# CHAPTER 5[†]: SHIELDING EVALUATION

## 5.0 INTRODUCTION

The shielding analysis of the HI-STORM 100 System, including the HI-STORM 100 overpack, HI-STORM 100S overpack, HI-STORM 100S Version B overpack[††], and the 100-ton (including the 100D) and 125-ton (including the 125D) HI-TRAC transfer casks, is presented in this chapter. The HI-STORM 100 System is designed to accommodate different MPCs within HI-STORM overpacks (the HI-STORM 100S overpack is a shorter version of the HI-STORM 100 overpack and the HI-STORM 100S Version B is shorter than both the HI-STORM 100 and 100S overpacks). The MPCs are designated as MPC-24, MPC-24E and MPC-24EF (24 PWR fuel assemblies), MPC-32 and MPC-32F (32 PWR fuel assemblies), and MPC-68, MPC-68F, and MPC-68FF (68 BWR fuel assemblies). The MPC-24E and MPC-24EF are essentially identical to the MPC-24 from a shielding perspective. Therefore only the MPC-24 is analyzed in this chapter. Likewise, the MPC-68, MPC-68F and MPC-68FF are identical from a shielding perspective as are the MPC-32 and MPC-32F and therefore only the MPC-68 and MPC-32 are analyzed. Throughout this chapter, unless stated otherwise, MPC-24 refers to either the MPC-24, MPC-24E, or MPC-24EF and MPC-32 refers to either the MPC-32 or MPC-32F and MPC-68 refers to the MPC-68, MPC-68F, and MPC-68FF.

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 Sections 2.1.3 and 2.1.9. Both damaged fuel assemblies and fuel debris are required to be loaded into Damaged Fuel Containers (DFCs).

The MPC-68, MPC-68F, and MPC-68FF are also capable of storing Dresden Unit 1 antimony-beryllium neutron sources and the single Thoria rod canister which contains 18 thoria rods that were irradiated in two separate fuel assemblies.

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† 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).

†† The HI-STORM 100S Version B was implemented in the HI-STORM FSAR (between Revisions 2 and 3) through the 10 CFR 72.48 process. The discussion of the HI-STORM 100S Version B and associated results were added to LAR 1014-2 at the end of the review cycle to support the NRC review of the radiation protection program proposed in the Certificate of Compliance in LAR 1014-2. The NRC did not review and approve any aspect of the design of the HI-STORM 100S Version B since it has been implemented under the provisions of 10 CFR 72.48.

PWR fuel assemblies may contain burnable poison rod assemblies (BPRAs), thimble plug devices (TPDs), control rod assemblies (CRAs) or axial power shaping rod assemblies (APSRs), neutron source assemblies (NSAs) or similarly named devices. These non-fuel hardware devices are an integral part of PWR fuel assemblies and therefore the HI-STORM 100 System has been designed to store PWR fuel assemblies with or without these devices. Since each device occupies the same location within a fuel assembly, a single PWR fuel assembly will not contain multiple devices, with the exception of instrument tube tie rods (ITTRs), which may be stored in the assembly along with other types of non-fuel hardware.

In order to offer the user more flexibility in fuel storage, the HI-STORM 100 System offers two different loading patterns in the MPC-24, MPC-24E, MPC-24EF, MPC-32, MPC-32F, MPC-68, and the MPC-68FF. These patterns are uniform and regionalized loading as described in Section 2.0.1 and 2.1.6. Since the different loading patterns have different allowable burnup and cooling times combinations, both loading patterns are discussed in this chapter.

The sections that follow will demonstrate that the design of the HI-STORM 100 dry cask storage system fulfills the following acceptance criteria outlined in the Standard Review Plan, NUREG-1536 [5.2.1]:

Acceptance Criteria

1. The minimum distance from each spent fuel handling and storage facility to the controlled area boundary must be at least 100 meters. The "controlled area" is defined in 10CFR72.3 as the area immediately surrounding an ISFSI or monitored retrievable storage (MRS) facility, for which the licensee exercises authority regarding its use and within which ISFSI operations are performed.

2. The cask vendor must show that, during both normal operations and anticipated occurrences, the radiation shielding features of the proposed dry cask storage system are sufficient to meet the radiation dose requirements in Sections 72.104(a). Specifically, the vendor must demonstrate this capability for a typical array of casks in the most bounding site configuration. For example, the most bounding configuration might be located at the minimum distance (100 meters) to the controlled area boundary, without any shielding from other structures or topography.

3. Dose rates from the cask must be consistent with a well established "as low as reasonably achievable" (ALARA) program for activities in and around the storage site.

4. After a design-basis accident, an individual at the boundary or outside the controlled area shall not receive a dose greater than the limits specified in 10CFR 72.106.

5. The proposed shielding features must ensure that the dry cask storage system meets the regulatory requirements for occupational and radiation dose limits for individual members of the public, as prescribed in 10 CFR Part 20, Subparts C and D.

This chapter contains the following information which demonstrates full compliance with the Standard Review Plan, NUREG-1536:

- A description of the shielding features of the HI-STORM 100 System, including the HI-TRAC transfer cask.
- A description of the bounding source terms.
- A general description of the shielding analysis methodology.
- A description of the analysis assumptions and results for the HI-STORM 100 System, including the HI-TRAC transfer cask.
- Analyses are presented for each MPC showing that the radiation dose rates follow As-Low-As-Reasonably-Achievable (ALARA) practices.
- The HI-STORM 100 System has been analyzed to show that the 10CFR72.104 and 10CFR72.106 controlled area boundary radiation dose limits are met during normal, off-normal, and accident conditions of storage for non-effluent radiation from illustrative ISFSI configurations at a minimum distance of 100 meters.
- Analyses are also presented which demonstrate that the storage of damaged fuel and fuel debris in the HI-STORM 100 System is acceptable during normal, off-normal, and accident conditions.

Chapter 2 contains a detailed description of structures, systems, and components important to safety.

Chapter 7 contains a discussion on the release of radioactive materials from the HI-STORM 100 System. Therefore, this chapter only calculates the dose from direct neutron and gamma radiation emanating from the HI-STORM 100 System.

Chapter 10, Radiation Protection, contains the following information:

- A discussion of the estimated occupational exposures for the HI-STORM 100 System, including the HI-TRAC transfer cask.
- A summary of the estimated radiation exposure to the public.

## 5.1 DISCUSSION AND RESULTS

The principal sources of radiation in the HI-STORM 100 System are:

- Gamma radiation originating from the following sources

    1. Decay of radioactive fission products
    2. Secondary photons from neutron capture in fissile and non-fissile nuclides
    3. Hardware activation products generated during core operations

- Neutron radiation originating from the following sources

    1. Spontaneous fission
    2. $\alpha$,n reactions in fuel materials
    3. Secondary neutrons produced by fission from subcritical multiplication
    4. $\gamma$,n reactions (this source is negligible)
    5. Dresden Unit 1 antimony-beryllium neutron sources

During loading, unloading, and transfer operations, shielding from gamma radiation is provided by the steel structure of the MPC and the steel, lead, and water of the HI-TRAC transfer cask. For storage, the gamma shielding is provided by the MPC, and the steel and concrete of the overpack. Shielding from neutron radiation is provided by the concrete of the overpack during storage and by the water of the HI-TRAC transfer cask during loading, unloading, and transfer operations. Additionally, in the HI-TRAC 125 and 125D top lid and the transfer lid of the HI-TRAC 125, a solid neutron shielding material, Holtite-A is used to thermalize the neutrons. Boron carbide, dispersed in the solid neutron shield material utilizes the high neutron absorption cross section of $^{10}B$ to absorb the thermalized neutrons.

The shielding analyses were performed with MCNP-4A [5.1.1] developed by Los Alamos National Laboratory (LANL). The source terms for the design basis fuels were calculated with the SAS2H and ORIGEN-S sequences from the SCALE 4.3 system [5.1.2, 5.1.3]. A detailed description of the MCNP models and the source term calculations are presented in Sections 5.3 and 5.2, respectively.

The design basis zircaloy clad fuel assemblies used for calculating the dose rates presented in this chapter are B&W 15x15 and the GE 7x7, for PWR and BWR fuel types, respectively. The design basis intact 6x6 and mixed oxide (MOX) fuel assemblies are the GE 6x6. The GE 6x6 is also the design basis damaged fuel assembly for the Dresden Unit 1 and Humboldt Bay array classes. Section 2.1.9 specifies the acceptable intact zircaloy clad fuel characteristics and the acceptable damaged fuel characteristics.

The design basis stainless steel clad fuels are the WE 15x15 and the A/C 10x10, for PWR and BWR fuel types, respectively. Section 2.1.9 specifies the acceptable fuel characteristics of stainless steel clad fuel for storage.

The MPC-24, MPC-24E, MPC-24EF, MPC-32, MPC-32F, MPC-68, and MPC-68FF are qualified for storage of SNF with different combinations of maximum burnup levels and minimum cooling times. Section 2.1.9 specifies the acceptable maximum burnup levels and minimum cooling times for storage of zircaloy clad fuel in these MPCs. Section 2.1.9 also specifies the acceptable maximum burnup levels and minimum cooling times for storage of stainless steel clad fuel. The burnup and cooling time values in Section 2.1.9, which differ by array class, were chosen based on an analysis of the maximum decay heat load that could be accommodated within each MPC. Section 5.2 of this chapter describes the choice of the design basis fuel assembly based on a comparison of source terms and also provides a description of how the allowable burnup and cooling times were derived. Since for a given cooling time, different array classes have different allowable burnups in Section 2.1.9, burnup and cooling times that bound array classes 14x14A and 9x9G were used for the analysis in this chapter since these array class burnup and cooling time combinations bound the combinations from the other PWR and BWR array classes. Section 5.2.5 describes how this results in a conservative estimate of the maximum dose rates.

Section 2.1.9 specifies that the maximum assembly average burnup for PWR and BWR fuel is 68,200 and 65,000 MWD/MTU, respectively. The analysis in this chapter conservatively considers burnups up to 75,000 and 70,000 MWD/MTU for PWR and BWR fuel, respectively.

The burnup and cooling time combinations listed below bound all acceptable uniform and regionalized loading burnup levels and cooling times from Section 2.1.9. All combinations were analyzed in the HI-STORM overpack and HI-TRAC transfer casks.

| Zircaloy Clad Fuel | | |
|---|---|---|
| **MPC-24** | **MPC-32** | **MPC-68** |
| 60,000 MWD/MTU<br>3 year cooling | 45,000 MWD/MTU<br>3 year cooling | 50,000 MWD/MTU<br>3 year cooling |
| 69,000 MWD/MTU<br>4 year cooling | 60,000 MWD/MTU<br>4 year cooling | 62,000 MWD/MTU<br>4 year cooling |
| 75,000 MWD/MTU<br>5 year cooling | 69,000 MWD/MTU<br>5 year cooling | 65,000 MWD/MTU<br>5 year cooling |
| | | 70,000 MWD/MTU<br>6 year cooling |

| Stainless Steel Clad Fuel | | |
|---|---|---|
| **MPC-24** | **MPC-32** | **MPC-68** |
| 40,000 MWD/MTU<br>8 year cooling | 40,000 MWD/MTU<br>9 year cooling | 22,500 MWD/MTU<br>10 year cooling |

Results are presented in this chapter for the single burnup and cooling time combination for zircaloy clad fuel from the above table which produces the highest dose rate at 1 meter from the midplane of the HI-STORM overpack and HI-TRAC transfer casks. The burnup and cooling time combination may be different for normal and accident conditions and for the different overpacks.
As mentioned earlier, there are different versions of the HI-STORM overpack: the HI-STORM 100, the HI-STORM 100S, and the HI-STORM 100S Version B. Section 5.3 describes all three overpacks. However, since the HI-STORM 100S Version B overpack has higher dose rates at the inlet vents and slightly higher offsite dose rates than the other overpacks, results are only presented for the HI-STORM 100S Version B overpack.

The 100-ton HI-TRAC with the MPC-24 has higher normal condition dose rates at the mid-plane than the 100-ton HI-TRAC with the MPC-32 or the MPC-68. Therefore, the MPC-24 results are presented in this section and the MPC-24 was used for the dose exposure estimates in Chapter 10. The MPC-32 results, MPC-68 results, and additional MPC-24 results are provided in Section 5.4 for comparison. The 100-ton HI-TRAC with the MPC-24 also has higher accident condition dose rates at the mid-plane than the 100-ton HI-TRAC with the MPC-32 or the MPC-68. Therefore, the MPC-24 results for accident condition are presented in the section. Accident condition results for the MPC-32 and MPC-68 in the 100-ton HI-TRAC are not provided in this chapter. The HI-TRAC 100D is a variation on the 100-ton HI-TRAC with fewer radial ribs and a slightly different lower water jacket. Section 5.4 presents results for the HI-TRAC 100D with the MPC-32.

The HI-TRAC 100 and 100D dose rates bound the HI-TRAC 125 and 125D dose rates for the same burnup and cooling time combinations. Therefore, for illustrative purposes, the MPC-24 was the only MPC analyzed in the HI-TRAC 125 and 125D. Since the HI-TRAC 125D has fewer radial ribs, the dose rate at the midplane of the HI-TRAC 125D is higher than the dose rate at the midplane of the HI-TRAC 125. Therefore, the results on the radial surface are only presented for the HI-TRAC 125D in this chapter.

As a general statement, the dose rates for uniform loading presented in this chapter bound the dose rates for regionalized loading therefore, dose rates for specific burnup and cooling time combinations in a regionalized loading pattern are not presented in this chapter. For regionalized loading where higher burned or shorter cooled assemblies are placed in the center of the cask, the dose rates would be substantially lower than the bounding dose rates presented here. For regionalized loading where the higher burned or shorter cooled assemblies are placed on the periphery, the dose rates could be closer to the bounding dose rates presented here. Section 5.4.9 provides an additional brief discussion on regionalized loading.

Unless otherwise stated all tables containing dose rates for design basis fuel refer to design basis intact zircaloy clad fuel.

### 5.1.1 Normal and Off-Normal Operations

Chapter 11 discusses the potential off-normal conditions and their effect on the HI-STORM 100 System. None of the off-normal conditions have any impact on the shielding analysis. Therefore, off-normal and normal conditions are identical for the purpose of the shielding evaluation.

The 10CFR72.104 criteria for radioactive materials in effluents and direct radiation during normal operations are:

1. *During normal operations and anticipated occurrences, the annual dose equivalent to any real individual who is located beyond the controlled area, must not exceed 25 mrem to the whole body, 75 mrem to the thyroid and 25 mrem to any other critical organ.*

2. Operational restrictions must be established to meet as low as reasonably achievable (ALARA) objectives for radioactive materials in effluents and direct radiation.

10CFR20 Subparts C and D specify additional requirements for occupational dose limits and radiation dose limits for individual members of the public. Chapter 10 specifically addresses these regulations.

In accordance with ALARA practices, design objective dose rates are established for the HI-STORM 100 System in Section 2.3.5.2 as: 300 mrem/hour on the radial surface of the overpack, 175 mrem/hour at the openings of the air vents, and 60 mrem/hour on the top of the overpack.

The HI-STORM overpack dose rates presented in this section are conservatively evaluated for the MPC-32, the MPC-68, and the MPC-24. All burnup and cooling time combinations analyzed bound the allowable burnup and cooling times specified in Section 2.1.9.

Figure 5.1.13 identifies the locations of the dose points referenced in the dose rate summary tables for the HI-STORM 100S Version B overpack. Dose Points #1 and #3 are the locations of the inlet and outlet air ducts, respectively. The dose values reported for these locations (adjacent and 1 meter) were averaged over the duct opening. Dose Point #4 is the peak dose location above the overpack shield block. For the adjacent top dose, this dose point is located over the air annulus between the MPC and the overpack. The dose values reported at the locations shown on Figure 5.1.13 are averaged over a region that is approximately 1 foot in width.

The total dose rates presented in this chapter for the MPC-24 and MPC-32 are presented for two cases: with and without BPRAs. The dose from the BPRAs was conservatively assumed to be the maximum calculated in Section 5.2.4.1. This is conservative because it is not expected that the cooling times for both the BPRAs and fuel assemblies would be such that they are both at the maximum design basis values.

Tables 5.1.11, 5.1.12, and 5.1.13 provide the maximum dose rates adjacent to the HI-STORM 100S Version B overpack during normal conditions for the MPC-32, MPC-24, and MPC-68. Tables 5.1.14 through 5.1.16 provide the maximum dose rates at one meter from the HI-STORM 100S Version B overpack.

The HI-STORM 100S Version B overpack was analyzed for the dose rate at the controlled area boundary. Although the dose rates for the MPC-32 in HI-STORM 100S Version B are greater than those for the MPC-24 in HI-STORM 100S Version B at the ventilation ducts, as shown in Tables 5.1.11 and 5.1.12, the MPC-24 was used in the calculations for the dose rates at the controlled area boundary for the HI-STORM 100S Version B overpack. This is acceptable because the vents are a small fraction of the radial surface area and the MPC-24 has higher dose rates at the radial midplane than the MPC-32 in the HI-STORM 100S Version B overpack. The MPC-24 was also chosen because, for a given cooling time, the MPC-24 has a higher allowable burnup than the MPC-32 or the MPC-68 (see Section 2.1.9). Consequently, for the allowable burnup and cooling times, the MPC-24 will have dose rates that are greater than or equivalent to those from the MPC-68 and MPC-32. The controlled area boundary dose rates were also calculated including the BPRA non-fuel hardware source. In the site specific dose analysis, users should perform an analysis which properly bounds the fuel to be stored including BPRAs if present.

Table 5.1.7 provides dose rates adjacent to and one meter from the 100-ton HI-TRAC. Table 5.1.8 provides dose rates adjacent to and one meter from the 125-ton HI-TRACs. Figures 5.1.2 and 5.1.4 identify the locations of the dose points referenced in Tables 5.1.7 and 5.1.8 for the HI-TRAC 125 and 100 transfer casks, respectively. The dose rates listed in Tables 5.1.7 and 5.1.8 correspond to the normal condition in which the MPC is dry and the HI-TRAC water jacket is filled with water. The dose rates below the HI-TRAC (Dose Point #5) are provided for two conditions. The first condition is when the pool lid is in use and the second condition is when the transfer lid is in use. The HI-TRAC 125D does not utilize the transfer lid, rather it utilizes the pool lid in conjunction with the mating device. Therefore the dose rates reported for the pool lid are applicable to both the HI-TRAC 125 and 125D while the dose rates reported for the transfer lid are applicable only to the HI-TRAC 125. The calculational model of the 100-ton HI-TRAC included a concrete floor positioned 6 inches (the typical carry height) below the pool lid to account for ground scatter. As a result of the modeling, the dose rate at 1 meter from the pool lid for the 100-ton HI-TRAC was not calculated. The dose rates provided in Tables 5.1.7 and 5.1.8 are for the MPC-24 with design basis fuel at burnups and cooling times, based on the allowed burnup and cooling times specified in Section 2.1.9, that result in dose rates that are generally higher in each of the two HI-TRAC designs. The burnup and cooling time combination used for both the 100-ton and 125-ton HI-TRAC was chosen to bound the allowable burnup and cooling times in Section 2.1.9. Results for other burnup and cooling times and for the MPC-68 and MPC-32 are provided in Section 5.4.

Because the dose rates for the 100-ton HI-TRAC transfer cask are significantly higher than the dose rates for the 125-ton HI-TRACs or the HI-STORM overpack, it is important to understand the behavior of the dose rates surrounding the external surface. To assist in this understanding, several figures, showing the dose rate profiles on the top, bottom and sides of the 100-ton HI-TRAC transfer cask, are presented below. The figures discussed below were all calculated without the gamma source from BPRAs and were calculated for an earlier design of the HI-TRAC which utilized 30 steel fins 0.375 inches thick compared to 10 steel fins 1.25 inches thick. The change in rib design only affects the magnitude of the dose rates presented for the radial surface but does not affect the conclusions discussed below.

