2 using the coefficients in Table 2.II.1.6, based on the decay heat limit in the last column.

Table 5.II.2.5 (Page 2 of 2)

DESIGN BASIS BURNUP, ENRICHMENT AND COOLING TIMES COMBINATIONS CONSIDERED FOR MPC-32M

Applicability	Burnup (MWd/mtU)	Enrichment (wt% ^{235}U)	Calculated Cooling Time (years)	Cooling Time Assumed in Dose Analysis (years)	Decay Heat Limit (kW)
Higher Heat Load Region for Regionalized Configuration	5000	1.1	0.87	1.0	1.81
	10000	1.1	1.09	1.0	
	20000	1.6	1.52	1.4	
	30000	2.4	1.95	1.8	
	40000	3.0	2.40	2.2	
	50000	3.6	2.89	2.8	
	60000	3.9	3.45	3.0	
	70000	4.2	4.11	4.0	
Zone 3 for Discrete Configuration	5000	1.1	0.74	1.0	3.26
	10000	1.1	0.83	1.0	
	20000	1.6	1.03	1.0	
	30000	2.4	1.23	1.2	
	40000	3.0	1.45	1.4	
	50000	3.6	1.70	1.6	
	60000	3.9	1.96	1.8	
	70000	4.2	2.24	2.2	

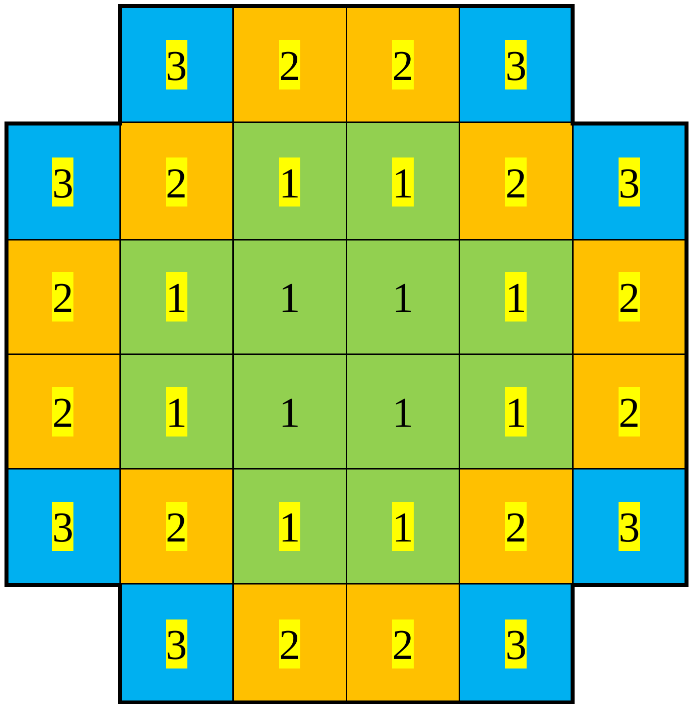

FIGURE 5.II.2-1 ZONE NUMBERS TO MODEL DISCRETE LOADING PATTERNS IN THE MPC-32M BASKET

5.II.3 Model Specifications

Generally, the model specification of the fuel assemblies, MPCs, radiation sources, etc. is the same as in Section 5.3 of the main body of this chapter, unless otherwise noted in the following subsections.

5.II.3.1 Description of the Radial and Axial Shielding Configuration

Full three-dimensional calculational models based on the drawings listed in Chapter 1 were used in the shielding analysis. Nominal dimensions are used in the models consistent with the main part of Chapter 5, unless stated otherwise. This is considered sufficient for the purpose of this supplement to demonstrate reasonable assurance of an adequate level of safety. However, as discussed in Supplement 1.II, some parameters may be customized on a site-specific basis to optimize the shielding performance. These changes will be considered in the site-specific calculations. The site-specific assessment also needs to verify that the fuel assembly design and assembly characteristics used in the calculations are appropriate.

Figures 5.II.3-1 through 5.II.3-3 show representative cross sections of the MCNP model for the HI-STORM Version E cask with the MPC-32M basket. The ribs, bolt recesses as well as the inlet and outlet vents are modeled explicitly, therefore, streaming through these components is accounted for in the dose rate calculations.