Figure 5.1.5 shows the dose rate profile at 1 foot from the side of the 100-ton HI-TRAC transfer cask with the MPC-24 for 35,000 MWD/MTU and 5 year cooling. This figure clearly shows the behavior of the total dose rate and each of the dose components as a function of the cask height. To capture the effect of scattering off the concrete floor, the calculational model simulates the 100-ton HI-TRAC at a height of 6 inches (the typical cask carry height) above the concrete floor. As expected, the total dose rate on the side near the top and bottom is dominated by the Co-60 gamma dose component, while the center dose rate is dominated by the fuel gamma dose component.

The total dose rate and individual dose rate components on the surface of the pool lid on the HI-TRAC-100 when uniformly loaded are provided in Figure 5.1.6, illustrating the significant reduction in dose rate with increasing distance from the center of the pool lid. Specifically, the total dose rate is shown to drop by a factor of more than 20 from the center of the pool lid to the outer edge of the HI-TRAC. Therefore, even though the dose rate in Table 5.1.7 at the center of the pool lid is substantial, the dose rate contribution, from the pool lid, to the personnel exposure is minimal.

The behavior of the dose rate 1-foot from the transfer lid is shown in Figure 5.1.7. Similarly, the total dose rate and the individual dose rate components 1-foot from the top lid, as a function of distance from the axis of the 100-ton HI-TRAC, are shown in Figure 5.1.8. For both lids (transfer and top), the reduction in dose rate with increased distance from the cask axial centerline is substantial.

Note that regionalized loading can have a significant effect on the variation of the dose rate on the top and bottom as a function of the distance from the cask centerline. For a regionalized loading with higher burnup fuel in the center region, the dose rate profiles would be even more pronounced, i.e. the difference between the dose rate in the center and the dose rate near the edge of the cask would be larger than shown in Figures 5.1.7 and 5.1.8. However, if a regionalized loading plan is selected where the higher burnup fuel is located in the outer region, then the difference would be less. In extreme cases, it would even be possible that the dose rate near the edge of the MPC is higher than the one at the center of the cask. This should be considered during loading operations in order to minimize occupational doses.

To reduce the dose rate above the water jacket, a localized temporary shield ring, described in Chapter 8, may be employed on the 125-ton HI-TRACs and on the 100-ton HI-TRAC. This temporary shielding, which is water, essentially extends the water jacket to the top of the HI-TRAC. The effect of the temporary shielding on the side dose rate above the water jacket (in the area around the lifting trunnions and the upper flange) is shown on Figure 5.1.9, which shows the dose profile on the side of the 100-ton HI-TRAC with the temporary shielding installed. For comparison, the total dose rate without temporary shielding installed is also shown on Figure 5.1.9. The results indicate that the temporary shielding reduces the dose rate by approximately a factor of 2 in the area above the water jacket.

To illustrate the reduction in dose rate with distance from the side of the 100-ton HI-TRAC, Figure 5.1.10 shows the total dose rate on the surface and at distances of 1-foot and 1-meter.

Figure 5.1.11 plots the total dose rate at various distances from the bottom of the transfer lid, including distances of 1, 5, 10, and 15 feet. Near the transfer lid, the total dose rate is shown to decrease significantly as a function of distance from the 100-ton HI-TRAC axial centerline. Near the axis of the HI-TRAC, the reduction in dose rate from the 1-foot distance to the 15-foot distance is approximately a factor of 15. The dose rate beyond the radial edge of the HI-TRAC is also shown to be relatively low at all distances from the HI-TRAC transfer lid. Thus, prudent transfer operating procedures will employ the use of distance to reduce personnel exposure. In addition, when the HI-TRAC is in the horizontal position and is being transported on site, a missile shield may be positioned in front of the HI-TRAC transfer lid or pool lid. If present, this shield would also serve as temporary gamma shielding which would greatly reduce the dose rate in the vicinity of the transfer lid or pool lid. For example, if the missile shield was a 2 inch thick steel plate, the gamma dose rate would be reduced by approximately 90%.

The dose to any real individual at or beyond the controlled area boundary is required to be below 25 mrem per year. The minimum distance to the controlled area boundary is 100 meters from the ISFSI. As mentioned, only the MPC-24 was used in the calculation of the dose rates at the controlled area boundary. Table 5.1.9 presents the annual dose to an individual from a single HI-STORM 100S Version B 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. These values were conservatively calculated for a burnup of 60,000 MWD/MTU and a 3-year cooling time. In addition, the annual dose was calculated for a burnup of 45,000 MWD/MTU with a corresponding cooling time of 9 years. BPRAs were included in these dose estimates. It is noted that these data are provided for illustrative purposes only. A detailed site-specific evaluation of dose at the controlled area boundary must be performed for each ISFSI in accordance with 10CFR72.212. The site-specific evaluation will consider dose from other portions of the facility and will consider the actual conditions of the fuel being stored (burnup and cooling time).

Figure 5.1.3 is an annual dose versus distance graph for the HI-STORM 100 cask array configurations provided in Table 5.1.9. This curve, which is based on an 8760 hour occupancy, is provided for illustrative purposes only and will be re-evaluated on a site-specific basis.

Section 5.2 lists the gamma and neutron sources for the design basis fuels. Since the source strengths of the GE 6x6 intact and damaged fuel and the GE 6x6 MOX fuel are significantly smaller in all energy groups than the intact design basis fuel source strengths, the dose rates from the GE 6x6 fuels for normal conditions are bounded by the MPC-68 analysis with the design basis intact fuel. Therefore, no explicit analysis of the MPC-68 with either GE 6x6 intact or damaged or GE 6x6 MOX fuel for normal conditions is required to demonstrate that the MPC-68 with GE 6x6 fuels will meet the normal condition regulatory requirements. Section 5.4.2 evaluates the effect of generic damaged fuel in the MPC-24E, MPC-32 and the MPC-68.

Section 5.2.6 lists the gamma and neutron sources from the Dresden Unit 1 Thoria rod canister and demonstrates that the Thoria rod canister is bounded by the design basis Dresden Unit 1 6x6 intact fuel.

Section 5.2.4 presents the Co-60 sources from the BPRAs, TPDs, CRAs and APSRs that are permitted for storage in the HI-STORM 100 System. Section 5.4.6 discusses the increase in dose rate as a result of adding non-fuel hardware in the MPCs.

Section 5.4.7 demonstrates that the Dresden Unit 1 fuel assemblies containing antimony-beryllium neutron sources are bounded by the shielding analysis presented in this section.

Section 5.2.3 lists the gamma and neutron sources for the design basis stainless steel clad fuel. The dose rates from this fuel are provided in Section 5.4.4.

The analyses summarized in this section demonstrate that the HI-STORM 100 System, including the HI-TRAC transfer cask, are in compliance with the 10CFR72.104 limits and ALARA practices.

### 5.1.2 Accident Conditions

The 10CFR72.106 radiation dose limits at the controlled area boundary for design basis accidents are:

> Any individual located on or beyond the nearest boundary of the controlled area may not receive from any design basis accident the more limiting of a total effective dose equivalent of 5 Rem, or the sum of the deep-dose equivalent and the committed dose equivalent to any individual organ or tissue (other than the lens of the eye) of 50 Rem. The lens dose equivalent shall not exceed 15 Rem and the shallow dose equivalent to skin or to any extremity shall not exceed 50 Rem. The minimum distance from the spent fuel or high-level radioactive waste handling and storage facilities to the nearest boundary of the controlled are shall be at least 100 meters.

Design basis accidents which may affect the HI-STORM overpack can result in limited and localized damage to the outer shell and radial concrete shield. As the damage is localized and the vast majority of the shielding material remains intact, the effect on the dose at the site boundary is negligible. Therefore, the site boundary, adjacent, and one meter doses for the loaded HI-STORM overpack for accident conditions are equivalent to the normal condition doses, which meet the 10CFR72.106 radiation dose limits.

The design basis accidents analyzed in Chapter 11 have one bounding consequence that affects the shielding materials of the HI-TRAC transfer cask. It is the potential for damage to the water jacket shell and the loss of the neutron shield (water). In the accident consequence analysis, it is conservatively assumed that the neutron shield (water) is completely lost and replaced by a void.

Throughout all design basis accident conditions the axial location of the fuel will remain fixed within the MPC because of the fuel spacers. The HI-STAR 100 System (Docket Number 72-1008) documentation provides analysis to demonstrate that the fuel spacers will not fail under any normal, off-normal, or accident condition of storage. Chapter 3 also shows that the HI-TRAC inner shell, lead, and outer shell remain intact throughout all design basis accident conditions. Localized damage of the HI-TRAC outer shell could be experienced. However, the localized deformations will have only a negligible impact on the dose rate at the boundary of the controlled area.

The complete loss of the HI-TRAC neutron shield significantly affects the dose at mid-height (Dose Point #2) adjacent to the HI-TRAC. Loss of the neutron shield has a small effect on the dose at the other dose points. To illustrate the impact of the design basis accident, the dose rates at Dose Point #2 (see Figures 5.1.2 and 5.1.4) are provided in Table 5.1.10 for the 100-ton and 125-ton HI-TRACs at a distance of 1 meter and for the 100-ton HI-TRAC at a distance of 100 meters The normal condition dose rates are provided for reference. Table 5.1.10 provides a comparison of the normal and accident condition dose rates at one meter from the HI-TRAC. The burnup and cooling time combinations used in Table 5.1.10 were the combinations that resulted in the highest post-accident condition dose rates. These burnup and cooling time combinations do not necessarily correspond to the burnup and cooling time combinations that result in the highest dose rate during normal conditions.. Based on the dose rate at 100 meters in Table 5.1.10, it would take 1608 hours (~67 days) for the dose at the controlled area boundary to reach 5 Rem. Assuming an accident duration of 30 days, the accumulated dose at the controlled area boundary would be 2.2Rem. Based on this dose rate and the short duration of use for the loaded HI-TRAC transfer cask, it is evident that the dose as a result of the design basis accident cannot exceed 5 Rem at the controlled area boundary for the short duration of the accident.

The consequences of the design basis accident conditions for the MPC-68 and MPC-24E storing damaged fuel and/or fuel debris differ slightly from those with intact fuel. It is conservatively assumed that during a drop accident (vertical, horizontal, or tip-over) the damaged fuel collapses and the pellets rest in the bottom of the damaged fuel container. Analyses in Section 5.4.2 demonstrates that the damaged fuel in the post-accident condition does not significantly affect the dose rates around the cask. Therefore, the damaged fuel post-accident dose rates are bounded by the intact fuel post-accident dose rates.

Analyses summarized in this section demonstrate that the HI-STORM 100 System, including the HI-TRAC transfer cask, are in compliance with the 10CFR72.106 limits.

Table 5.1.1

[INTENTIONALLY DELETED]

Table 5.1.2

[INTENTIONALLY DELETED]

Table 5.1.3

[INTENTIONALLY DELETED]

Table 5.1.4

[INTENTIONALLY DELETED]

Table 5.1.5

[INTENTIONALLY DELETED]

Table 5.1.6

[INTENTIONALLY DELETED]

Table 5.1.7

DOSE RATES FROM THE 100-TON HI-TRAC FOR NORMAL CONDITIONS
MPC-24 DESIGN BASIS ZIRCALOY CLAD FUEL
60,000 MWD/MTU AND 3-YEAR COOLING

| Dose Point Location | Fuel Gammas (mrem/hr) | (n,γ) Gammas (mrem/hr) | $^{60}$Co Gammas (mrem/hr) | Neutrons (mrem/hr) | Totals (mrem/hr) | Totals with BPRAs (mrem/hr) |
|---|---|---|---|---|---|---|
| **ADJACENT TO THE 100-TON HI-TRAC** | | | | | | |
| 1 | 124.94 | 33.16 | 958.00 | 469.38 | 1585.48 | 1594.02 |
| 2 | 3196.67† | 134.95 | 0.96 | 249.02 | 3581.60 | 3828.84 |
| 3 | 36.47 | 6.50 | 528.22 | 392.74 | 963.94 | 1112.46 |
| 3 (temp) | 16.31 | 11.57 | 244.83 | 6.31 | 279.02 | 347.16 |
| 4 | 80.38 | 2.57 | 425.12 | 483.50 | 991.57 | 1116.07 |
| 4 (outer) | 23.94 | 1.63 | 105.85 | 326.35 | 457.77 | 489.10 |
| 5 (pool lid) | 623.98 | 47.34 | 4826.78 | 3152.66 | 8650.76 | 8715.53 |
| 5 (transfer) | 1243.30 | 2.59 | 7192.64 | 1805.36 | 10243.89 | 10340.73 |
| 5(t-outer) | 318.58 | 0.89 | 696.19 | 713.29 | 1728.95 | 1750.42 |
| **ONE METER FROM THE 100-TON HI-TRAC** | | | | | | |
| 1 | 422.99 | 17.82 | 142.41 | 76.30 | 659.52 | 692.00 |
| 2 | 1400.26† | 41.25 | 11.27 | 93.37 | 1546.14 | 1655.62 |
| 3 | 177.50 | 9.93 | 118.30 | 36.64 | 342.37 | 391.80 |
| 3 (temp) | 176.53 | 10.66 | 100.76 | 13.85 | 301.80 | 346.37 |
| 4 | 27.82 | 0.45 | 131.25 | 120.44 | 279.96 | 318.53 |
| 5 (transfer) | 552.69 | 0.48 | 2938.22 | 503.83 | 3995.21 | 4034.34 |
| 5(t-outer) | 76.44 | 1.54 | 264.85 | 144.64 | 487.47 | 491.37 |

Notes:

- Refer to Figures 5.1.2 and 5.1.4 for dose locations.
- Dose location 3(temp) represents dose location 3 with temporary shielding installed.
- Dose location 4(outer) is the radial segment at dose location 4 which is 18-30 inches from the center of the overpack.
- Dose location 5(t-outer) is the radial segment at dose location 5 (transfer lid) which is 30-42 and 54-66 inches from the center of the lid for the adjacent and one meter locations, respectively. The inner radius of the HI-TRAC is 34.375 in. and the outer radius of the water jacket is 44.375 in.
- Dose rate based on no water within the MPC. For the majority of the duration that the HI-TRAC pool lid is installed, the MPC cavity will be flooded with water. The water within the MPC greatly reduces the dose rate.

† The cobalt activation of incore grid spacers accounts for approximately 6% of the surface and one-meter dose rates.

Table 5.1.8

DOSE RATES FROM THE 125-TON HI-TRACS FOR NORMAL CONDITIONS
MPC-24 DESIGN BASIS ZIRCALOY CLAD FUEL
75,000 MWD/MTU AND 5-YEAR COOLING

| **Dose Point Location** | **Fuel Gammas (mrem/hr)** | **(n,γ) Gammas (mrem/hr)** | **$^{60}$Co Gammas (mrem/hr)** | **Neutrons (mrem/hr)** | **Totals (mrem/hr)** | **Totals with BPRAs (mrem/hr)** |
|---|---|---|---|---|---|---|
| **ADJACENT TO THE 125-TON HI-TRACs** | | | | | | |
| 1 | 6.32 | 61.85 | 100.63 | 415.90 | 584.70 | 585.42 |
| 2 | 113.33† | 183.20 | 0.01 | 287.94 | 584.49 | 600.36 |
| 3 | 1.41 | 6.55 | 62.26 | 663.65 | 733.88 | 753.59 |
| 4 | 41.57 | 8.40 | 340.67 | 767.94 | 1158.58 | 1274.01 |
| 4 (outer) | 4.84 | 6.00 | 42.31 | 16.11 | 69.26 | 83.45 |
| 5 (pool) | 54.77 | 3.67 | 454.56 | 2883.53 | 3396.53 | 3404.24 |
| 5 (transfer) | 65.81 | 4.78 | 601.40 | 440.29 | 1112.28 | 1117.76 |
| **ONE METER FROM THE 125-TON HI-TRACs** | | | | | | |
| 1 | 14.93 | 24.68 | 12.90 | 68.44 | 120.95 | 122.99 |
| 2 | 50.47† | 59.39 | 0.52 | 98.23 | 208.61 | 215.68 |
| 3 | 5.66 | 13.95 | 12.58 | 61.07 | 93.26 | 98.17 |
| 4 | 11.54 | 2.03 | 82.02 | 79.09 | 174.68 | 202.33 |
| 5 (transfer) | 25.98 | 0.92 | 290.76 | 76.26 | 393.92 | 396.85 |

Notes:
- Refer to Figures 5.1.2 and 5.1.4 for dose locations.
- Dose location 4(outer) is the radial segment at dose location 4 which is 18-24 inches from the center of the overpack.
- Dose rate based on no water within the MPC. For the majority of the duration that the HI-TRAC pool lid is installed, the MPC cavity will be flooded with water. The water within the MPC greatly reduces the dose rate.

† The cobalt activation of incore grid spacers accounts for 9.4% of the surface and one-meter dose rates.

Table 5.1.9

DOSE RATES FOR ARRAYS OF MPC-24
WITH DESIGN BASIS ZIRCALOY CLAD FUEL
AT VARYING BURNUP AND COOLING TIMES

| Array Configuration | 1 cask | 2x2 | 2x3 | 2x4 | 2x5 |
|---|---|---|---|---|---|
| **HI-STORM 100S Version B Overpack** | | | | | |
| **60,000 MWD/MTU AND 3-YEAR COOLING** | | | | | |
| Annual Dose (mrem/year) † | 19.26 | 16.41 | 24.62 | 20.36 | 16.34 |
| Distance to Controlled Area Boundary (meters) ††,††† | 350 | 450 | 450 | 500 | 550 |
| **45,000 MWD/MTU AND 9-YEAR COOLING** | | | | | |
| Annual Dose (mrem/year) † | 23.56 | 14.30 | 21.46 | 15.89 | 19.86 |
| Distance to Controlled Area Boundary (meters) †† | 200 | 300 | 300 | 350 | 350 |

† 8760 hr. annual occupancy is assumed.

†† Dose location is at the center of the long side of the array.

††† Actual controlled area boundary dose rates will be lower because the maximum permissible burnup for 3-year cooling, as specified in the Section 2.1.9, is lower than the burnup used for this analysis.

Table 5.1.10

DOSE RATES FROM HI-TRAC
FOR ACCIDENT CONDITIONS
MPC-24 DESIGN BASIS ZIRCALOY CLAD FUEL
AT BOUNDING BURNUP AND COOLING TIMES

| **Dose Point[†] Location** | **Fuel Gammas[††] (mrem/hr)** | **$^{60}$Co Gammas (mrem/hr)** | **Neutrons (mrem/hr)** | **Totals (mrem/hr)** | **Totals with BPRAs (mrem/hr)** |
|---|---|---|---|---|---|
| **ONE METER FROM HI-TRAC** | | | | | |
| **125-TON HI-TRACs** | | | | | |
| **75,000 MWD/MTU AND 5-YEAR COOLING** | | | | | |
| 2 (Accident Condition) | 92.26 | 1.02 | 3476.98 | 3570.26 | 3583.16 |
| 2 (Normal Condition) | 109.86 | 0.52 | 98.23 | 208.61 | 215.68 |
| **100-TON HI-TRAC** | | | | | |
| **75,000 MWD/MTU AND 5-YEAR COOLING** | | | | | |
| 2 (Accident Condition) | 1354.67 | 17.88 | 4359.16 | 5731.72 | 5927.95 |
| 2 (Normal Condition) | 829.09 | 9.90 | 168.82 | 1007.81 | 1117.29 |
| **100 METERS FROM HI-TRAC** | | | | | |
| **100-TON HI-TRAC** | | | | | |
| **75,000 MWD/MTU AND 5-YEAR COOLING** | | | | | |
| 2 (Accident Condition) | 0.68 | 0.10 | 2.22 | 3.00 | 3.11 |

† Refer to Figures 5.1.2 and 5.1.4.