Figures 5.II.3-4 and 5.II.3-5 show representative cross sections of the MCNP model for the HI-TRAC Version MS cask with the MPC-68M basket. The ribs and bolt recesses are modeled explicitly, therefore, streaming through these components is accounted for in the dose rate calculations. In order to account for ground scatter, the calculational model simulates the HI-TRAC Version MS cask at a height of 6 inches (the typical cask carry height) above the concrete floor. As a result of such modeling, the dose rate at 1 meter from the pool lid is not calculated.

Table 5.II.3.1 shows the variation in the HI-TRAC Version MS main shielding component thicknesses, i.e. for lead and water in the cask wall, which are used in the calculations in this supplement.

Several conservative assumptions and approximations were made in modeling the MPC. The conservative approximations are listed below.

- For both MPC-32M and MPC-68M baskets, the basket flow holes at the base of the basket are modeled as a complete loss of basket material between the bottom and top edge of the flow hole. The basket shim flow holes are modeled as a complete loss of shim material below the top edge of the flow hole. This is conservative since more material is neglected than actually removed by the presence of flow holes;
- For both MPC-32M and MPC-68M baskets, no elevation of the fuel assemblies above the MPC baseplate is assumed. This is conservative since the bottom nozzle is located adjacent to the flow holes as well as closer to the bottom vent ducts and bottom cask surface;
- The MPC-32M baseplate can be made with the optionally increased thickness. Nonetheless, a baseplate with the lowest nominal thickness is conservatively considered in the calculations;

- Several simplifications are made in the model of the MPC-32M and/or MPC-68M basket shims. Specifically,
  - The rounding of the shim corners is neglected. Since the amount of extra material is roughly compensated by the amount of lost material due to these simplifications, a small (if any) net effect on results is expected;
  - The potential tiny gaps between the basket shims and basket/enclosure are not modeled since an insignificant impact on results is expected;
  - For MPC-32M, in the overlap of the peripheral shim walls and the basket corners (enriched with B_4C), the basket material is conservatively neglected (see Figure 5.II.3-2).

5.II.3.2 Regional Densities

In addition to the composition and densities of the various materials used in the HI-STORM 100 System shielding analyses and presented in Table 5.3.2, the shielding models of HI-STORM Version E and HI-TRAC Version MS casks employ the materials provided in Table 5.II.3.2.

The concrete density shown in Table 5.II.3.2 represents the minimum concrete density in the body and lid of HI-STORM Version E overpack.

Both the MPC-32M and MPC-68M baskets are manufactured using the Metamic-HT panels, made of aluminum and B_4C powder. The lower bound B_4C content is conservatively used in modeling of Metamic-HT.

Table 5.II.3.1

SHIELDING THICKNESS OF HI-TRAC VERSION MS USED IN THE CALCULATIONS

Thickness, inches	Lead Cylinder	Water Jacket
Minimum	2.75	3.875
Adjusted	3.625	3.875
Reference, based on drawing in Section 1.II.5	4.0	4.75

Table 5.II.3.2

COMPOSITION OF THE MATERIALS IN THE HI-STORM 100 SYSTEM

Component	Density (g/cm^3)	Elements	Mass Fraction (%)
Metamic-HT	[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]		
Aluminum	2.7	Al	100
Carbon Steel	7.82	C	1
		Fe	99
Air	1.17e-3	N	78 (atomic fraction %)
		O	22 (atomic fraction %)
Concrete	2.723	H	1
		O	53.2
		Si	33.7
		Al	3.4
		Na	2.9
		Ca	4.4
		Fe	1.4

[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]

FIGURE 5.II.3-4 CALCULATIONAL MODEL (AXIAL CROSS-SECTION) OF HI-TRAC VERSION MS (SHOWN WITH THE MPC-68M)

[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]

FIGURE 5.II.3-5 CALCULATIONAL MODEL (RADIAL CROSS-SECTION) OF HI-TRAC VERSION MS (SHOWN WITH THE MPC-68M)

5.II.4 Shielding Evaluation

5.II.4.1 General

In general, the same methodology is used as described in Section 5.4 of the main body of this chapter for the dose rate calculations, unless otherwise noted in the following subsections.

A newer version of the MCNP radiation transport code is used, namely MCNP5-1.51, instead of version MCNP-4A used for the evaluations documented in the main part of this Chapter. This was mainly done for convenience, since the new version offers updated modeling and calculation options. A comparison between the two versions, for the same model and content, shows essentially the same results.

Modeling of the content for the MPC-32M is presented in detail in Section 5.II.2.

Bounding results for the HI-STORM 100S Version E are summarized in Section 5.II.1, Tables 5.II.1.1 and 5.II.1.2.

For the HI-TRAC MS with the MPC-32M, results are presented in Section 5.II.1, in Table 5.II.1.3 for normal conditions and Table 5.II.1.4 for accident conditions. Results for accident conditions are presented there for upper bound content, and lower bound shielding thicknesses, so they present an overall bounding condition, and no further information is needed. However, for normal conditions, as discussed in Section 5.II.1, results are presented for upper bound content, but for shielding thicknesses that result in radial dose rates consistent with the dose limit selected for ALARA purposes. For illustrative purposes, additional calculations were performed for different assumptions on content or shielding thicknesses (see Table 5.II.3.1). Results for all calculations, showing only total dose rates for all relevant surface and 1 m dose locations, are summarized and compared in Table 5.II.4.1. The following conditions are shown:

- Bounding content, thickness selected to match external dose rate limit. These are the results from Section 5.II.1;
- Minimum thickness, content adjusted to match external dose limit. This is presented as an example to show what content limits will result in dose rates matching the limit, even if the HI-TRAC MS with minimum shielding thicknesses is used. The following limitations are used for this example:
    - Zone 1 and 2: Same as in Table 5.II.2.5;
    - Zone 3: Same burnups as in Table 5.II.2.5, but all cooling times set to a fixed value of 8 years;
- Bounding content and minimum thicknesses;
- Bounding content and reference thicknesses, assuming a higher crane capacity;
- Bounding content and reference thicknesses, but the annulus between the transfer cask and MPC is flooded by water. This condition represents a typical configuration for most loading operations in the vicinity of the transfer cask.

The results and comparisons show that for bounding content and bounding shielding thicknesses, the external dose rates would be unacceptably high, justifying the introduction of the dose limit. However, the results and comparisons also show that for HI-TRAC MS version designed for higher crane capacities, the external dose rates can be significantly lower than those presented in Section 5.II.1.

Note that dose location 4, in the top of the HI-TRAC, shows a high dose rate in almost all cases. However, this is present only in a very narrow area above the annulus between the MPC and HI-TRAC, and for the condition where both the MPC and annulus are empty, i.e. no longer filled with water. Under this condition there is essentially no need for any access to this narrow area, so this high dose rate is inconsequential from an operational dose perspective. For illustration, the results in Table 5.II.4.1 show that the dose rate in the top of the HI-TRAC is substantially reduced when the annulus between the HI-TRAC and MPC is flooded.

Additionally, the HI-STORM 100S Version E and HI-TRAC MS are qualified to contain all other canisters in the main part of this chapter, including all "E", "F" and "FF" versions, and the MPC-68M in Supplement 5.III. All these are bounded by the does rates presented for the MPC-32M in this supplement, due to the high source term used for evaluating the MPC-32M. To demonstrate that this is the case, a comparison is performed, with two of these MPCs, namely the MPC-24 analyzed in the main part of this chapter, and the MPC-68M analyzed in Supplement 5.III, and for both the HI-STORM 100S Version E and the HI-TRAC MS. The following content is modeled for those:

The MPC-24 is qualified for uniform and regionalized loading. In the main part of this chapter, a uniform loading is used that was shown to bound all regionalized conditions for the systems analyzed there. Since it is not clear if that uniform loading also bound regionalized loading conditions when the MPC-24 is in the systems considered here, the regionalized loading configurations are analyzed explicitly here. The burnup and cooling time combinations are based on the specifications defined in Paragraph 2.1.9.1

[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]

The comparison is presented in Tables 5.II.4.3 and 5.II.4.4 for HI-TRAC Version MS and HI-STORM 100S Version E, respectively. It shows that these two MPCs are bounded by the analyses presented here by a substantial margin, so all other MPCs are equally qualified for the systems analyzed in this supplement. These margins also justify the selection of MPCs used for the comparison, specifically, using only a single MPC from the main part of the chapter. The results presented in the main part of the chapter for the various MPCs show that, using the respective design basis content, dose rates around the casks are similar, so with the margin determined here, analyzing only one of these is considered sufficient.