†† Gammas generated by neutron capture are included with fuel gammas.

Table 5.1.11

DOSE RATES ADJACENT TO HI-STORM 100S VERSION B OVERPACK
FOR NORMAL CONDITIONS
MPC-32 DESIGN BASIS ZIRCALOY CLAD FUEL AT BOUNDING
BURNUP AND COOLING TIME
45,000 MWD/MTU AND 3-YEAR COOLING

| **Dose Point† Location** | **Fuel Gammas†† (mrem/hr)** | **$^{60}$Co Gammas (mrem/hr)** | **Neutrons (mrem/hr)** | **Totals (mrem/hr)** | **Totals with BPRAs (mrem/hr)** |
|---|---|---|---|---|---|
| 1 | 41.37 | 70.98 | 14.80 | 127.15 | 130.10 |
| 2 | 239.51 | 0.32 | 4.24 | 244.08 | 261.07 |
| 3 | 11.22 | 17.82 | 5.51 | 34.54 | 40.95 |
| 4 | 12.02 | 4.29 | 4.11 | 20.43 | 22.78 |

† Refer to Figure 5.1.13.

†† Gammas generated by neutron capture are included with fuel gammas.

Table 5.1.12

DOSE RATES ADJACENT TO HI-STORM 100S VERSION B OVERPACK
FOR NORMAL CONDITIONS
MPC-24 DESIGN BASIS ZIRCALOY CLAD FUEL AT BOUNDING
BURNUP AND COOLING TIME
60,000 MWD/MTU AND 3-YEAR COOLING

| Dose Point† Location | Fuel Gammas†† (mrem/hr) | $^{60}Co$ Gammas (mrem/hr) | Neutrons (mrem/hr) | Totals (mrem/hr) | Totals with BPRAs (mrem/hr) |
|---|---|---|---|---|---|
| 1 | 34.25 | 57.09 | 29.86 | 121.20 | 122.67 |
| 2 | 252.16 | 0.10 | 7.16 | 259.41 | 273.60 |
| 3 | 13.56 | 15.57 | 9.82 | 38.94 | 43.90 |
| 4 | 13.42 | 4.65 | 7.22 | 25.29 | 27.30 |

† Refer to Figure 5.1.13.

†† Gammas generated by neutron capture are included with fuel gammas.

Table 5.1.13

DOSE RATES ADJACENT TO HI-STORM 100S VERSION B OVERPACK
FOR NORMAL CONDITIONS
MPC-68 DESIGN BASIS ZIRCALOY CLAD FUEL AT BOUNDING
BURNUP AND COOLING TIME
50,000 MWD/MTU AND 3-YEAR COOLING

| **Dose Point† Location** | **Fuel Gammas†† (mrem/hr)** | **$^{60}$Co Gammas (mrem/hr)** | **Neutrons (mrem/hr)** | **Totals (mrem/hr)** |
|---|---|---|---|---|
| 1 | 20.15 | 56.22 | 18.80 | 95.17 |
| 2 | 211.31 | 0.12 | 6.38 | 217.81 |
| 3 | 4.39 | 18.15 | 3.73 | 26.27 |
| 4 | 7.76 | 5.05 | 3.40 | 16.20 |

† Refer to Figure 5.1.13.

†† Gammas generated by neutron capture are included with fuel gammas.

Table 5.1.14

DOSE RATES AT ONE METER FROM HI-STORM 100S VERSION B OVERPACK
FOR NORMAL CONDITIONS
MPC-32 DESIGN BASIS ZIRCALOY CLAD FUEL AT BOUNDING
BURNUP AND COOLING TIME
45,000 MWD/MTU AND 3-YEAR COOLING

| Dose Point† Location | Fuel Gammas†† (mrem/hr) | $^{60}$Co Gammas (mrem/hr) | Neutrons (mrem/hr) | Totals (mrem/hr) | Totals with BPRAs (mrem/hr) |
|---|---|---|---|---|---|
| 1 | 32.51 | 18.19 | 2.41 | 53.10 | 55.78 |
| 2 | 124.98 | 1.42 | 1.75 | 128.15 | 136.88 |
| 3 | 14.74 | 8.67 | 0.75 | 24.16 | 28.13 |
| 4 | 2.79 | 1.31 | 1.16 | 5.26 | 5.89 |

† Refer to Figure 5.1.13.

†† Gammas generated by neutron capture are included with fuel gammas.

Table 5.1.15

DOSE RATES AT ONE METER FROM HI-STORM 100S VERSION B OVERPACK
FOR NORMAL CONDITIONS
MPC-24 DESIGN BASIS ZIRCALOY CLAD FUEL AT BOUNDING
BURNUP AND COOLING TIME
60,000 MWD/MTU AND 3-YEAR COOLING

| Dose Point† Location | Fuel Gammas†† (mrem/hr) | $^{60}$Co Gammas (mrem/hr) | Neutrons (mrem/hr) | Totals (mrem/hr) | Totals with BPRAs (mrem/hr) |
|---|---|---|---|---|---|
| 1 | 33.12 | 16.07 | 4.80 | 54.00 | 55.76 |
| 2 | 129.84 | 1.15 | 2.84 | 133.83 | 141.21 |
| 3 | 15.89 | 7.23 | 1.30 | 24.42 | 27.44 |
| 4 | 3.22 | 1.41 | 2.36 | 6.99 | 7.54 |

† Refer to Figure 5.1.13.

†† Gammas generated by neutron capture are included with fuel gammas.

Table 5.1.16

DOSE RATES AT ONE METER FROM HI-STORM 100S VERSION B OVERPACK
FOR NORMAL CONDITIONS
MPC-68 DESIGN BASIS ZIRCALOY CLAD FUEL AT BOUNDING
BURNUP AND COOLING TIME
50,000 MWD/MTU AND 3-YEAR COOLING

| **Dose Point† Location** | **Fuel Gammas†† (mrem/hr)** | **$^{60}$Co Gammas (mrem/hr)** | **Neutrons (mrem/hr)** | **Totals (mrem/hr)** |
|---|---|---|---|---|
| 1 | 25.76 | 15.91 | 3.21 | 44.88 |
| 2 | 107.43 | 0.95 | 2.46 | 110.84 |
| 3 | 7.78 | 8.96 | 0.73 | 17.47 |
| 4 | 1.78 | 1.65 | 0.84 | 4.27 |

† Refer to Figure 5.1.13.

†† Gammas generated by neutron capture are included with fuel gammas.

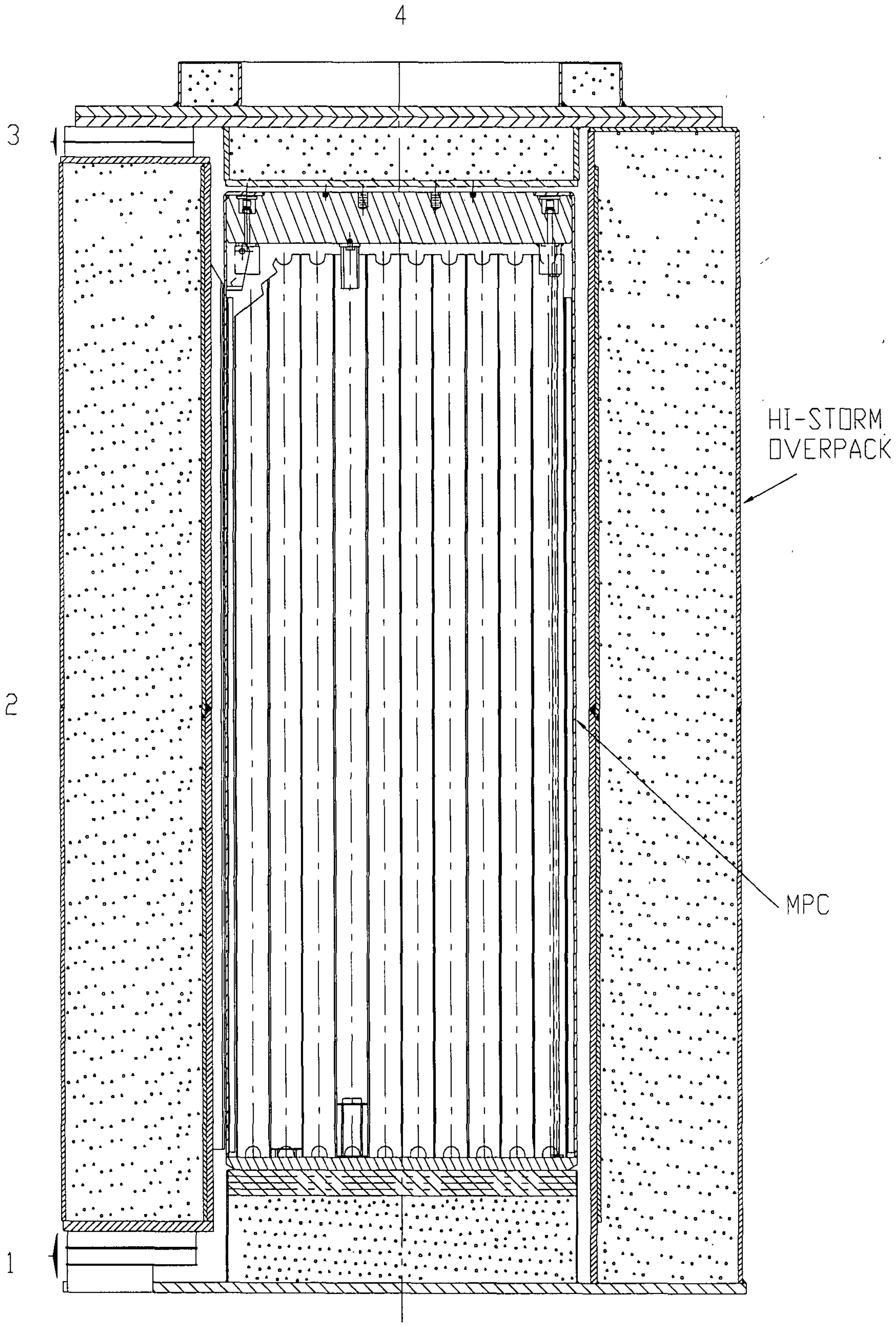


FIGURE 5.1.1; CROSS SECTION ELEVATION VIEW OF HI-STORM 100 OVERPACK
WITH DOSE POINT LOCATION

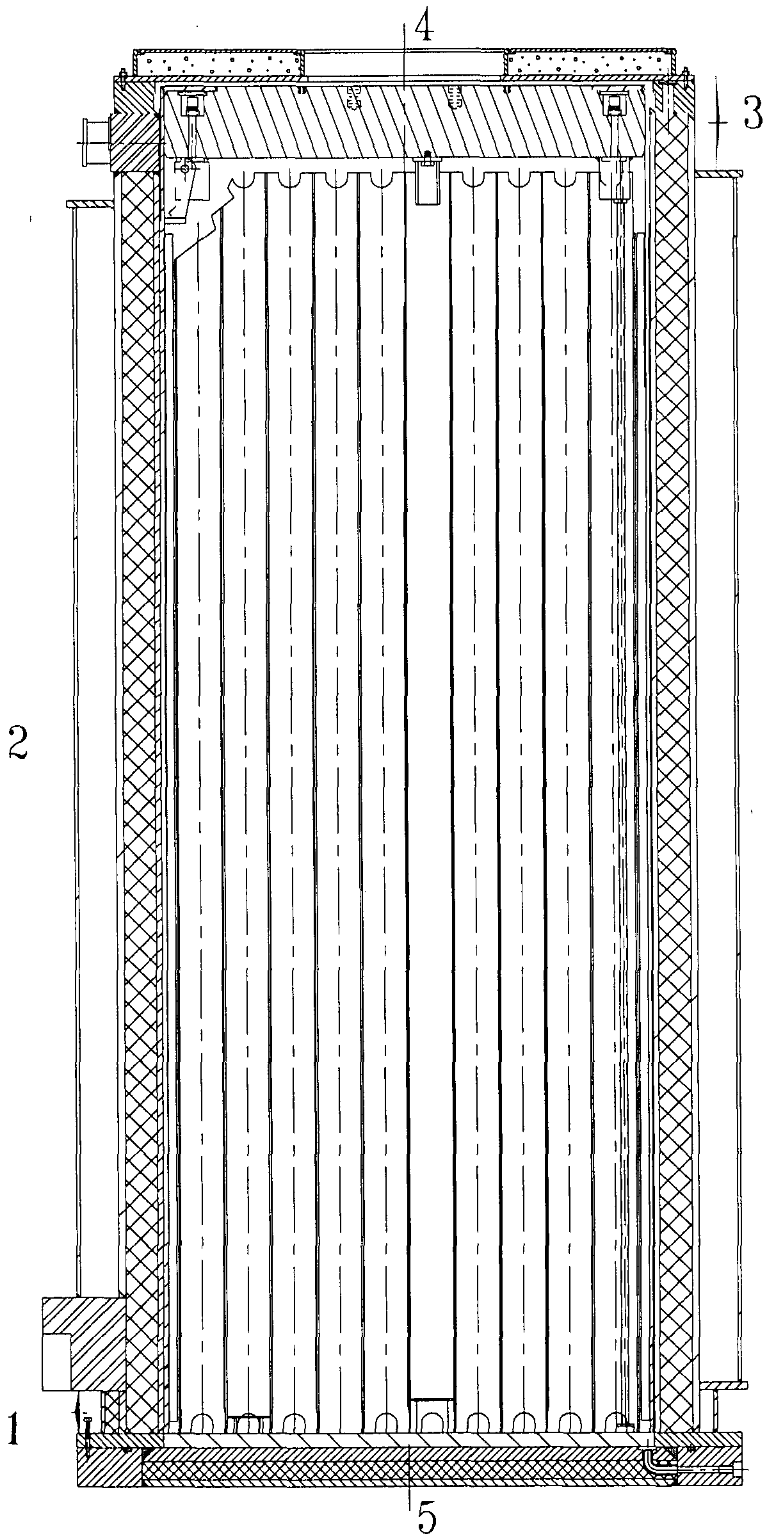


FIGURE 5.1.2; CROSS SECTION ELEVATION VIEW OF 125 TON HI-TRAC TRANSFER CASK WITH DOSE POINT LOCATIONS

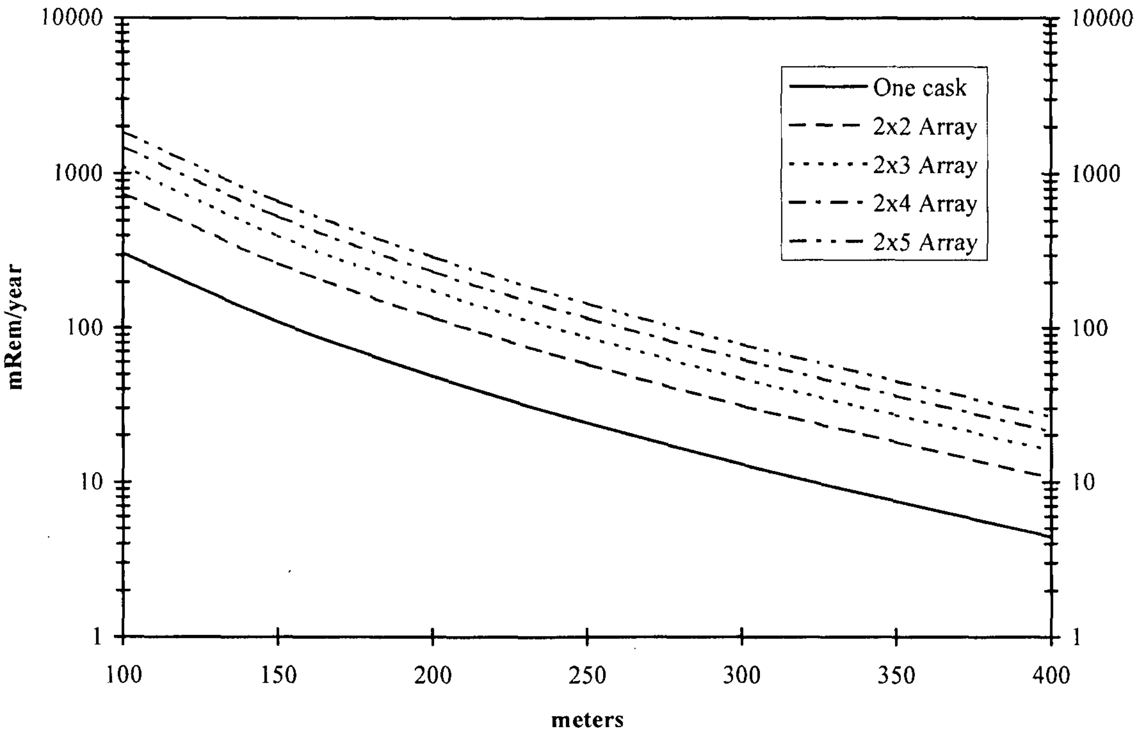


FIGURE 5.1.3; ANNUAL DOSE VERSUS DISTANCE FOR VARIOUS CONFIGURATIONS OF THE MPC-24 FOR 47,500 MWD/MTU AND 3-YEAR COOLING (8760 HOUR OCCUPANCY ASSUMED)

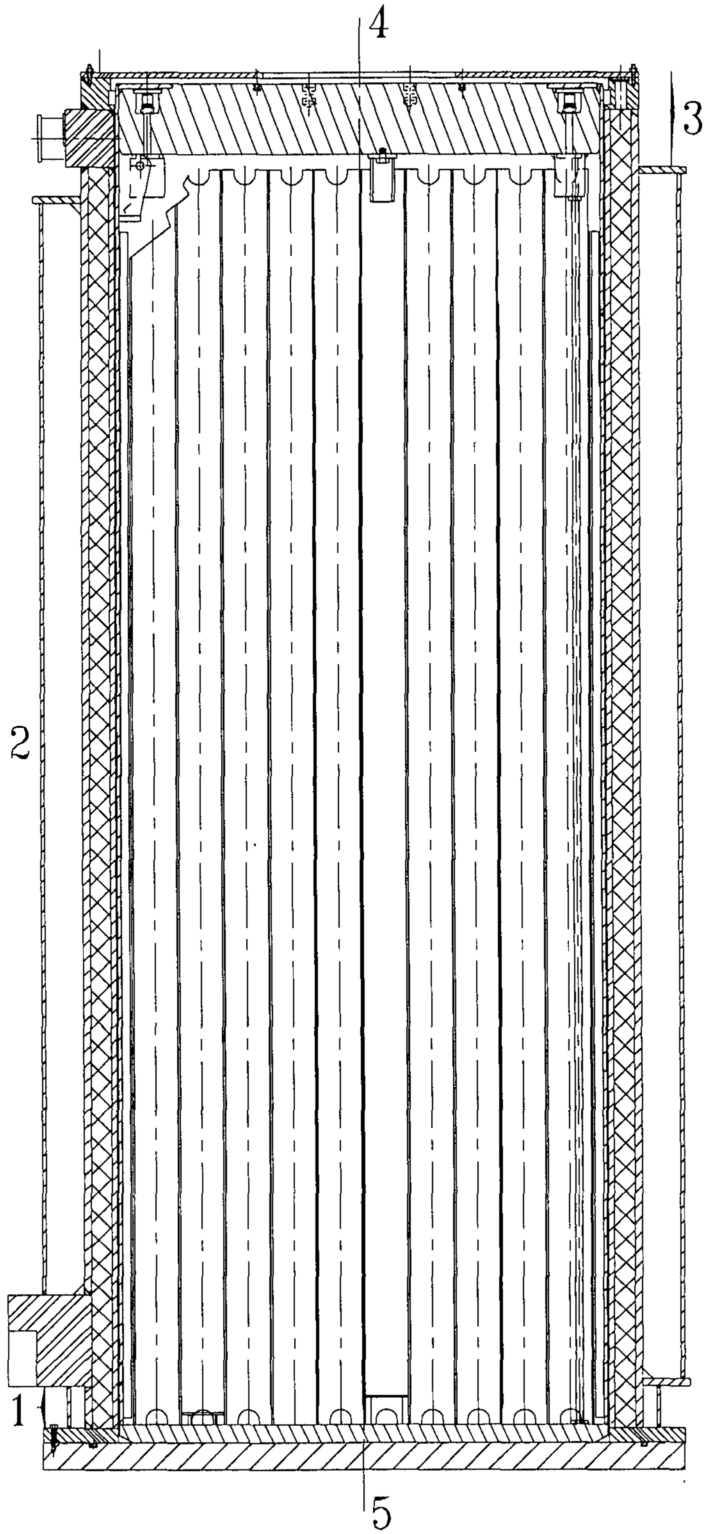


FIGURE 5.1.4; CROSS SECTION ELEVATION VIEW OF 100 TON HI-TRAC TRANSFER CASK (WITH POOL LID) WITH DOSE POINT LOCATIONS

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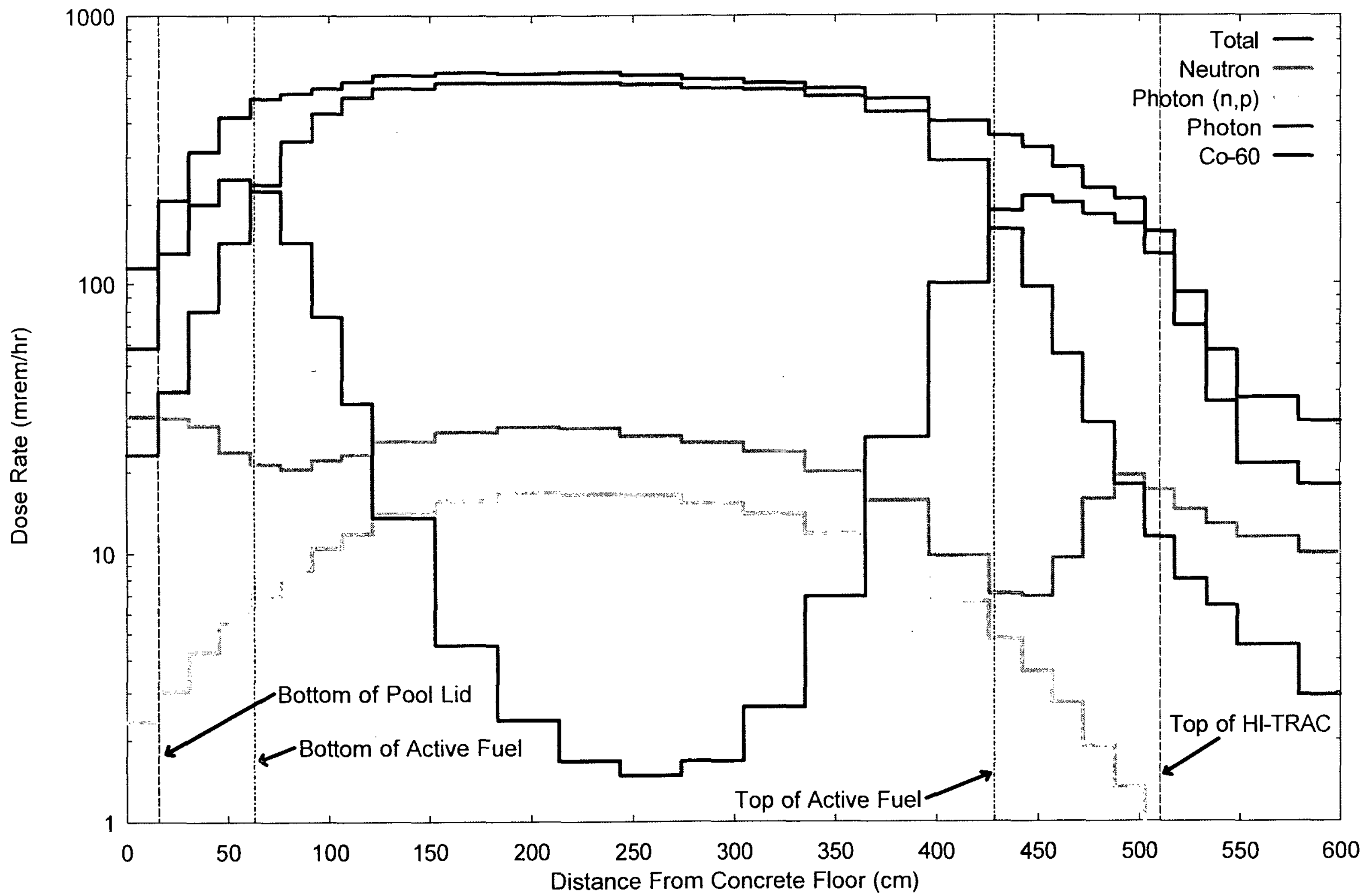


FIGURE 5.1.5; DOSE RATE 1-FOOT FROM THE SIDE OF THE 100-TON HI-TRAC TRANSFER CASK WITH THE MPC-24 FOR 35,000 MWD/MTU AND 5-YEAR COOLING

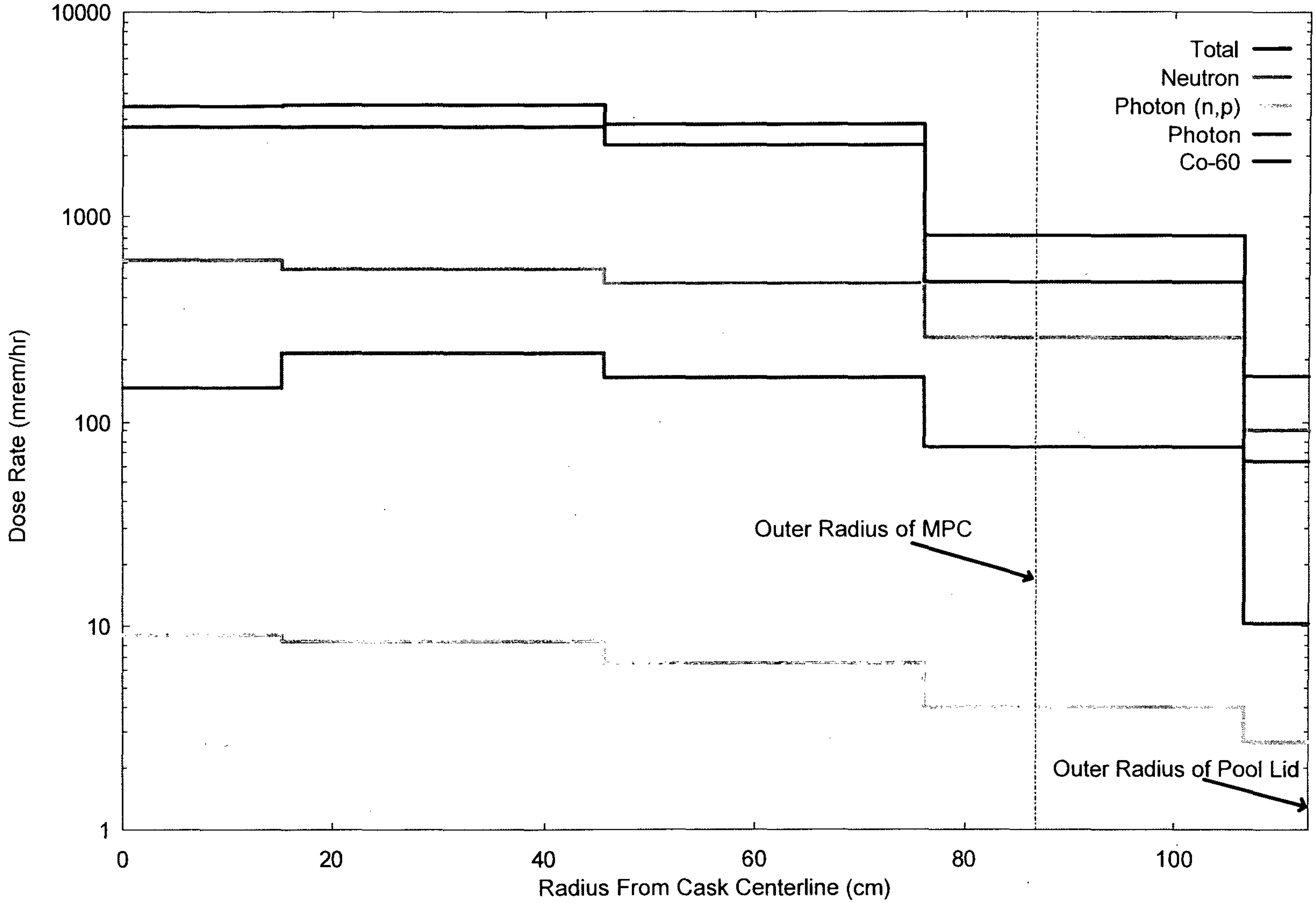


FIGURE 5.1.6; DOSE RATE ON THE SURFACE OF THE POOL LID ON THE 100-TON HI-TRAC TRANSFER CASK WITH THE MPC-24 FOR 35,000 MWD/MTU AND 5-YEAR COOLING

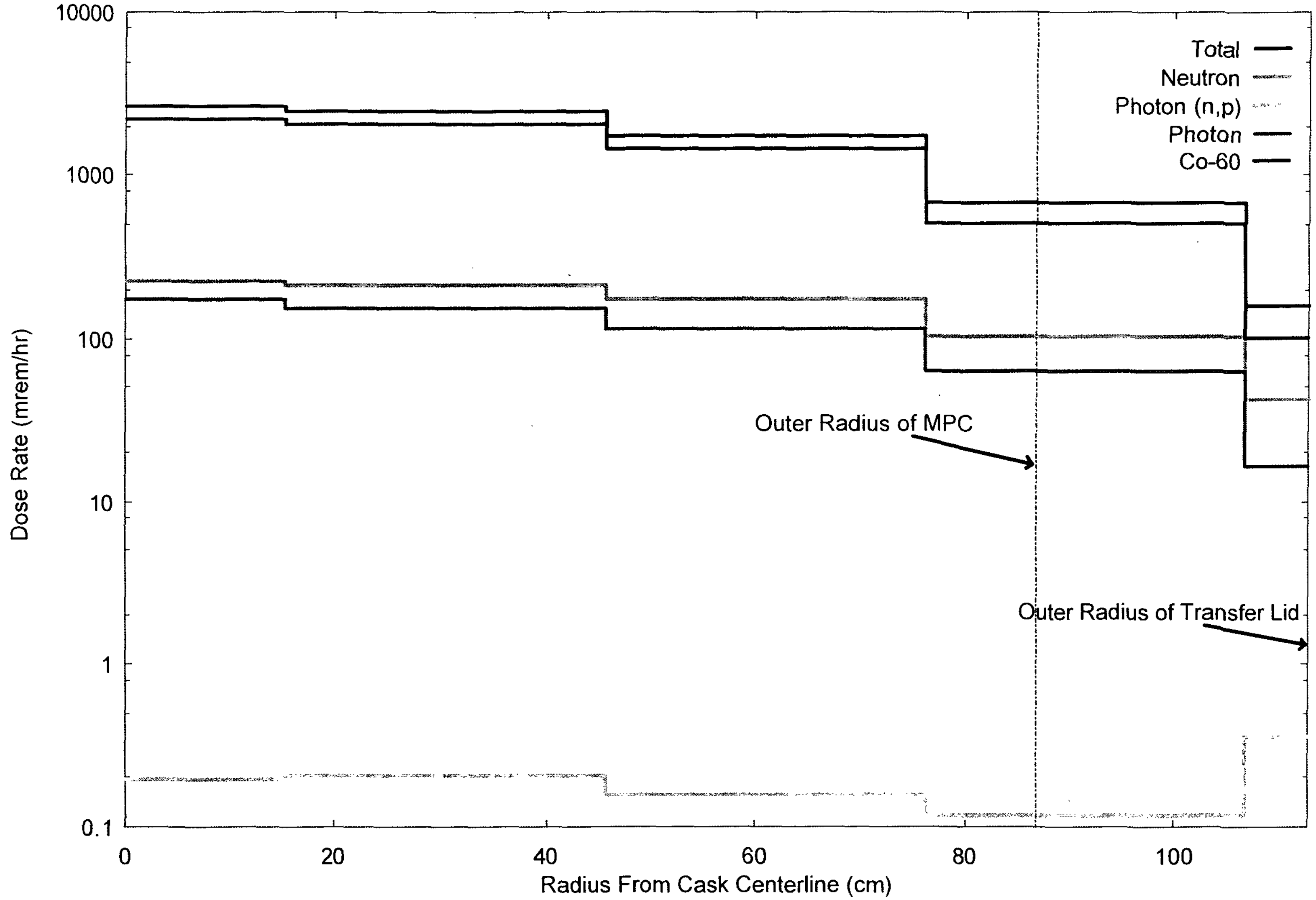


FIGURE 5.1.7; DOSE RATE 1-FOOT FROM THE BOTTOM OF TRANSFER LID ON THE 100-TON HI-TRAC TRANSFER CASK WITH THE MPC-24 FOR 35,000 MWD/MTU AND 5-YEAR COOLING

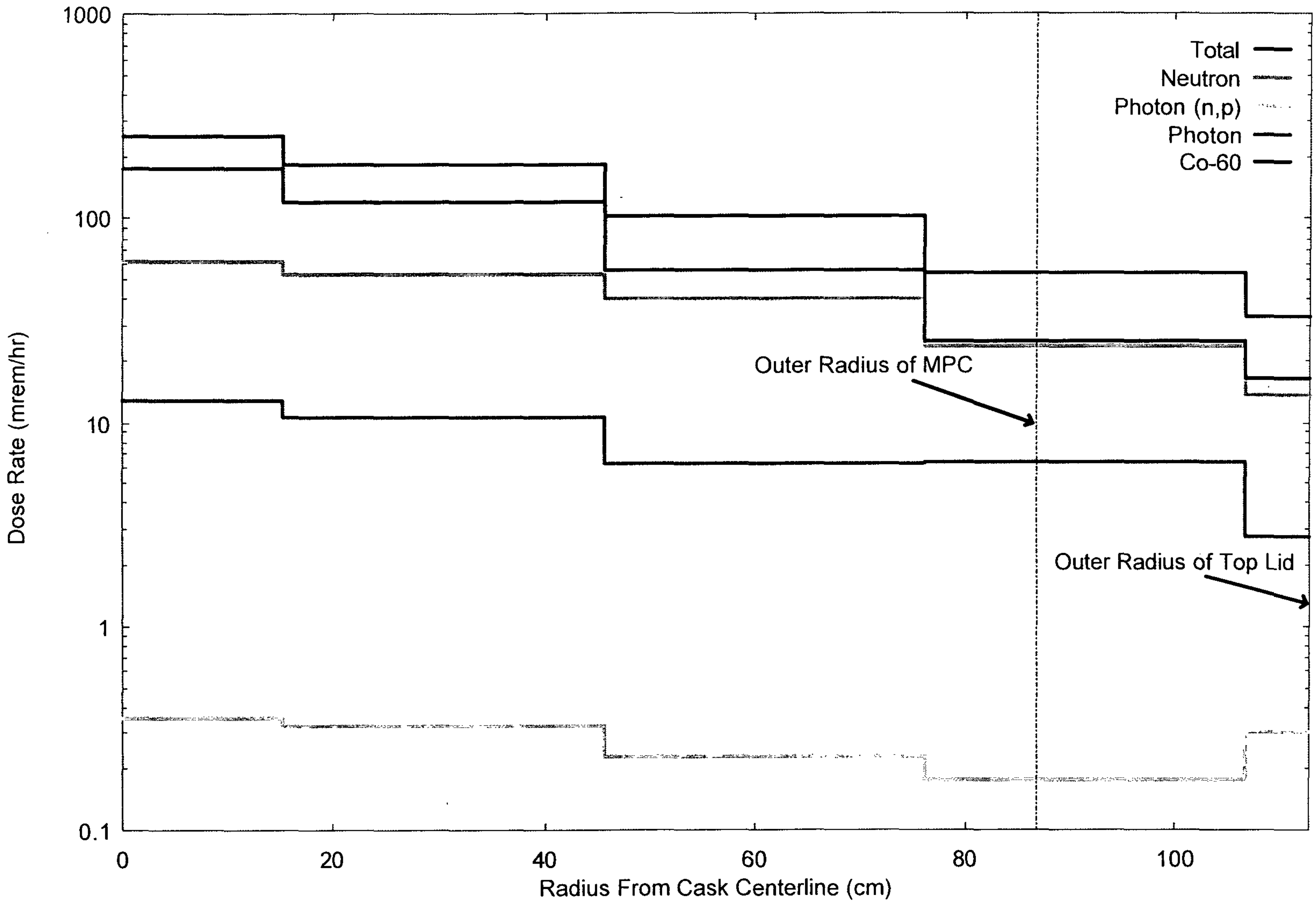


FIGURE 5.1.8; DOSE RATE 1-FOOT FROM THE TOP OF TOP LID ON THE 100-TON HI-TRAC TRANSFER CASK WITH THE MPC-24 FOR 35,000 MWD/MTU AND 5-YEAR COOLING

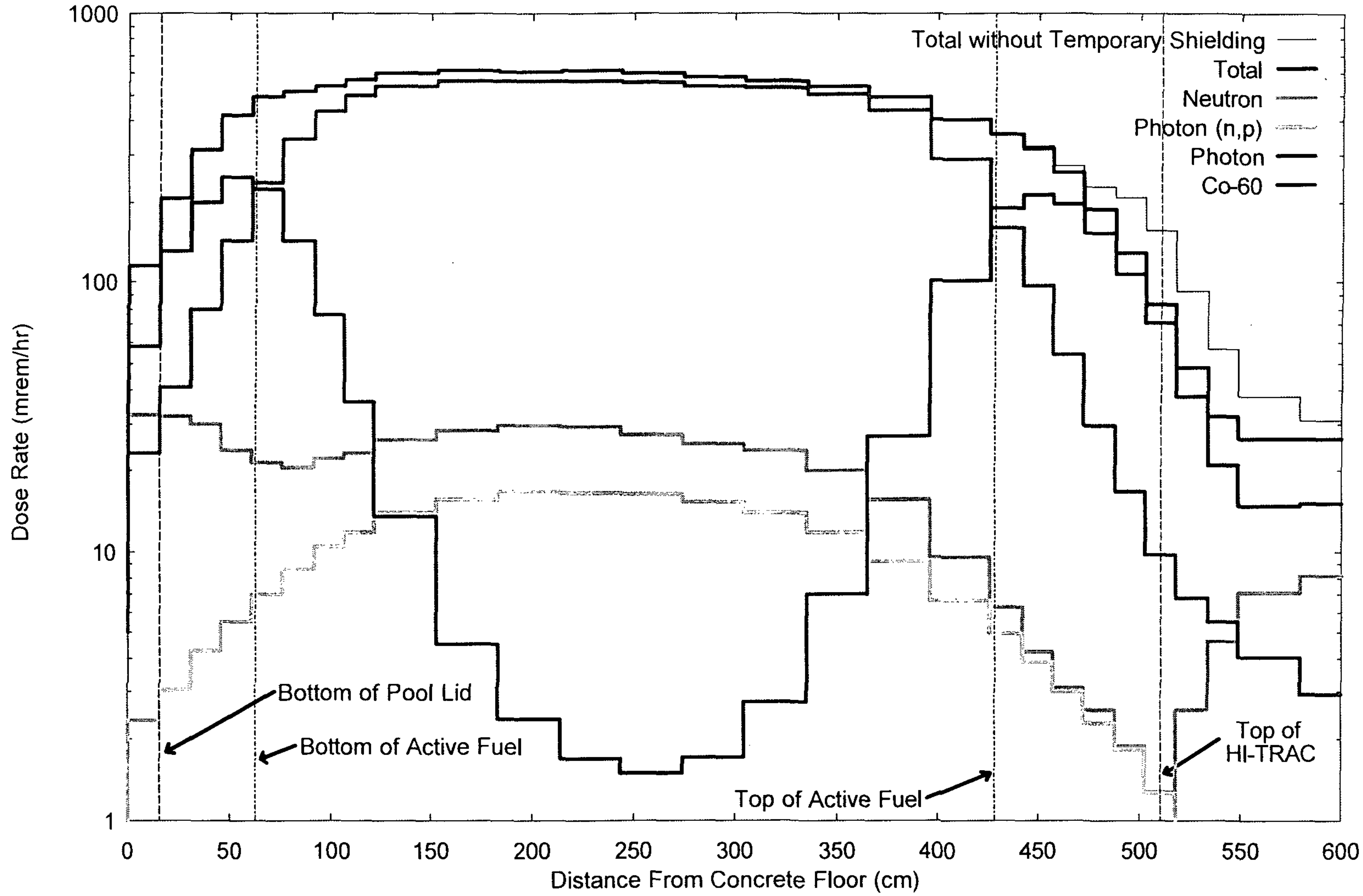


FIGURE 5.1.9; DOSE RATE 1-FOOT FROM THE SIDE OF THE 100-TON HI-TRAC TRANSFER CASK WITH TEMPORARY SHIELDING INSTALLED, WITH THE MPC-24 FOR 35,000 MWD/MTU AND 5-YEAR COOLING (TOTAL DOSE WITHOUT TEMPORARY SHIELDING SHOWN FOR COMPARISON)