5.II.4.2 Site Boundary Evaluation

The methodology for calculating the dose from a single HI-STORM overpack loaded with an MPC and from various arrays of loaded HI-STORMs at distances equal to and greater than 100 meters is described in Chapter 5. For a single cask, it establishes three dose rates: from the side (A), the top (B) and the side shielded by other casks, using a calculated back-row factor (C). In the main chapter, these are individually determined by separate calculations. For the HI-STORM 100S Version E, these three values are based on a single calculation, and the experience from the calculations in the main part of this chapter as follows:

- A single model is evaluated, that provides the combined side and top dose rate (A+B), for several distances;
- The calculations in the main section show that the contribution from the top is only a very small fraction (<1%) of the total. Dose rate from the single calculations stated above is split into the side (A) and top (B) component by assuming the contribution from the top is 10%. This is conservative for cask arrays, since it will overestimate the contribution from the top of the shielded casks;
- Since the outer dimensions of the Version E is essentially the same as that for the other versions of the HI-STORM 100, the same backrow factor of 0.2 is used.

Results of the analyses are presented in Tables 5.II.4.5 and 5.II.4.6, for 100% occupancy (8760 hours), and using bounding source terms. Table 5.II.4.5 shows the annual dose rate, by dose component, at 300 m. Table 5.II.4.6 shows the annual dose values A, B and C for determining the dose from ISFSI arrays, for various distances.

5.II.4.3 Non-Fuel Hardware

The design basis ^{60}Co activity of 895 Ci, used as the activity limit for BPRAs in Subsection 5.4.6, and the ^{60}Co activity of BPRA with 1 year cooling (see Subsection 5.II.2.3) have been explicitly evaluated in this supplement and the reasonably highest dose rates are reported.

The comparison of the source terms for the other non-fuel hardware with the reduced cooling time in Subsection 5.II.2.3 with the reference activities in Section 5.2.4 showed that most of the increased ^{60}Co activities are well bounded by the activity increase of BPRA with 1 year cooling time, which is used in the dose rate calculations. The activity increase for CRAs and APSRs is higher, but according to the results provided in Subsection 5.4.6, the dose rates on the radial surface and at a distance from the overpack due to the storage of these devices is at least 16 times less than the dose rate from BPRAs, and the dose rate out the top of the overpack is essentially 0. Hence the ^{60}Co activity of BPRA with 1 year cooling time is considered bounding and used in the dose rate calculations in this supplement.

It should be noted that the dose rate out the bottom of the overpack is substantial due to these devices. However, the conclusions made in Subsection 5.4.6, that these dose rates occur in an area which is not normally occupied and, therefore, they do not pose a risk from an operations perspective, are still applicable.

5.II.4.4 Generic PWR Damaged Fuel

Calculations documented in Paragraph 5.4.2.2, modeling various fuel reconfiguration conditions to represent damaged fuel and fuel debris, show that the presence of damaged fuel and fuel debris have no

significant effect on external dose rates. The systems analyzed in this supplement are based on the same design principles as those in the main part of this report, the conclusions from Paragraph 5.4.2.2 should therefore be directly applicable. As a verification, and to evaluate if the differences in the design details and number of DFCs change any of the conclusions, calculations have been performed for the HI-STORM 100S Version E and the HI-TRAC MS with damaged fuel and fuel debris modeling. The calculations show generally the same trends as those presented in Paragraph 5.4.2.2, i.e. that the effect of damaged fuel and fuel debris on external dose rates are not significant. The only exception is the dose rate at 1 m from the HI-STORM outlets, for the case when it is assumed that the periphery of the basket contains a total of 16 DFCs filled in its entirety with fuel debris at bounding fuel specification. In this case, a local increase in dose rates of about 60% is calculated at 1 m from the outlets. However, this does not invalidate the overall conclusions, since the increase is locally limited, and based on conservative and simplified modeling not considered to be a realistic representation of such a loading.