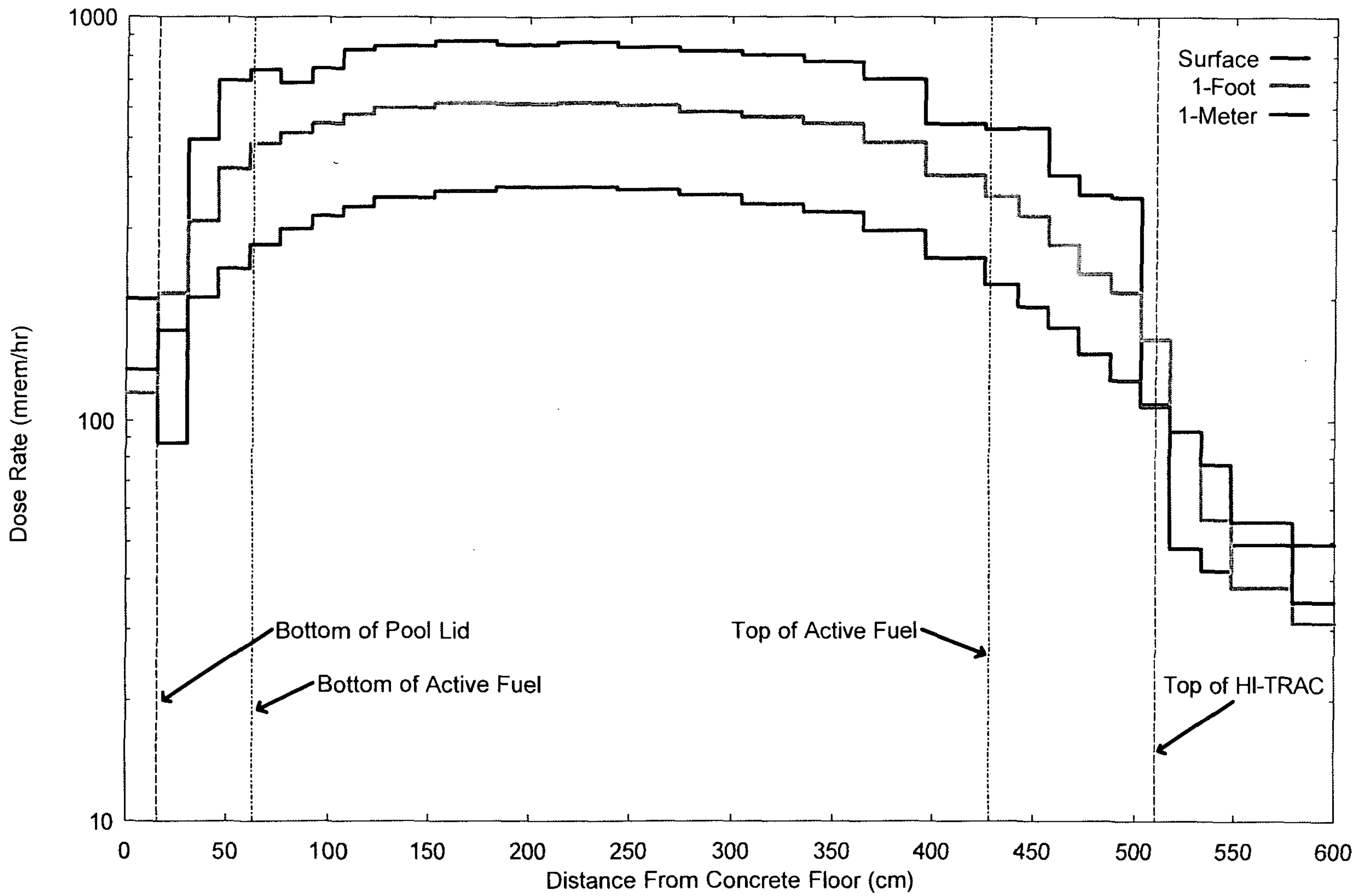


FIGURE 5.1.10; DOSE RATE AT VARIOUS DISTANCES FROM THE SIDE OF THE 100-TON HI-TRAC TRANSFER CASK WITH THE MPC-24 FOR 35,000 MWD/MTU AND 5-YEAR COOLING

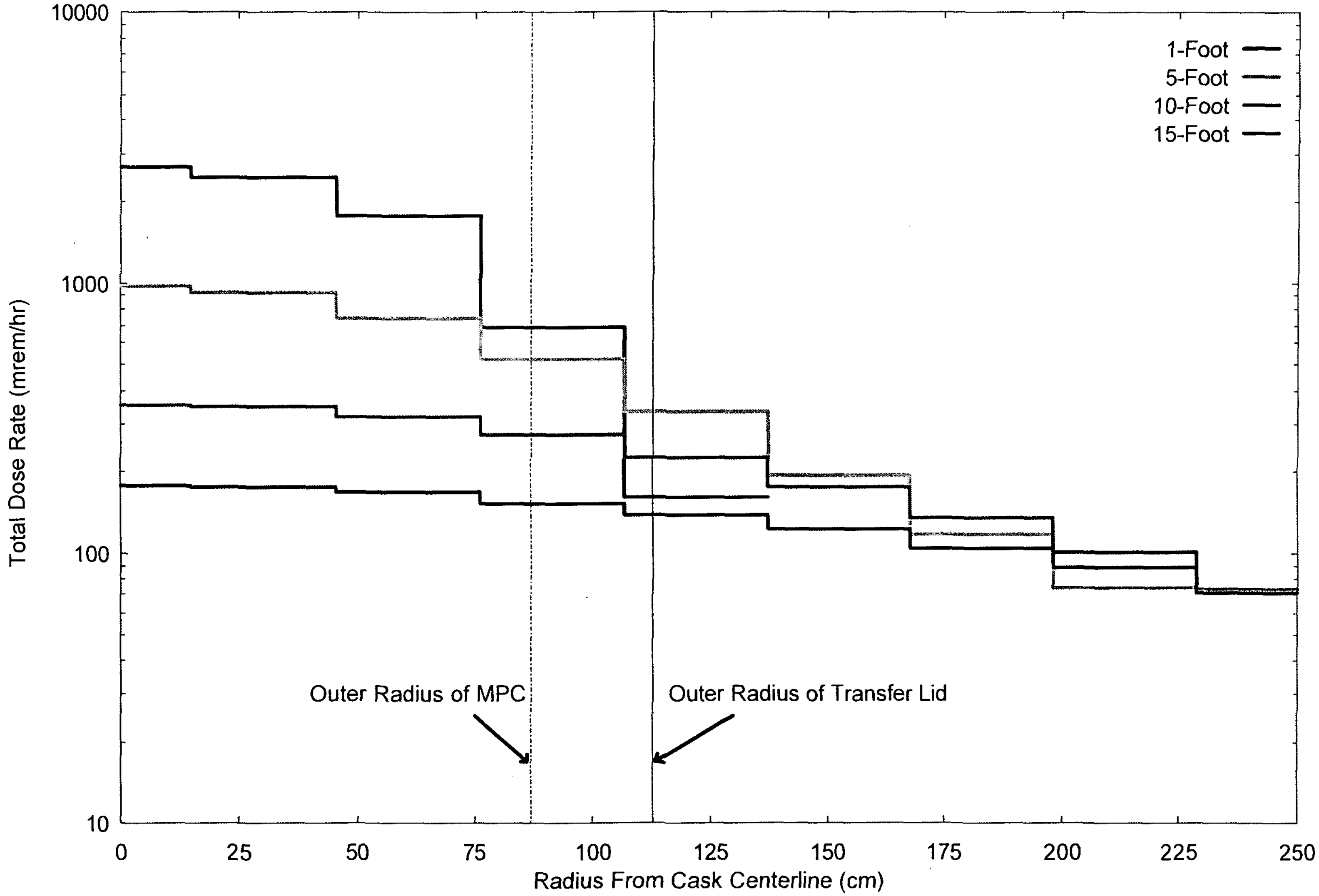


FIGURE 5.1.11; DOSE RATE AT VARIOUS DISTANCES FROM THE BOTTOM OF TRANSFER LID ON THE 100-TON HI-TRAC TRANSFER CASK WITH THE MPC-24 FOR 35,000 MWD/MTU AND 5-YEAR COOLING

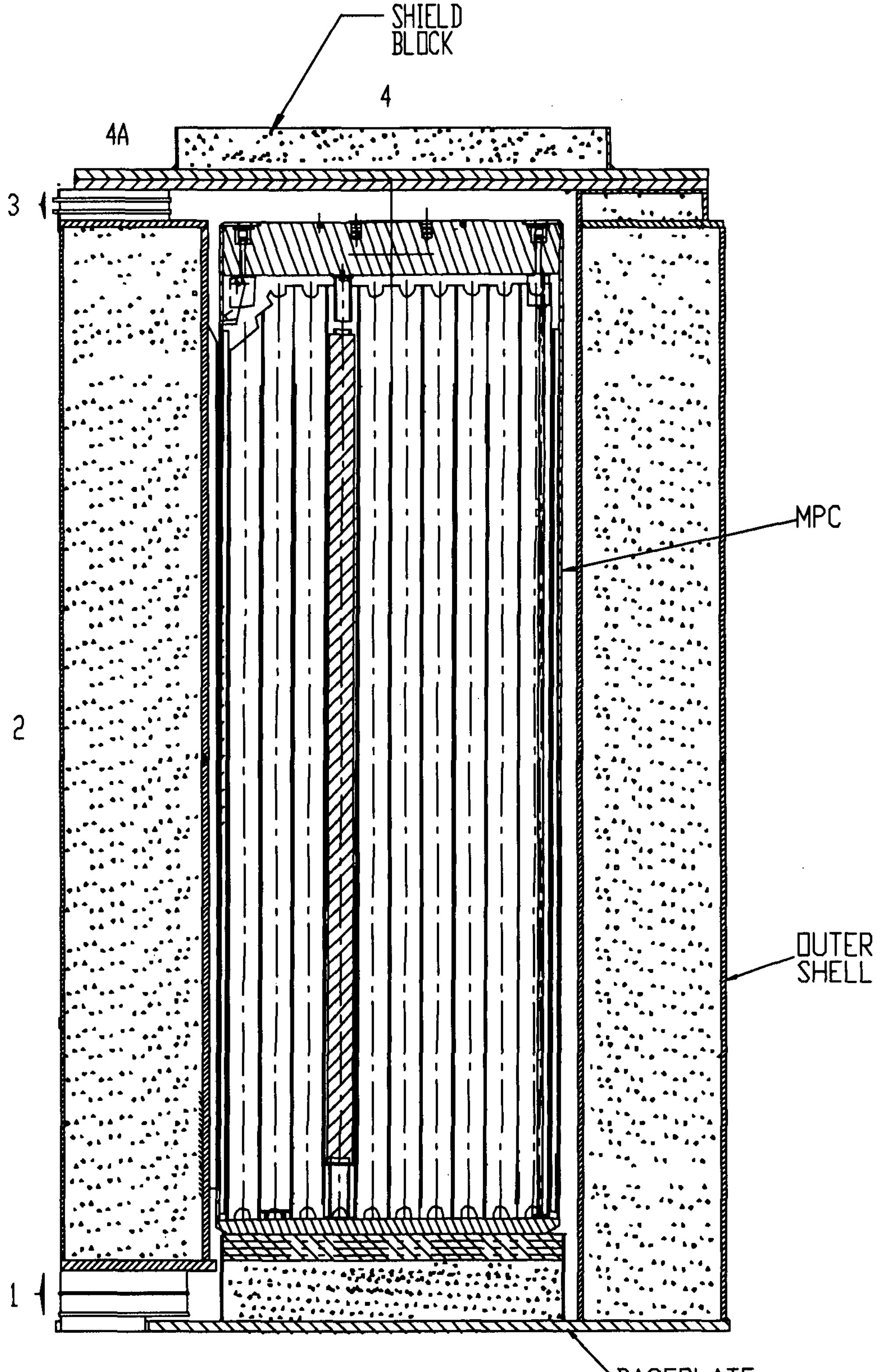


FIGURE 5.1.12; CROSS SECTION ELEVATION VIEW OF THE HI-STORM 100S OVERPACK WITH DOSE POINT LOCATION

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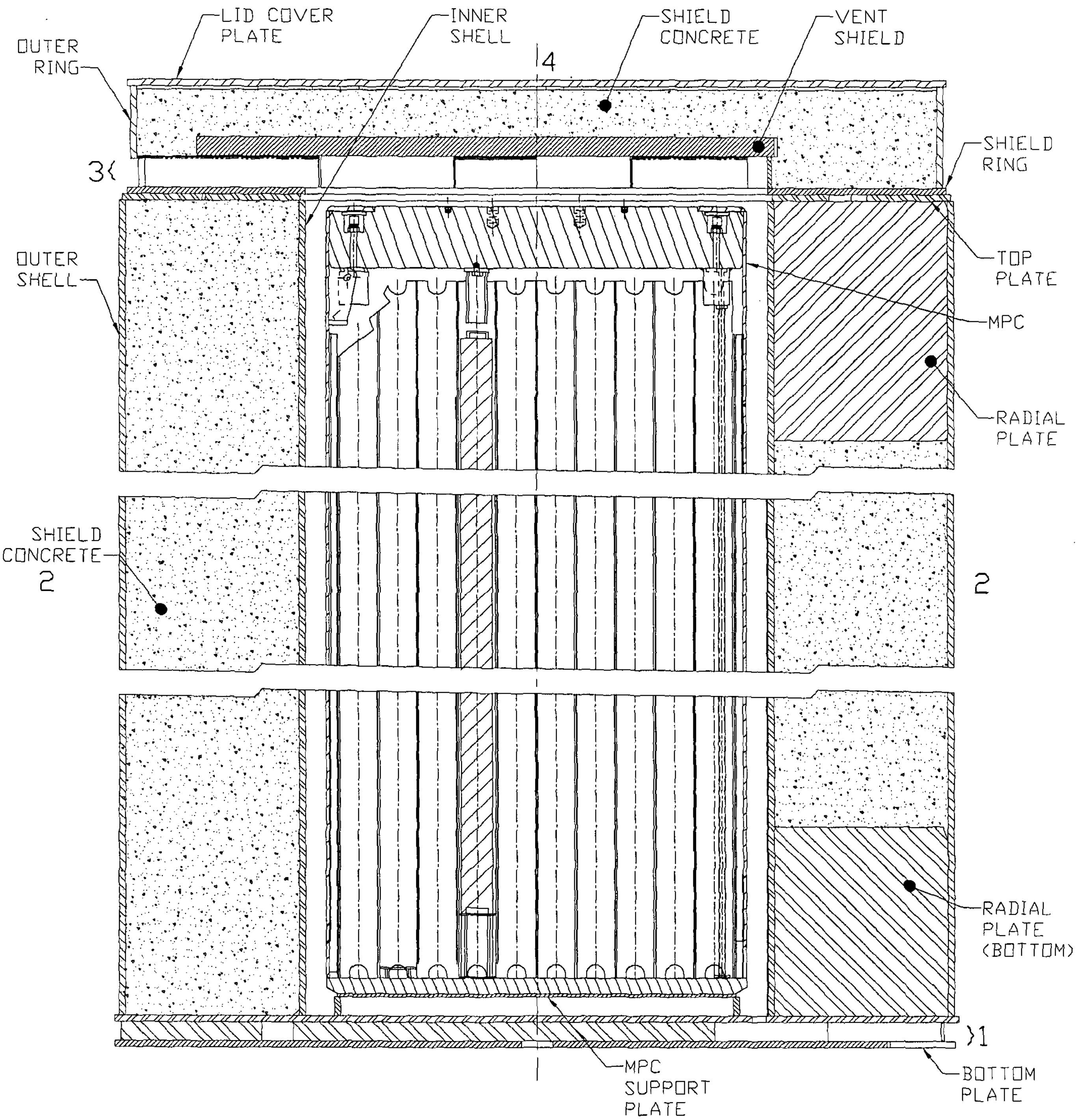


FIGURE 5.1.13; HI-STORM 100S VERSION B OVERPACK CROSS SECTIONAL ELEVATION VIEW WITH DOSE POINT LOCATION

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## 5.2 SOURCE SPECIFICATION

The neutron and gamma source terms, decay heat values, and quantities of radionuclides available for release were calculated with the SAS2H and ORIGEN-S modules of the SCALE 4.3 system [5.1.2, 5.1.3]. SAS2H has been extensively compared to experimental isotopic validations and decay heat measurements. References [5.2.8] through [5.2.12] and [5.2.15] present isotopic comparisons for PWR and BWR fuels for burnups ranging to 47 GWD/MTU and reference [5.2.13] presents results for BWR measurements to a burnup of 57 GWD/MTU. A comparison of calculated and measured decays heats is presented in reference [5.2.14]. All of these studies indicate good agreement between SAS2H and measured data. Additional comparisons of calculated values and measured data are being performed by various institutions for high burnup PWR and BWR fuel. These new results, when published, are expected to further confirm the validity of SAS2H for the analysis of PWR and BWR fuel.

Sample input files for SAS2H and ORIGEN-S are provided in Appendices 5.A and 5.B, respectively. The gamma source term is actually comprised of three distinct sources. The first is a gamma source term from the active fuel region due to decay of fission products. The second source term is from $^{60}Co$ activity of the steel structural material in the fuel element above and below the active fuel region. The third source is from (n,$\gamma$) reactions described below.

A description of the design basis zircaloy clad fuel for the source term calculations is provided in Table 5.2.1. The PWR fuel assembly described is the assembly that produces the highest neutron and gamma sources and the highest decay heat load for a given burnup and cooling time from the following fuel assembly classes listed in Table 2.1.1: B&W 15x15, B&W 17x17, CE 14x14, CE 16x16, WE 14x14, WE 15x15, WE 17x17, St. Lucie, and Ft. Calhoun. The BWR fuel assembly described is the assembly that produces the highest neutron and gamma sources and the highest decay heat load for a given burnup and cooling time from the following fuel assembly classes listed in Table 2.1.2: GE BWR/2-3, GE BWR/4-6, Humboldt Bay 7x7, and Dresden 1 8x8. Multiple SAS2H and ORIGEN-S calculations were performed to confirm that the B&W 15x15 and the GE 7x7, which have the highest $UO_2$ mass, bound all other PWR and BWR fuel assemblies, respectively. Section 5.2.5 discusses, in detail, the determination of the design basis fuel assemblies.

The design basis Humboldt Bay and Dresden 1 6x6 fuel assembly is described in Table 5.2.2. The fuel assembly type listed produces the highest total neutron and gamma sources from the fuel assemblies at Dresden 1 and Humboldt Bay. Table 5.2.21 provides a description of the design basis Dresden 1 MOX fuel assembly used in this analysis. The design basis 6x6 and MOX fuel assemblies which are smaller than the GE 7x7, are assumed to have the same hardware characteristics as the GE 7x7. This is conservative because the larger hardware mass of the GE 7x7 results in a larger $^{60}Co$ activity.

The design basis stainless steel clad fuel assembly for the Indian Point 1, Haddam Neck, and San Onofre 1 assembly classes is described in Table 5.2.3. This table also describes the design basis stainless steel clad LaCrosse fuel assembly.

The design basis assemblies mentioned above are the design basis assemblies for both intact and damaged fuel and fuel debris for their respective array classes. Analyses of damaged fuel are presented in Section 5.4.2.

In performing the SAS2H and ORIGEN-S calculations, a single full power cycle was used to achieve the desired burnup. This assumption, in conjunction with the above-average specific powers listed in Tables 5.2.1, 5.2.2, 5.2.3, and 5.2.21 resulted in conservative source term calculations.

Sections 5.2.1 and 5.2.2 describe the calculation of gamma and neutron source terms for zircaloy clad fuel while Section 5.2.3 discusses the calculation of the gamma and neutron source terms for the stainless steel clad fuel.

## 5.2.1 Gamma Source

Tables 5.2.4 through 5.2.6 provide the gamma source in MeV/s and photons/s as calculated with SAS2H and ORIGEN-S for the design basis zircaloy clad fuels at varying burnups and cooling times. Tables 5.2.7 and 5.2.22 provides the gamma source in MeV/s and photons/s for the design basis 6x6 and MOX fuel, respectively.

Specific analysis for the HI-STORM 100 System, which includes the HI-STORM storage overpacks and the HI-TRAC transfer casks, was performed to determine the dose contribution from gammas as a function of energy. This analysis considered dose locations external to the 100-ton HI-TRAC transfer cask and the HI-STORM 100 overpack and vents. The results of this analysis have revealed that, due to the magnitude of the gamma source at lower energies, gammas with energies as low as 0.45 MeV must be included in the shielding analysis. The effect of gammas with energies above 3.0 MeV, on the other hand, was found to be insignificant (less than 1% of the total gamma dose at all high dose locations). This is due to the fact that the source of gammas in this range (i.e., above 3.0 MeV) is extremely low (less than 1% of the total source). Therefore, all gammas with energies in the range of 0.45 to 3.0 MeV are included in the shielding calculations. Dose rate contributions from above and below this range were evaluated and found to be negligible. Photons with energies below 0.45 MeV are too weak to penetrate the HI-STORM overpack or HI-TRAC, and photons with energies above 3.0 MeV are too few to contribute significantly to the external dose.

The primary source of activity in the non-fuel regions of an assembly arises from the activation of $^{59}Co$ to $^{60}Co$. The primary source of $^{59}Co$ in a fuel assembly is impurities in the steel structural material above and below the fuel. The zircaloy in these regions is neglected since it does not have a significant $^{59}Co$ impurity level. Reference [5.2.2] indicates that the impurity level in steel is 800 ppm or 0.8 gm/kg. Conservatively, the impurity level of $^{59}Co$ was assumed to be 1000 ppm or 1.0 gm/kg. Therefore, Inconel and stainless steel in the non-fuel regions are both conservatively assumed to have the same 1.0 gm/kg impurity level.

Holtec International has gathered information from utilities and vendors which shows that the 1.0 gm/kg impurity level is very conservative for fuel which has been manufactured since the mid-to-late 1980s after the implementation of an industry wide cobalt reduction program. The typical Cobalt-59 impurity level for fuel since the late 1980s is less than 0.5 gm/kg. Based on this, fuel with a short cooling time, 5 to 9 years, would have a Cobalt-59 impurity level less than 0.5 gm/kg. Therefore, the use of a bounding Cobalt-59 impurity level of 1.0 gm/kg is very conservative, particularly for recently manufactured assemblies. Analysis in Reference [5.2.3] indicates that the cobalt impurity in steel and inconel for fuel manufactured in the 1970s ranged from approximately 0.2 gm/kg to 2.2 gm/kg. However, older fuel manufactured with higher cobalt impurity levels will also have a corresponding longer cooling time and therefore will be bounded by the analysis presented in this chapter. As confirmation of this statement, Appendix D presents a comparison of the dose rates around the 100-ton HI-TRAC and the HI-STORM with the MPC-24 for a short cooling time (5 years) using the 1.0 gm/kg mentioned above and for a long cooling time (9 years) using a higher cobalt impurity level of 4.7 gm/kg for inconel. These results confirm that the dose rates for the longer cooling time with the higher impurity level are essentially equivalent to (within 11%) or bounded by the dose rates for the shorter cooling time with the lower impurity level. Therefore, the analysis in this chapter is conservative.

Some of the PWR fuel assembly designs (B&W and WE 15x15) utilized inconel in-core grid spacers while other PWR fuel designs use zircaloy in-core grid spacers. In the mid 1980s, the fuel assembly designs using inconel in-core grid spacers were altered to use zircaloy in-core grid spacers. Since both designs may be loaded into the HI-STORM 100 system, the gamma source for the PWR zircaloy clad fuel assembly includes the activation of the in-core grid spacers. Although BWR assembly grid spacers are zircaloy, some assembly designs have inconel springs in conjunction with the grid spacers. The gamma source for the BWR zircaloy clad fuel assembly includes the activation of these springs associated with the grid spacers.

The non-fuel data listed in Table 5.2.1 were taken from References [5.2.2], [5.2.4], and [5.2.5]. As stated above, a Cobalt-59 impurity level of 1 gm/kg (0.1 wt%) was used for both inconel and stainless steel. Therefore, there is little distinction between stainless steel and inconel in the source term generation and since the shielding characteristics are similar, stainless steel was used in the MCNP calculations instead of inconel. The BWR masses are for an 8x8 fuel assembly. These masses are also appropriate for the 7x7 assembly since the masses of the non-fuel hardware from a 7x7 and an 8x8 are approximately the same. The masses listed are those of the steel components. The zircaloy in these regions was not included because zircaloy does not produce significant activation. The masses are larger than most other fuel assemblies from other manufacturers. This, in combination with the conservative $^{59}$Co impurity level and the use of conservative flux weighting fractions (discussed below) results in an over-prediction of the non-fuel hardware source that bounds all fuel for which storage is requested.

The masses in Table 5.2.1 were used to calculate a $^{59}$Co impurity level in the fuel assembly material. The grams of impurity were then used in ORIGEN-S to calculate a $^{60}$Co activity level for the desired burnup and decay time. The methodology used to determine the activation level was developed from Reference [5.2.3] and is described here.

1. The activity of the $^{60}$Co is calculated using ORIGEN-S. The flux used in the calculation was the in-core fuel region flux at full power.

2. The activity calculated in Step 1 for the region of interest was modified by the appropriate scaling factors listed in Table 5.2.10. These scaling factors were taken from Reference [5.2.3].

Tables 5.2.11 through 5.2.13 provide the $^{60}$Co activity utilized in the shielding calculations for the non-fuel regions of the assemblies in the MPC-32, MPC-24, and the MPC-68 for varying burnup and cooling times. The design basis 6x6 and MOX fuel assemblies are conservatively assumed to have the same $^{60}$Co source strength as the BWR design basis fuel. This is a conservative assumption as the design basis 6x6 fuel and MOX fuel assemblies are limited to a significantly lower burnup and longer cooling time than the design basis fuel.

In addition to the two sources already mentioned, a third source arises from (n,γ) reactions in the material of the MPC and the overpack. This source of photons is properly accounted for in MCNP when a neutron calculation is performed in a coupled neutron-gamma mode.

There is some uncertainty associated with the ORIGEN-S calculations due to uncertainty in the physics data (e.g. cross sections, decay constants, etc.) and the modeling techniques. References [5.2.9], [5.2.10], and [5.2.15] perform comparisons between calculations and experimental isotopic measurement data. These comparisons indicate that calculated to measured ratios for Cs-134 and Eu-154, two of the major contributors to the gamma source, range from 0.79 to 1.009 and 0.79 to 0.98, respectively. These values provide representative insight into the entire range of possible error in the source term calculations. However, any non-conservatism associated with the uncertainty in the source term calculations is offset by the conservative nature of the source term and shielding calculations performed in this chapter, and therefore no adjustments were made to the calculated values.

### 5.2.2 Neutron Source

It is well known that the neutron source strength increases as enrichment decreases, for a constant burnup and decay time. This is due to the increase in Pu content in the fuel, which increases the inventory of other transuranium nuclides such as Cm. The gamma source also varies with enrichment, although only slightly. Because of this effect and in order to obtain conservative source terms, low initial fuel enrichments were chosen for the BWR and PWR design basis fuel assemblies. The enrichments are appropriately varied as a function of burnup. Table 5.2.24 presents the $^{235}$U initial enrichments for various burnup ranges from 20,000 - 75,000 MWD/MTU for PWR and 20,000 - 70,000 MWD/MTU for BWR zircaloy clad fuel. These enrichments are based on References [5.2.6] and [5.2.7]. Table 8 of reference [5.2.6] presents average enrichments for burnup ranges. The initial enrichments chosen in Table 5.2.24, for burnups up to 50,000 MWD/MTU, are approximately the average enrichments from Table 8 of reference [5.2.6] for the burnup range that is 5,000 MWD/MTU less than the ranges listed in

Table 5.2.24. These enrichments are below the enrichments typically required to achieve the burnups that were analyzed. For burnups greater than 50,000 MWD/MTU, the data on historical and projected burnups available in the LWR Quantities Database in reference [5.2.7] and some additional data from nuclear plants was reviewed and conservatively low enrichments were chosen for each burnup range above 50,000 MWD/MTU.

Inherent to this approach of selecting minimum enrichments that bound the vast majority of discharged fuel is the fact that a small number of atypical assemblies will not be bounded. However, these atypical assemblies are very few in number (as evidenced by the referenced discharge data), and thus, it is unlikely that a single cask would contain several of these outlying assemblies. Further, because the approach is based on using minimum enrichments for given burnup ranges, any atypical assemblies that may exist are expected to have enrichments that are very near to the minimum enrichments used in the analysis. Therefore, the result is an insignificant effect on the calculated dose rates. Consequently, the minimum enrichment values used in the shielding analysis are adequate to bound the fuel authorized by the limits in Section 2.1.9 for loading in the HI-STORM system. Since the enrichment does affect the source term evaluation, it is recommended that the site-specific dose evaluation consider the enrichment for the fuel being stored.

The neutron source calculated for the design basis fuel assemblies for the MPC-24, MPC-32, and MPC-68 and the design basis 6x6 fuel are listed in Tables 5.2.15 through 5.2.18 in neutrons/s for varying burnup and cooling times. Table 5.2.23 provides the neutron source in neutrons/sec for the design basis MOX fuel assembly. $^{244}$Cm accounts for approximately 92-97% of the total number of neutrons produced. Alpha,n reactions in isotopes other than $^{244}$Cm account for approximately 0.3-2% of the neutrons produced while spontaneous fission in isotopes other than $^{244}$Cm account for approximately 2-8% of the neutrons produced within the $UO_2$ fuel. In addition, any neutrons generated from subcritical multiplication, (n,2n) or similar reactions are properly accounted for in the MCNP calculation.

There is some uncertainty associated with the ORIGEN-S calculations due to uncertainty in the physics data (e.g. cross sections, decay constants, etc.) and the modeling techniques. References [5.2.9], [5.2.10], and [5.2.15] perform comparisons between calculations and experimental isotopic measurement data. These comparisons indicate that calculated to measured ratios for Cm-244 ranges from 0.81 to 0.95. These values provide representative insight into the entire range of possible error in the source term calculations. However, any non-conservatism associated with the uncertainty in the source term calculations is offset by the conservative nature of the source term and shielding calculations performed in this chapter, and therefore no adjustments were made to the calculated values.

### 5.2.3 Stainless Steel Clad Fuel Source

Table 5.2.3 lists the characteristics of the design basis stainless steel clad fuel. The fuel characteristics listed in this table are the input parameters that were used in the shielding calculations described in this chapter. The active fuel length listed in Table 5.2.3 is actually longer than the true active fuel length of 122 inches for the WE 15x15 and 83 inches for the LaCrosse 10x10. Since the true active fuel length is shorter than the design basis zircaloy clad active fuel length, it would be incorrect to calculate source terms for the stainless steel fuel using the correct fuel length and compare them directly to the zircaloy clad fuel source terms because this does not reflect the potential change in dose rates. As an example, if it is assumed that the source strength for both the stainless steel and zircaloy fuel is 144 neutrons/s and that the active fuel lengths of the stainless steel fuel and zircaloy fuel are 83 inches and 144 inches, respectively; the source strengths per inch of active fuel would be different for the two fuel types, 1.73 neutrons/s/inch and 1 neutron/s/inch for the stainless steel and zircaloy fuel, respectively. The result would be a higher neutron dose rate at the center of the cask with the stainless steel fuel than with the zircaloy clad fuel; a conclusion that would be overlooked by just comparing the source terms. This is an important consideration because the stainless steel clad fuel differs from the zircaloy clad in one important aspect: the stainless steel cladding will contain a significant photon source from Cobalt-60 which will be absent from the zircaloy clad fuel.

In order to eliminate the potential confusion when comparing source terms, the stainless steel clad fuel source terms were calculated with the same active fuel length as the design basis zircaloy clad fuel. Reference [5.2.2] indicates that the Cobalt-59 impurity level in steel is 800 ppm or 0.8 gm/kg. This impurity level was used for the stainless steel cladding in the source term calculations. It is assumed that the end fitting masses of the stainless steel clad fuel are the same as the end fitting masses of the zircaloy clad fuel. Therefore, separate source terms are not provided for the end fittings of the stainless steel fuel.

Tables 5.2.8, 5.2.9, 5.2.19, and 5.2.20 list the gamma and neutron source strengths for the design basis stainless steel clad fuel. It is obvious from these source terms that the neutron source strength for the stainless steel fuel is lower than for the zircaloy fuel. However, this is not true for all photon energy groups. The peak energy group is from 1.0 to 1.5 MeV, which results from the large Cobalt activation in the cladding. Since some of the source strengths are higher for the stainless steel fuel, Section 5.4.4 presents the dose rates at the center of the overpack for the stainless steel fuel. The center dose location is the only location of concern since the end fittings are assumed to be the same mass as the end fittings for the zircaloy clad fuel. In addition, the burnup is lower and the cooling time is longer for the stainless steel fuel compared to the zircaloy clad fuel.

### 5.2.4 Non-fuel Hardware

Burnable poison rod assemblies (BPRAs), thimble plug devices (TPDs), control rod assemblies (CRAs), and axial power shaping rods (APSRs) are permitted for storage in the HI-STORM 100 System as an integral part of a PWR fuel assembly. BPRAs and TPDs may be stored in any fuel location while CRAs and APSRs are restricted as specified in Section 2.1.9.

### 5.2.4.1 BPRAs and TPDs

Burnable poison rod assemblies (BPRA) (including wet annular burnable absorbers) and thimble plug devices (TPD) (including orifice rod assemblies, guide tube plugs, and water displacement guide tube plugs) are an integral, yet removable, part of a large portion of PWR fuel. The TPDs are not used in all assemblies in a reactor core but are reused from cycle to cycle. Therefore, these devices can achieve very high burnups. In contrast, BPRAs are burned with a fuel assembly in core and are not reused. In fact, many BPRAs are removed after one or two cycles before the fuel assembly is discharged. Therefore, the achieved burnup for BPRAs is not significantly different than fuel assemblies. Vibration suppressor inserts are considered to be in the same category as BPRAs for the purposes of the analysis in this chapter since these devices have the same configuration (long non-absorbing thimbles which extend into the active fuel region) as a BPRA without the burnable poison.

TPDs are made of stainless steel and contain a small amount of inconel. These devices extend down into the plenum region of the fuel assembly but do not extend into the active fuel region with the exception of the W 14x14 water displacement guide tube plugs. Since these devices are made of stainless steel, there is a significant amount of cobalt-60 produced during irradiation. This is the only significant radiation source from the activation of steel and inconel.

BPRAs are made of stainless steel in the region above the active fuel zone and may contain a small amount of inconel in this region. Within the active fuel zone the BPRAs may contain 2-24 rodlets which are burnable absorbers clad in either zircaloy or stainless steel. The stainless steel clad BPRAs create a significant radiation source (Co-60) while the zircaloy clad BPRAs create a negligible radiation source. Therefore the stainless steel clad BPRAs are bounding.

SAS2H and ORIGEN-S were used to calculate a radiation source term for the TPDs and BPRAs. In the ORIGEN-S calculations the cobalt-59 impurity level was conservatively assumed to be 0.8 gm/kg for stainless steel and 4.7 gm/kg for inconel. These calculations were performed by irradiating the appropriate mass of steel and inconel using the flux calculated for the design basis B&W 15x15 fuel assembly. The mass of material in the regions above the active fuel zone was scaled by the appropriate scaling factors listed in Table 5.2.10 in order to account for the reduced flux levels above the fuel assembly. The total curies of cobalt were calculated for the TPDs and BPRAs as a function of burnup and cooling time. For burnups beyond 45,000 MWD/MTU, it was assumed, for the purpose of the calculation, that the burned fuel assembly was replaced with a fresh fuel assembly every 45,000 MWD/MTU. This was achieved in ORIGEN-S by resetting the flux levels and cross sections to the 0 MWD/MTU condition after every 45,000 MWD/MTU.

Since the HI-STORM 100 cask system is designed to store many varieties of PWR fuel, a bounding TPD and BPRA had to be determined for the purposes of the analysis. This was accomplished by analyzing all of the BPRAs and TPDs (Westinghouse and B&W 14x14 through 17x17) found in references [5.2.5] and [5.2.7] to determine the TPD and BPRA which produced the highest Cobalt-60 source term and decay heat for a specific burnup and cooling time. The bounding TPD was determined to be the Westinghouse 17x17 guide tube plug and the bounding

BPRA was actually determined by combining the higher masses of the Westinghouse 17x17 and 15x15 BPRAs into a singly hypothetical BPRA. The masses of this TPD and BPRA are listed in Table 5.2.30. As mentioned above, reference [5.2.5] describes the Westinghouse 14x14 water displacement guide tube plug as having a steel portion which extends into the active fuel zone. This particular water displacement guide tube plug was analyzed and determined to be bounded by the design basis TPD and BPRA.