5.II.4.5 Stainless Steel Clad Fuel Source

Fuel assemblies with stainless steel cladding (SS-clad) are qualified for MPC-32, based on more restrictive burnup and cooling time restrictions than for the zircalloy-clad fuel (see Table 2.1.24), and separate dose analyses (see Subsection 5.4.4). The same restrictive burnup and cooling time requirements are applied for loading of stainless steel clad fuel assemblies into MPC-32M (see Table 2.II.1.1). Comparing the gamma sources in all 7 energy groups for the bounding SS-clad fuel with those provided in Table 5.II.2.1 for the design basis zircaloy clad fuel shows that they are bounded with a significant margin. Hence the dose rates for the HI STORM 100 System with MPC-32M filled with the allowable stainless steel clad fuel would be less than those of design basis zircaloy clad fuel, and no further analyses are needed for stainless steel clad fuel in MPC-32M.

Table 5.II.4.1

TOTAL DOSE RATES AROUND THE HI-TRAC MS WITH THE MPC-32M FOR DIFFERENT CONTENT AND SHIELDING THICKNESS COMBINATIONS

Content/Shielding Configuration					
Content	Bounding	Adjusted	Bounding	Bounding	Bounding
Shielding[1]	Adjusted	Minimum	Minimum	Reference	Reference
Annulus[2]	Empty	Empty	Empty	Empty	Water
Dose Point[3] **Location**	**TOTAL DOSE RATES (mrem/hr)**[4]				
ADJACENT TO HI-TRAC					
1	1747	1041	1769	1812	1285
2	3934	3933	12267	2147	1610
3	80	145	203	54	25
4	7224	4399	7275	7250	2641
5	12556	11902	12237	12474	11758
ONE METER FROM HI-TRAC					
1	758	871	1924	522	417
2	1323	1576	4243	723	575
3	323	620	1104	171	130
4	1530	1174	1551	1539	1050

[1] Refer to Table 5.II.3.1.
[2] Radial annulus between the HI-TRAC cask and MPC enclosure vessel.
[3] Refer to Figure 5.II.3-4.
[4] Values are rounded to nearest integer.

Table 5.II.4.2

REGIONALIZED LOADING COMBINATIONS FOR MPC-24

Heat Load Ratio (X)	Loading Region	Short Cooling Time			Long Cooling Time		
		Enrichment[1], wt% ^{235}U	Cooling Time, years	Burnup, MWD/MTU	Enrichment, wt% ^{235}U	Cooling Time, years	Burnup, MWD/MTU
0.5	Inner	1.1	2.0	10000	5.0	30.0	75000
	Outer	2.6	2.0	25000	5.0	6.0	75000
1.0	Inner/ Outer	1.1	2.0	15000	5.0	15.0	75000
3.0	Inner	2.3	2.0	20000	5.0	8.0	75000
	Outer	1.1	2.0	5000	4.5	40	60000

[1] Based on Tables 5.2.24 and 5.II.2.4.

Table 5.II.4.3

COMPARISON OF TOTAL DOSE RATES AROUND THE HI-TRAC MS FOR DIFFERENT MPCs

MPC	**MPC-32M**	**MPC-24**		**MPC-68M**	
Content	**Discrete**	**Uniform**	**Regionalized**	**Uniform**	**Regionalized**
Dose Point[1] Location	**TOTAL DOSE RATES (mrem/hr) [2]**				
ADJACENT TO HI-TRAC					
1	1769	1005	702	1010	815
2	12267	6620	5469	5888	4129
3	203	77	52	95	64
4	7275	3937	2672	3601	2488
5	12237	7738	4781	8123	5849
ONE METER FROM HI-TRAC					
1	1924	1054	785	968	622
2	4243	2521	2154	2260	1537
3	1104	495	392	479	289
4	1551	852	570	699	467

[1] Refer to Figure 5.II.3-4.

[2] Values are rounded to nearest integer.