Once the bounding BPRA and TPD were determined, the allowable Co-60 source and decay heat from the BPRA and TPD were specified as: 50 curies Co-60 and 0.77 watts for each TPD and 895 curies Co-60 and 14.4 watts for each BPRA. Table 5.2.31 shows the curies of Co-60 that were calculated for BPRAs and TPDs in each region of the fuel assembly (e.g. incore, plenum, top). An allowable burnup and cooling time, separate from the fuel assemblies, is used for BPRAs and TPDs. These burnup and cooling times assure that the Cobalt-60 activity remains below the allowable levels specified above. It should be noted that at very high burnups, greater than 200,000 MWD/MTU the TPD Co-60 source actually decreases as the burnup continues to increase. This is due to a decrease in the Cobalt-60 production rate as the initial Cobalt-59 impurity is being depleted. Conservatively, a constant cooling time has been specified for burnups from 180,000 to 630,000 MWD/MTU for the TPDs.

Section 5.4.6 discusses the increase in the cask dose rates due to the insertion of BPRAs or TPDs into fuel assemblies.

### 5.2.4.2 CRAs and APSRs

Control rod assemblies (CRAs) (including control element assemblies and rod cluster control assemblies) and axial power shaping rod assemblies (APSRs) are an integral portion of a PWR fuel assembly. These devices are utilized for many years (upwards of 20 years) prior to discharge into the spent fuel pool. The manner in which the CRAs are utilized vary from plant to plant. Some utilities maintain the CRAs fully withdrawn during normal operation while others may operate with a bank of rods partially inserted (approximately 10%) during normal operation. Even when fully withdrawn, the ends of the CRAs are present in the upper portion of the fuel assembly since they are never fully removed from the fuel assembly during operation. The result of the different operating styles is a variation in the source term for the CRAs. In all cases, however, only the lower portion of the CRAs will be significantly activated. Therefore, when the CRAs are stored with the PWR fuel assembly, the activated portion of the CRAs will be in the lower portion of the cask. CRAs are fabricated of various materials. The cladding is typically stainless steel, although inconel has been used. The absorber can be a single material or a combination of materials. AgInCd is possibly the most common absorber although $B_4C$ in aluminum is used, and hafnium has also been used. AgInCd produces a noticeable source term in the 0.3-1.0 MeV range due to the activation of Ag. The source term from the other absorbers is negligible, therefore the AgInCd CRAs are the bounding CRAs.

APSRs are used to flatten the power distribution during normal operation and as a result these devices achieve a considerably higher activation than CRAs. There are two types of B&W

stainless steel clad APSRs: gray and black. According to reference [5.2.5], the black APSRs have 36 inches of AgInCd as the absorber while the gray ones use 63 inches of inconel as the absorber. Because of the cobalt-60 source from the activation of inconel, the gray APSRs produce a higher source term than the black APSRs and therefore are the bounding APSR.

Since the level of activation of CRAs and APSRs can vary, the quantity that can be stored in an MPC is being limited. These devices are required to be stored in the locations as outlined in Section 2.1.9.

In order to determine the impact on the dose rates around the HI-STORM 100 System, source terms for the CRAs and APSRs were calculated using SAS2H and ORIGEN-S. In the ORIGEN-S calculations the cobalt-59 impurity level was conservatively assumed to be 0.8 gm/kg for stainless steel and 4.7 gm/kg for inconel. These calculations were performed by irradiating 1 kg of steel, inconel, and AgInCd using the flux calculated for the design basis B&W 15x15 fuel assembly. The total curies of cobalt for the steel and inconel and the 0.3-1.0 MeV source for the AgInCd were calculated as a function of burnup and cooling time to a maximum burnup of 630,000 MWD/MTU. For burnups beyond 45,000 MWD/MTU, it was assumed, for the purpose of the calculation, that the burned fuel assembly was replaced with a fresh fuel assembly every 45,000 MWD/MTU. This was achieved in ORIGEN-S by resetting the flux levels and cross sections to the 0 MWD/MTU condition after every 45,000 MWD/MTU. The sources were then scaled by the appropriate mass using the flux weighting factors for the different regions of the assembly to determine the final source term. Two different configurations were analyzed for both the CRAs and APSRs with an additional third configuration analyzed for the APSRs. The configurations, which are summarized below, are described in Tables 5.2.32 for the CRAs and Table 5.2.33 for the APSR. The masses of the materials listed in these tables were determined from a review of [5.2.5] with bounding values chosen. The masses listed in Tables 5.2.32 and 5.2.33 do not match exact values from [5.2.5] because the values in the reference were adjusted to the lengths shown in the tables.

<u>Configuration 1: CRA and APSR</u>
This configuration had the lower 15 inches of the CRA and APSR activated at full flux with two regions above the 15 inches activated at a reduced power level. This simulates a CRA or APSR which was operated at 10% insertion. The regions above the 15 inches reflect the upper portion of the fuel assembly.

<u>Configuration 2: CRA and APSR</u>
This configuration represents a fully removed CRA or APSR during normal core operations. The activated portion corresponds to the upper portion of a fuel assembly above the active fuel length with the appropriate flux weighting factors used.

<u>Configuration 3: APSR</u>
This configuration represents a fully inserted gray APSR during normal core operations. The region in full flux was assumed to be the 63 inches of the absorber.

Tables 5.2.34 and 5.2.35 present the source terms, including decay heat, that were calculated for the CRAs and APSRs respectively. The only significant source from the activation of inconel or steel is Co-60 and the only significant source from the activation of AgInCd is from 0.3-1.0 MeV. The source terms for CRAs, Table 5.2.34, were calculated for a maximum burnup of 630,000 MWD/MTU and a minimum cooling time of 5 years. Because of the significant source term in APSRs that have seen extensive in-core operations, the source term in Table 5.2.35 was calculated to be a bounding source term for a variable burnup and cooling time as outlined in Section 2.1.9. The very larger Cobalt-60 activity in configuration 3 in Table 5.2.35 is due to the assumed Cobalt-59 impurity level of 4.7 gm/kg. If this impurity level were similar to the assumed value for steel, 0.8 gm/kg, this source would decrease by approximately a factor of 5.8.

Section 5.4.6 discusses the effect on dose rate of the insertion of APSRs into the inner four fuel assemblies in the MPC-24 and inner twelve fuel assemblies in the MPC-32, as well as the insertion of CRAs into the inner twelve fuel assemblies of the MPC-24 and MPC-32.

### 5.2.5 Choice of Design Basis Assembly

The analysis presented in this chapter was performed to bound the fuel assembly classes listed in Tables 2.1.1 and 2.1.2. In order to perform a bounding analysis, a design basis fuel assembly must be chosen. Therefore, a fuel assembly from each fuel class was analyzed and a comparison of the neutrons/sec, photons/sec, and thermal power (watts) was performed. The fuel assembly that produced the highest source for a specified burnup, cooling time, and enrichment was chosen as the design basis fuel assembly. A separate design basis assembly was chosen for the PWR MPCs (MPC-24 and MPC-32) and the BWR MPCs (MPC-68).

#### 5.2.5.1 PWR Design Basis Assembly

Table 2.1.1 lists the PWR fuel assembly classes that were evaluated to determine the design basis PWR fuel assembly. Within each class, the fuel assembly with the highest $UO_2$ mass was analyzed. Since the variations of fuel assemblies within a class are very minor (pellet diameter, clad thickness, etc.), it is conservative to choose the assembly with the highest $UO_2$ mass. For a given class of assemblies, the one with the highest $UO_2$ mass will produce the highest radiation source because, for a given burnup (MWD/MTU) and enrichment, the highest $UO_2$ mass will have produced the most energy and therefore the most fission products.

Table 5.2.25 presents the characteristics of the fuel assemblies analyzed to determine the design basis zircaloy clad PWR fuel assembly. The corresponding fuel assembly array class from Section 2.1.9 is also listed in the table. The fuel assembly listed for each class is the assembly with the highest $UO_2$ mass. The St. Lucie and Ft. Calhoun classes are not present in Table 5.2.25. These assemblies are shorter versions of the CE 16x16 and CE 14x14 assembly classes, respectively. Therefore, these assemblies are bounded by the CE 16x16 and CE 14x14 classes and were not explicitly analyzed. Since the Indian Point 1, Haddam Neck, and San Onofre 1 classes are stainless steel clad fuel, these classes were analyzed separately and are discussed below. All fuel assemblies in Table 5.2.25 were analyzed at the same burnup and cooling time.

The initial enrichment used in the analysis is consistent with Table 5.2.24. The results of the comparison are provided in Table 5.2.27. These results indicate that the B&W 15x15 fuel assembly has the highest radiation source term of the zircaloy clad fuel assembly classes considered in Table 2.1.1. This fuel assembly also has the highest $UO_2$ mass (see Table 5.2.25) which confirms that, for a given initial enrichment, burnup, and cooling time, the assembly with the highest $UO_2$ mass produces the highest radiation source term. The power/assembly values used in Table 5.2.25 were calculated by dividing 110% of the thermal power for commercial PWR reactors using that array class by the number of assemblies in the core. The higher thermal power, 110%, was used to account for potential power uprates. The power level used for the B&W15 is an additional 17% higher for consistency with previous revisions of the FSAR which also used this assembly as the design basis assembly.

The Haddam Neck and San Onofre 1 classes are shorter stainless steel clad versions of the WE 15x15 and WE 14x14 classes, respectively. Since these assemblies have stainless steel clad, they were analyzed separately as discussed in Section 5.2.3. Based on the results in Table 5.2.27, which show that the WE 15x15 assembly class has a higher source term than the WE 14x14 assembly class, the Haddam Neck, WE 15x15, fuel assembly was analyzed as the bounding PWR stainless steel clad fuel assembly. The Indian Point 1 fuel assembly is a unique 14x14 design with a smaller mass of fuel and clad than the WE14x14. Therefore, it is also bounded by the WE 15x15 stainless steel fuel assembly.

As discussed below in Section 5.2.5.3, the allowable burnup limits in Section 2.1.9 were calculated for different array classes rather than using the design basis assembly to calculate the allowable burnups for all array classes. As mentioned above, the design basis assembly has the highest neutron and gamma source term of the various array classes for the same burnup and cooling time. In order to account for the fact that different array classes have different allowable burnups for the same cooling time, burnups which bound the 14x14A array class were used with the design basis assembly for the analysis in this chapter because those burnups bound the burnups from all other PWR array classes. This approach assures that the calculated source terms and dose rates will be conservative.

### 5.2.5.2 BWR Design Basis Assembly

Table 2.1.2 lists the BWR fuel assembly classes that were evaluated to determine the design basis BWR fuel assembly. Since there are minor differences between the array types in the GE BWR/2-3 and GE BWR/4-6 assembly classes, these assembly classes were not considered individually but rather as a single class. Within that class, the array types, 7x7, 8x8, 9x9, and 10x10 were analyzed to determine the bounding BWR fuel assembly. Since the Humboldt Bay 7x7 and Dresden 1 8x8 are smaller versions of the 7x7 and 8x8 assemblies they are bounded by the 7x7 and 8x8 assemblies in the GE BWR/2-3 and GE BWR/4-6 classes. Within each array type, the fuel assembly with the highest $UO_2$ mass was analyzed. Since the variations of fuel assemblies within an array type are very minor, it is conservative to choose the assembly with the highest $UO_2$ mass. For a given array type of assemblies, the one with the highest $UO_2$ mass will produce the highest radiation source because, for a given burnup (MWD/MTU) and enrichment, it will have produced the most energy and therefore the most fission products. The Humboldt Bay 6x6, Dresden 1 6x6, and LaCrosse assembly classes were not considered in the determination of the bounding fuel assembly. However, these assemblies were analyzed explicitly as discussed below.

Table 5.2.26 presents the characteristics of the fuel assemblies analyzed to determine the design basis zircaloy clad BWR fuel assembly. The corresponding fuel assembly array class from Section 2.1.9 is also listed in the table. The fuel assembly listed for each array type is the assembly that has the highest $UO_2$ mass. All fuel assemblies in Table 5.2.26 were analyzed at the same burnup and cooling time. The initial enrichment used in these analyses is consistent with Table 5.2.24. The results of the comparison are provided in Table 5.2.28. These results indicate that the 7x7 fuel assembly has the highest radiation source term of the zircaloy clad fuel assembly classes considered in Table 2.1.2. This fuel assembly also has the highest $UO_2$ mass which confirms that, for a given initial enrichment, burnup, and cooling time, the assembly with the highest $UO_2$ mass produces the highest radiation source term. According to Reference [5.2.6], the last discharge of a 7x7 assembly was in 1985 and the maximum average burnup for a 7x7 during their operation was 29,000 MWD/MTU. This clearly indicates that the existing 7x7 assemblies have an average burnup and minimum cooling time that is well within the burnup and cooling time limits in Section 2.1.9. Therefore, the 7x7 assembly has never reached the burnup level analyzed in this chapter. However, in the interest of conservatism the 7x7 was chosen as the bounding fuel assembly array type. The power/assembly values used in Table 5.2.26 were calculated by dividing 120% of the thermal power for commercial BWR reactors by the number of assemblies in the core. The higher thermal power, 120%, was used to account for potential power uprates. The power level used for the 7x7 is an additional 4% higher for consistency with previous revisions of the FSAR which also used this assembly as the design basis assembly.

Since the LaCrosse fuel assembly type is a stainless steel clad 10x10 assembly it was analyzed separately. The maximum burnup and minimum cooling time for this assembly are limited to 22,500 MWD/MTU and 10-year cooling as specified in Section 2.1.9. This assembly type is discussed further in Section 5.2.3.

The Humboldt Bay 6x6 and Dresden 1 6x6 fuel are older and shorter fuel than the other array types analyzed and therefore are considered separately. The Dresden 1 6x6 was chosen as the design basis fuel assembly for the Humboldt Bay 6x6 and Dresden 1 6x6 fuel assembly classes because it has the higher $UO_2$ mass. Dresden 1 also contains a few 6x6 MOX fuel assemblies, which were explicitly analyzed as well.

Reference [5.2.6] indicates that the Dresden 1 6x6 fuel assembly has a higher $UO_2$ mass than the Dresden 1 8x8 or the Humboldt Bay fuel (6x6 and 7x7). Therefore, the Dresden 1 6x6 fuel assembly was also chosen as the bounding assembly for damaged fuel and fuel debris for the Humboldt Bay and Dresden 1 fuel assembly classes.

Since the design basis 6x6 fuel assembly can be intact or damaged, the analysis presented in Section 5.4.2 for the damaged 6x6 fuel assembly also demonstrates the acceptability of storing intact 6x6 fuel assemblies from the Dresden 1 and Humboldt Bay fuel assembly classes.

As discussed below in Section 5.2.5.3, the allowable burnup limits in Section 2.1.9 were calculated for different array classes rather than using the design basis assembly to calculate the allowable burnups for all array classes. As mentioned above, the design basis assembly has the highest neutron and gamma source term of the various array classes for the same burnup and cooling time. In order to account for the fact that different array classes have different allowable burnups for the same cooling time, burnups which bound the 9x9G array class were used with the design basis assembly for the analysis in this chapter because those burnups bound the burnups from all other BWR array classes. This approach assures that the calculated source terms and dose rates will be conservative.

### 5.2.5.3 Decay Heat Loads and Allowable Burnup and Cooling Times

Section 2.1.6 describes the calculation of the MPC maximum decay heat limits per assembly. These limits, which differ for uniform and regionalized loading, are presented in Section 2.1.9. The allowable burnup and cooling time limits are derived based on the allowable decay heat limits. Since the decay heat of an assembly will vary slightly with enrichment for a fixed burnup and cooling time, an equation is used to represent burnup as a function of decay heat and enrichment. This equation is of the form:

$$B_u = A*q + B*q^2 + C*q^3 + D*E_{235}^2 + E*E_{235}*q + F*E_{235}*q^2 + G$$

where:
$B_u$ = Burnup in MWD/MTU
q = assembly decay heat (kW)
$E_{235}$ = wt.% $^{235}U$

The coefficients for this equation were developed by fitting ORIGEN-S calculated data for a specific cooling time using GNUPLOT [5.2.16]. ORIGEN-S calculations were performed for enrichments ranging from 0.7 to 5.0 wt.% $^{235}U$ and burnups from 10,000 to 65,000 MWD/MTU for BWRs and 10,000 to 70,000 MWD/MTU for PWRs. The burnups were increased in 2,500 MWD/MTU increments. Using the ORIGEN-S data, the coefficients A through G were determined and then the constant, G, was adjusted so that all data points were bounded (i.e. calculated burnup less than or equal to ORIGEN-S value) by the fit. The coefficients were calculated using ORIGEN-S data for cooling times from 3 years to 20 years. As a result, Section 2.1.9 provides different equation coefficients for each cooling time from 3 to 20 years. Additional discussion on the determination of the equation coefficients is provided in Appendix 5.F. Since the decay heat increases as the enrichment decreases, the allowable burnup will decrease as the enrichment decreases. Therefore, the enrichment used to calculated the allowable burnups becomes a minimum enrichment value and assemblies with an enrichment higher than the value used in the equation are acceptable for storage assuming they also meet the corresponding burnup and decay heat requirements. Even though the lower limit of 0.7 wt.% $^{235}U$ was used in developing the coefficients, these equations are valid for the few assemblies that might exist with enrichments below 0.7 wt.% $^{235}U$. This is because the curve fit is very well behaved in the enrichment range from 0.7 to 5.0 wt.% $^{235}U$ and, therefore, it is expected that the curve fit will remain accurate for enrichments below 0.7 wt.% $^{235}U$.

Different array classes or combinations of classes were analyzed separately to determine the allowable burnup as a function of cooling time for the specified allowable decay heat limits. Calculating allowable burnups for individual array classes is appropriate because even two assemblies with the same MTU may have a different allowable burnup for the same allowable cooling time and permissible decay heat. The heavy metal mass specified in Table 5.2.25 and 5.2.26 and Section 2.1.9 for the various array classes is the value that was used in the determination of the coefficients as a function of cooling time and is the maximum for the respective assembly class. Equation coefficients for each array class listed in Tables 5.2.25 and 5.2.26 were developed. In the end, the equation for the 17x17B and 17x17C array classes resulted in almost identical burnups. Therefore, in Section 2.1.9 these array classes were combined and the coefficients for the 17x17C array class were used since these coefficients produce slightly lower allowable burnups.

There is some uncertainty associated with the ORIGEN-S calculations due to uncertainty in the physics data (e.g. cross sections, decay constants, etc.) and the modeling techniques. To estimate this uncertainty, an approach similar to the one in Reference [5.2.14] was used. As a result, the potential error in the ORIGEN-S decay heat calculations was estimated to be in the range of 3.5 to 5.5% at 3 year cooling time and 1.5 to 3.5% at 20 year cooling. The difference is due to the change in isotopes important to decay heat as a function of cooling time. In order to be conservative in the derivation of the coefficients for the burnup equation, a 5% decay heat penalty was applied for both the PWR and BWR array classes.

As a demonstration that the decay heat values used to determine the allowable burnups are conservative, a comparison between these calculated decay heats and the decay heats reported in Reference [5.2.7] are presented in Table 5.2.29. This comparison is made for a burnup of 30,000 MWD/MTU and a cooling time of 5 years. The burnup was chosen based on the limited burnup data available in Reference [5.2.7].

As mentioned above, the fuel assembly burnup and cooling times in Section 2.1.9 were calculated using the decay heat limits which are also stipulated in Section 2.1.9. The burnup and cooling times for the non-fuel hardware, in Section 2.1.9, were chosen based on the radiation source term calculations discussed previously. The fuel assembly burnup, decay heat, and enrichment equations were derived without consideration for the decay heat from BPRAs, TPDs, CRAs, or APSRs. This is acceptable since the user of the HI-STORM 100 system is required to demonstrate compliance with the assembly decay heat limits in Section 2.1.9 regardless of the heat source (assembly or non-fuel hardware) and the actual decay heat from the non-fuel hardware is expected to be minimal. In addition, the shielding analysis presented in this chapter conservatively calculates the dose rates using both the burnup and cooling times for the fuel assemblies and non-fuel hardware. Therefore, the safety of the HI-STORM 100 system is guaranteed through the bounding analysis in this chapter, represented by the burnup and cooling time limits in the CoC, and the bounding thermal analysis in Chapter 4, represented by the decay heat limits in the CoC.