Table 5.II.4.4

COMPARISON OF TOTAL DOSE RATES AROUND THE HI-STORM 100S VERISON E FOR DIFFERENT MPCs

MPC	MPC-32M	MPC-24		MPC-68M	
Content	**Discrete**	**Uniform**	**Regionalized**	**Uniform**	**Regionalized**
Dose Point[1] Location	**TOTAL DOSE RATES (mrem/hr) [2]**				
ADJACENT TO OVERPACK					
1	577	252	170	393	265
2	135	70	78	87	59
3	160	88	59	79	59
4	13	9	6	7	4
ONE METER FROM OVERPACK					
1	53	27	28	35	23
2	85	43	43	57	37
3	32	16	11	14	9
4	4	2	2	2	1

[1] Refer to Figures 5.II.3-1 AND 5.II.3-3.

[2] Values are rounded to nearest integer.

5.II.5 Regulatory Requirements

The analyses summarized in this supplement demonstrate that the design variations of the HI-STORM 100 System, including the HI-STORM 100S Version E storage cask, the HI-TRAC Version MS transfer cask, MPC-32M as well as the MPC-32 Version 1 and MPC-68 Version 1 canisters, are capable of meeting the applicable regulatory requirements, and support ALARA practices. Thus, this shielding evaluation provides reasonable assurance that the HI-STORM 100 System will allow safe storage of spent fuel.

SUPPLEMENT 10.II: RADIATION PROTECTION

10.II.0 Introduction

This supplement addresses certain variations of the HI-STORM 100 System, namely the HI-STORM 100S Version E storage cask, the HI-TRAC Version MS transfer cask, MPC-32M as well as the MPC-32 Version 1 and MPC-68 Version 1 canisters. These variations are based on the same design considerations and use the same operational features as those described in the main part of this chapter. Therefore, all principal and qualitative discussions in the main part of this chapter on radiation protection, ALARA and regulatory compliance are directly applicable to the design variations addressed here and are not repeated. This supplement to Chapter 10 therefore only discusses consequences of any differences in the designs compared to the main part of this chapter, and these are evaluated based on the more detailed shielding discussions and calculations presented in Supplement 5.II.

One notable difference in the shielding design and ALARA consideration is the variable shielding radial thickness of HI-TRAC Version MS, compared to the fixed dimensions for the 100-ton and 125-ton HI-TRACs in the main part of the chapter. This allows a shielding optimization of the HI-TRAC, based on the site-specific cask weight limits, that is not possible with the 100 or 125-ton HI-TRAC designs. Even a small increase of the HI-TRAC shielding weight can have a significant impact on the dose rates around the cask, as shown in Section 5.II.4. Consistent with the approach in Section 5.II.1, results are presented here for the HI-TRAC MS with the bounding content and shielding thicknesses that result in side dose rates consistent with the applicable dose rate limit for that area.

The MPC-32 Version 1 and MPC-68 Version 1 canisters are variations of the MPC-32 and MPC-68 presented in the main part of this chapter. Based on the discussion in Section 5.II.1, the same or an even better shielding performance is expected for these two versions, and they are therefore qualified without any further analysis.

10.II.1 Ensuring that Occupational Radiation Exposures are As-Low-As-Reasonably-Achievable (ALARA)

Section 10.1 presents auxiliary and temporary shielding options, in Table 10.1.2, that are required for the 100 t and 125 t HI-TRAC transfer casks and the HI-STORM 100 overpack. The same options are applicable to the HI-TRAC MS and HI-STORM Version E, except that HI-TRAC Version MS, as the HI-TRACs 100D and 125D casks, use a mating device and no transfer step. For clarity, the options and requirements for the HI-STORM Version E and the HI-TRAC MS are summarized in Table 10.II.1.1.

Table 10.II.1.1

[PROPRIETARY INFORMATION WITHHELD IN ACCORDANCE WITH 10 CFR 2.390]

10.II.3 Estimated On-Site Collective Dose Assessment

The loading operations for the HI-STORM 100S Version E and HI-TRAC Version MS casks are principally the same as for the reference HI-STORM 100S Version B and 100-ton HI-TRAC, evaluated in the main body of this chapter. However, due to the different design details and different content, individual dose rates may be different. To indicate the effect of those different dose rates, Table 10.3.1b was used as a starting point, and Table 10.II.3.1 shows the same information, with dose rates adjusted for the HI-STORM 100 Version E, the HI-TRAC MS, and the MPC-32M with the bounding content. Consistent with the approach in Section 5.II.1, results are presented for the HI-TRAC MS with shielding thicknesses that result in side dose rates consistent with the applicable dose rate limit for that area.

[PROPRIETARY INFORMATION WITHHELD IN ACCORDANCE WITH 10 CFR 2.390]

[PROPRIETARY INFORMATION WITHHELD IN ACCORDANCE WITH 10 CFR 2.390]

10.II.4 Estimated Collective Dose Assessment

The general discussions in Section 10.4 are directly applicable to the HI-STORM Version E and HI-TRAC Version MS casks, hence only differences in doses and dose rates are presented here.

[PROPRIETARY INFORMATION WITHHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 10.II.4.1

[PROPRIETARY INFORMATION WITHHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 10.II.4.2

[PROPRIETARY INFORMATION WITHHELD IN ACCORDANCE WITH 10 CFR 2.390]

BASES TABLE OF CONTENTS

B 5.0 Administrative Controls and Programs (LCO) APPLICABILITY

B 5.3 Radiation Protection Program

BASES	
B5.3.1	5.3.1 requires that the licensee appropriately includes provisions in their radiation protection program to account for dry storage of the system from loading through unloading. These provisions should also include the requirements included in Section 5.3 of the CoC.
B5.3.2	5.3.2 includes the requirements of 10CFR72.212(b)(2)(i)(c) for a documented evaluation that the dose limits of 10CFR72.104(a) are met. This evaluation should utilize the site-specific ISFSI layout, the planned number of casks, and the cask contents to demonstrate compliance with 10CFR72.104
B5.3.3	In accordance with 5.3.3, licensees should use the analysis performed in 5.3.2 to establish individual cask surface dose rate limits for the HI-TRAC TRANSFER CASK and the HI-STORM OVERPACK, in accordance with the measurement locations specified in 5.3.8. At the top of the OVERPACK, the side of the OVERPACK, and on the side of the TRANSFER CASK, and the inlet and outlet ducts on the OVERPACK. If measured dose rates exceed these limits, it could be an indication of a loading error that may require corrective actions These calculated limits are used in comparison with the measured values in 5.3.8.
B5.3.4	5.3.4 contains additional dose rate limits for a loaded OVERPACK and TRANSFER CASK. These dose rate limits are set at a value above the maximum expected dose rates at the locations described in 5.3.8, from a system loaded with design basis fuel. The measured dose rate limit for the side of the TRANSFER CASK is 4000 mrem/hr (gamma + neutron). If measured dose rates exceed these limits, it could be an indication of a design or loading error that may require corrective actions. Section 5.II.1 of this FSAR contains additional discussions on the selection of the location and dose rate limits.
B5.3.5	5.3.5 provides the requirement that the licensee measure dose rates at the locations outlined in 5.3.8 and compare them to the lower of the two limits established in Section 5.3.3 or 5.3.4. This ensures that the most conservative limit is used.
B5.3.6	5.3.6 establishes corrective actions that shall be taken in the event of measured dose rates that exceed the lower of the two limits in Section 5.3.3 or 5.3.4. These corrective actions include verifying that contents were loaded correctly, performing analyses to ensure 10CFR72.104 dose limits are met, and determining the cause of the higher dose rate.

BASES	
B5.3.7	5.3.7 states that any evaluation under 5.3.6 that shows that 10CFR72.104 dose rate limits will not be met will prevent the MPC from being installed in the OVERPACK or it will be removed from the OVERPACK. This control ensures that the site continues to meet all regulatory requirements.
B5.3.8	5.3.8 establishes locations for surface dose rate measurements. Compliance with 10CFR72.104 dose limits are confirmed with a comparison between these measured dose rates and the dose limits of the system set by calculation and maximum limits in 5.3.3 and 5.3.4 as described in 5.3.5. The measurement locations specified in 5.3.8 ensure the measured dose rates are compared with the analysis described in 5.3.3 at the same geometric location. Comparing the calculated dose rates at the same location as the measured dose rates, provides assurance that the calculated dose (from 5.3.2) bound the actual doses at the site boundary, and therefore assures compliance with 10CFR72.104(a). Even though comparison of dose rates can occur across any location, the locations chosen in 5.3.8 were based on positions where higher dose rates are expected. Higher dose rates provide better measurements to protect against measurement inaccuracy.