### 5.2.6 Thoria Rod Canister

Dresden Unit 1 has a single DFC containing 18 thoria rods which have obtained a relatively low burnup, 16,000 MWD/MTU. These rods were removed from two 8x8 fuel assemblies which contained 9 rods each. The irradiation of thorium produces an isotope which is not commonly found in depleted uranium fuel. Th-232 when irradiated produces U-233. The U-233 can undergo an (n,2n) reaction which produces U-232. The U-232 decays to produce Tl-208 which produces a 2.6 MeV gamma during Beta decay. This results in a significant source in the 2.5-3.0 MeV range which is not commonly present in depleted uranium fuel. Therefore, this single DFC container was analyzed to determine if it was bounded by the current shielding analysis.

A radiation source term was calculated for the 18 thoria rods using SAS2H and ORIGEN-S for a burnup of 16,000 MWD/MTU and a cooling time of 18 years. Table 5.2.36 describes the 8x8 fuel assembly that contains the thoria rods. Table 5.2.37 and 5.2.38 show the gamma and neutron source terms, respectively, that were calculated for the 18 thoria rods in the thoria rod canister. Comparing these source terms to the design basis 6x6 source terms for Dresden Unit 1 fuel in Tables 5.2.7 and 5.2.18 clearly indicates that the design basis source terms bound the thoria rods source terms in all neutron groups and in all gamma groups except the 2.5-3.0 MeV group. As mentioned above, the thoria rods have a significant source in this energy range due to the decay of Tl-208.

Section 5.4.8 provides a further discussion of the thoria rod canister and its acceptability for storage in the HI-STORM 100 System.

### 5.2.7 Fuel Assembly Neutron Sources

Neutron source assemblies (NSAs) are used in reactors for startup. There are different types of neutron sources (e.g. californium, americium-beryllium, plutonium-beryllium, polonium-beryllium, antimony-beryllium). These neutron sources are typically inserted into the water rod of a fuel assembly and are usually removable.

#### 5.2.7.1 PWR Neutron Source Assemblies

During in-core operations, the stainless steel and inconel portions of the NSAs become activated, producing a significant amount of Co-60. Reference [5.2.5] provides the masses of steel and inconel for the NSAs. Using these masses it was determined that the total activation of a primary or secondary source is bound by the total activation of a BPRA (see Table 5.2.31). Therefore, storage of NSAs is acceptable and a detailed dose rate analysis using the gamma source from activated NSAs is not performed. Conservatively, the burnup and cooling time limits for TPDs, as listed in Section 2.1.9, are being applied to NSAs since they cover a larger range of burnups.

Antimony-beryllium sources are used as secondary (regenerative) neutron sources in reactor cores. The Sb-Be source produces neutrons from a gamma-n reaction in the beryllium, where the gamma originates from the decay of neutron-activated antimony. The very short half-life of $^{124}$Sb, 60.2 days, however results in a complete decay of the initial amount generated in the reactor within a few years after removal from the reactor. The production of neutrons by the Sb-Be source through regeneration in the MPC is orders of magnitude lower than the design-basis fuel assemblies. Therefore Sb-Be sources do not contribute to the total neutron source in the MPC.

Primary neutron sources (californium, americium-beryllium, plutonium-beryllium and polonium-beryllium) are usually placed in the reactor with a source-strength on the order of 5E+08 n/s. This source strength is similar to, but not greater than, the maximum design-basis fuel assembly source strength listed in Tables 5.2.15 and 5.2.16.

By the time NSAs are stored in the MPC, the primary neutron sources will have been decaying for many years since they were first inserted into the reactor (typically greater than 10 years). For the $^{252}$Cf source, with a half-life of 2.64 years, this means a significant reduction in the source intensity; while the $^{210}$Po-Be source, with a half-life of 138 days, is virtually eliminated. The $^{238}$Pu-Be and $^{241}$Am-Be sources, however, have a significantly longer half-life, 87.4 years and 433 years, respectively. As a result, their source intensity does not decrease significantly before storage in the MPC. Since the $^{238}$Pu-Be and $^{241}$Am-Be sources may have a source intensity similar to a design-basis fuel assembly when they are stored in the MPC, only a single NSA is permitted for storage in the MPC. Since storage of a single NSA would not significantly increase the total neutron source in an MPC, storage of NSAs is acceptable and detailed dose rate analysis of the neutron source from NSAs is not performed.

For ease of implementation in the CoC, the restriction concerning the number of NSAs is being applied to all types of NSAs. In addition, conservatively NSAs are required to be stored in the inner region of the MPC basket as specified in Section 2.1.9.

#### 5.2.7.2 BWR Neutron Source Assemblies

Dresden Unit 1 has a few antimony-beryllium neutron sources. These sources have been analyzed in Section 5.4.7 to demonstrate that they are acceptable for storage in the HI-STORM 100 System.

### 5.2.8 Stainless Steel Channels

The LaCrosse nuclear plant used two types of channels for their BWR assemblies: stainless steel and zircaloy. Since the irradiation of zircaloy does not produce significant activation, there are no restrictions on the storage of these channels and they are not explicitly analyzed in this chapter. The stainless steel channels, however, can produce a significant amount of activation, predominantly from Co-60. LaCrosse has thirty-two stainless steel channels, a few of which have been in the reactor core for, approximately, the lifetime of the plant. Therefore, the activation of the stainless steel channels was conservatively calculated to demonstrate that they are acceptable for storage in the HI-STORM 100 system. For conservatism, the number of stainless steel channels in an MPC-68 is being limited to sixteen and Section 2.1.9 requires that these channels be stored in the inner sixteen locations.

The activation of a single stainless steel channel was calculated by simulating the irradiation of the channels with ORIGEN-S using the flux calculated from the LaCrosse fuel assembly. The mass of the steel channel in the active fuel zone (83 inches) was used in the analysis. For burnups beyond 22,500 MWD/MTU, it was assumed, for the purpose of the calculation, that the burned fuel assembly was replaced with a fresh fuel assembly every 22,500 MWD/MTU. This was achieved in ORIGEN-S by resetting the flux levels and cross sections to the 0 MWD/MTU condition after every 22,500 MWD/MTU.

LaCrosse was commercially operated from November 1969 until it was shutdown in April 1987. Therefore, the shortest cooling time for the assemblies and the channels is 13 years. Assuming the plant operated continually from 11/69 until 4/87, approximately 17.5 years or 6388 days, the accumulated burnup for the channels would be 186,000 MWD/MTU (6388 days times 29.17 MW/MTU from Table 5.2.3). Therefore, the cobalt activity calculated for a single stainless steel channel irradiated for 180,000 MWD/MTU was calculated to be 667 curies of Co-60 for 13 years cooling. This is equivalent to a source of 4.94E+13 photons/sec in the energy range of 1.0-1.5 MeV.

In order to demonstrate that sixteen stainless steel channels are acceptable for storage in an MPC-68, a comparison of source terms is performed. Table 5.2.8 indicates that the source term for the LaCrosse design basis fuel assembly in the 1.0-1.5 MeV range is 6.34E+13 photons/sec for 10 years cooling, assuming a 144 inch active fuel length. This is equivalent to 4.31E+15 photons/sec/cask. At 13 years cooling, the fuel source term in that energy range decreases to 4.31E+13 photons/sec which is equivalent to 2.93E+15 photons/sec/cask. If the source term from the stainless steel channels is scaled to 144 inches and added to the 13 year fuel source term the result is 4.30E+15 photons/sec/cask (2.93E+15 photons/sec/cask + 4.94E+13 photons/sec/channel x 144 inch/83 inch x 16 channels/cask). This number is equivalent to the 10 year 4.31E+15 photons/sec/cask source calculated from Table 5.2.8 and used in the shielding analysis in this chapter. Therefore, it is concluded that the storage of 16 stainless steel channels in an MPC-68 is acceptable.

Table 5.2.1

DESCRIPTION OF DESIGN BASIS ZIRCALOY CLAD FUEL

| | PWR | BWR |
|---|---|---|
| Assembly type/class | B&W 15×15 | GE 7×7 |
| Active fuel length (in.) | 144 | 144 |
| No. of fuel rods | 208 | 49 |
| Rod pitch (in.) | 0.568 | 0.738 |
| Cladding material | Zircaloy-4 | Zircaloy-2 |
| Rod diameter (in.) | 0.428 | 0.570 |
| Cladding thickness (in.) | 0.0230 | 0.0355 |
| Pellet diameter (in.) | 0.3742 | 0.488 |
| Pellet material | $UO_2$ | $UO_2$ |
| Pellet density (gm/cc) | 10.412 (95% of theoretical) | 10.412 (95% of theoretical) |
| Enrichment (w/o $^{235}U$) | 3.6 | 3.2 |
| | | |
| | | |
| Specific power (MW/MTU) | 40 | 30 |
| Weight of $UO_2$ (kg)[††] | 562.029 | 225.177 |
| Weight of U (kg)[††] | 495.485 | 198.516 |

Notes:

1. The B&W 15x15 is the design basis assembly for the following fuel assembly classes listed in Table 2.1.1: B&W 15x15, B&W 17x17, CE 14x14, CE 16x16, WE 14x14, WE 15x15, WE 17x17, St. Lucie, and Ft. Calhoun.
2. The GE 7x7 is the design basis assembly for the following fuel assembly classes listed in Table 2.1.2: GE BWR/2-3, GE BWR/4-6, Humboldt Bay 7x7, and Dresden 1 8x8.

†† Derived from parameters in this table.

Table 5.2.1 (continued)

DESCRIPTION OF DESIGN BASIS FUEL

| | PWR | BWR |
|---|---|---|
| No. of Water Rods | 17 | 0 |
| Water Rod O.D. (in.) | 0.53 | N/A |
| Water Rod Thickness (in.) | 0.016 | N/A |
| Lower End Fitting (kg) | 8.16 (steel)<br>1.3 (inconel) | 4.8 (steel) |
| Gas Plenum Springs (kg) | 0.48428 (inconel)<br>0.23748 (steel) | 1.1 (steel) |
| Gas Plenum Spacer (kg) | 0.82824 | N/A |
| Expansion Springs (kg) | N/A | 0.4 (steel) |
| Upper End Fitting (kg) | 9.28 (steel) | 2.0 (steel) |
| Handle (kg) | N/A | 0.5 (steel) |
| Incore Grid Spacers (kg) | 4.9 (inconel) | 0.33 (inconel springs) |

Table 5.2.2

DESCRIPTION OF DESIGN BASIS GE 6x6 ZIRCALOY CLAD FUEL

| | **BWR** |
|---|---|
| Fuel type | GE 6x6 |
| Active fuel length (in.) | 110 |
| No. of fuel rods | 36 |
| Rod pitch (in.) | 0.694 |
| Cladding material | Zircaloy-2 |
| Rod diameter (in.) | 0.5645 |
| Cladding thickness (in.) | 0.035 |
| Pellet diameter (in.) | 0.494 |
| Pellet material | $UO_2$ |
| Pellet density (gm/cc) | 10.412 (95% of theoretical) |
| Enrichment (w/o $^{235}U$) | 2.24 |
| Burnup (MWD/MTU) | 30,000 |
| Cooling Time (years) | 18 |
| Specific power (MW/MTU) | 16.5 |
| Weight of $UO_2$ (kg)† | 129.5 |
| Weight of U (kg)† | 114.2 |

Notes:
1. The 6x6 is the design basis damaged fuel assembly for the Humboldt Bay (all array types) and the Dresden 1 (all array types) damaged fuel assembly classes. It is also the design basis fuel assembly for the intact Humboldt Bay 6x6 and Dresden 1 6x6 fuel assembly classes.
2. This design basis damaged fuel assembly is also the design basis fuel assembly for fuel debris.

† Derived from parameters in this table.

Table 5.2.3

DESCRIPTION OF DESIGN BASIS STAINLESS STEEL CLAD FUEL

| | **PWR** | **BWR** |
|---|---|---|
| Fuel type | WE 15x15 | LaCrosse 10x10 |
| Active fuel length (in.) | 144 | 144 |
| No. of fuel rods | 204 | 100 |
| Rod pitch (in.) | 0.563 | 0.565 |
| Cladding material | 304 SS | 348H SS |
| Rod diameter (in.) | 0.422 | 0.396 |
| Cladding thickness (in.) | 0.0165 | 0.02 |
| Pellet diameter (in.) | 0.3825 | 0.35 |
| Pellet material | $UO_2$ | $UO_2$ |
| Pellet density (gm/cc) | 10.412 (95% of theoretical) | 10.412 (95% of theoretical) |
| Enrichment (w/o $^{235}U$) | 3.5 | 3.5 |
| Burnup (MWD/MTU)† | 40,000 (MPC-24 and 32) | 22,500 (MPC-68) |
| Cooling Time (years)† | 8 (MPC-24), 9 (MPC-32) | 10 (MPC-68) |
| Specific power (MW/MTU) | 37.96 | 29.17 |
| No. of Water Rods | 21 | 0 |
| Water Rod O.D. (in.) | 0.546 | N/A |
| Water Rod Thickness (in.) | 0.017 | N/A |

Notes:
1. The WE 15x15 is the design basis assembly for the following fuel assembly classes listed in Table 2.1.1: Indian Point 1, Haddam Neck, and San Onofre 1.
2. The LaCrosse 10x10 is the design basis assembly for the following fuel assembly class listed in Table 2.1.2: LaCrosse.

† Burnup and cooling time combinations are equivalent to or conservatively bound the limits in Section 2.1.9.

Table 5.2.4

CALCULATED MPC-32 PWR FUEL GAMMA SOURCE PER ASSEMBLY
FOR DESIGN BASIS ZIRCALOY CLAD FUEL
FOR VARYING BURNUPS AND COOLING TIMES

| **Lower Energy** | **Upper Energy** | **45,000 MWD/MTU 3 Year Cooling** | | **69,000 MWD/MTU 5 Year Cooling** | |
|---|---|---|---|---|---|
| (MeV) | (MeV) | (MeV/s) | (Photons/s) | (MeV/s) | (Photons/s) |
| 0.45 | 0.7 | 3.05E+15 | 5.30E+15 | 3.26E+15 | 5.67E+15 |
| 0.7 | 1.0 | 1.37E+15 | 1.62E+15 | 1.23E+15 | 1.44E+15 |
| 1.0 | 1.5 | 2.96E+14 | 2.37E+14 | 2.69E+14 | 2.15E+14 |
| 1.5 | 2.0 | 2.91E+13 | 1.66E+13 | 1.41E+13 | 8.08E+12 |
| 2.0 | 2.5 | 3.79E+13 | 1.68E+13 | 7.56E+12 | 3.36E+12 |
| 2.5 | 3.0 | 1.14E+12 | 4.13E+11 | 3.56E+11 | 1.29E+11 |
| Total | | 4.78E+15 | 7.18E+15 | 4.78E+15 | 7.34E+15 |

Table 5.2.5

CALCULATED MPC-24 PWR FUEL GAMMA SOURCE PER ASSEMBLY
FOR DESIGN BASIS ZIRCALOY CLAD FUEL
FOR VARYING BURNUPS AND COOLING TIMES

| **Lower Energy** | **Upper Energy** | **60,000 MWD/MTU 3 Year Cooling** | | **75,000 MWD/MTU 5 Year Cooling** | |
|---|---|---|---|---|---|
| (MeV) | (MeV) | (MeV/s) | (Photons/s) | (MeV/s) | (Photons/s) |
| 0.45 | 0.7 | 4.11E+15 | 7.14E+15 | 3.55E+15 | 6.17E+15 |
| 0.7 | 1.0 | 1.98E+15 | 2.33E+15 | 1.36E+15 | 1.60E+15 |
| 1.0 | 1.5 | 4.04E+14 | 3.23E+14 | 2.94E+14 | 2.35E+14 |
| 1.5 | 2.0 | 3.41E+13 | 1.95E+13 | 1.50E+13 | 8.59E+12 |
| 2.0 | 2.5 | 3.95E+13 | 1.76E+13 | 7.63E+12 | 3.39E+12 |
| 2.5 | 3.0 | 1.29E+12 | 4.70E+11 | 3.72E+11 | 1.35E+11 |
| Total | | 6.57E+15 | 9.84E+15 | 5.23E+15 | 8.02E+15 |

Table 5.2.6

CALCULATED MPC-68 BWR FUEL GAMMA SOURCE PER ASSEMBLY
FOR DESIGN BASIS ZIRCALOY CLAD FUEL
FOR VARYING BURNUPS AND COOLING TIMES

| **Lower Energy** | **Upper Energy** | **50,000 MWD/MTU 3 Year Cooling** | |
|---|---|---|---|
| (MeV) | (MeV) | (MeV/s) | (Photons/s) |
| 0.45 | 0.7 | 1.28E+15 | 2.23E+15 |
| 0.7 | 1.0 | 5.76E+14 | 6.77E+14 |
| 1.0 | 1.5 | 1.18E+14 | 9.47E+13 |
| 1.5 | 2.0 | 1.04E+13 | 5.92E+12 |
| 2.0 | 2.5 | 1.20E+13 | 5.33E+12 |
| 2.5 | 3.0 | 4.04E+11 | 1.47E+11 |
| Total | | 2.00E+15 | 3.01E+15 |

Table 5.2.7

CALCULATED MPC-68 BWR FUEL GAMMA SOURCE PER ASSEMBLY
FOR DESIGN BASIS ZIRCALOY CLAD GE 6x6 FUEL

| **Lower Energy** | **Upper Energy** | **30,000 MWD/MTU 18-Year Cooling** | |
|---|---|---|---|
| (MeV) | (MeV) | (MeV/s) | (Photons/s) |
| 4.5e-01 | 7.0e-01 | 1.53e+14 | 2.65e+14 |
| 7.0e-01 | 1.0 | 3.97e+12 | 4.67e+12 |
| 1.0 | 1.5 | 3.67e+12 | 2.94e+12 |
| 1.5 | 2.0 | 2.20e+11 | 1.26e+11 |
| 2.0 | 2.5 | 1.35e+09 | 5.99e+08 |
| 2.5 | 3.0 | 7.30e+07 | 2.66e+07 |
| Totals | | 1.61e+14 | 2.73e+14 |

Table 5.2.8

CALCULATED BWR FUEL GAMMA SOURCE PER ASSEMBLY
FOR STAINLESS STEEL CLAD FUEL

| **Lower Energy** | **Upper Energy** | **22,500 MWD/MTU 10-Year Cooling** | |
|---|---|---|---|
| (MeV) | (MeV) | (MeV/s) | (Photons/s) |
| 4.5e-01 | 7.0e-01 | 2.72e+14 | 4.74+14 |
| 7.0e-01 | 1.0 | 1.97e+13 | 2.31e+13 |
| 1.0 | 1.5 | 7.93e+13 | 6.34e+13 |
| 1.5 | 2.0 | 4.52e+11 | 2.58e+11 |
| 2.0 | 2.5 | 3.28e+10 | 1.46e+10 |
| 2.5 | 3.0 | 1.69e+9 | 6.14e+8 |
| Totals | | 3.72e+14 | 5.61e+14 |

Note: These source terms were calculated for a 144-inch fuel length. The limits in Section 2.1.9 are based on the actual 83-inch active fuel length.

Table 5.2.9

CALCULATED PWR FUEL GAMMA SOURCE PER ASSEMBLY
FOR STAINLESS STEEL CLAD FUEL

| **Lower Energy** | **Upper Energy** | **40,000 MWD/MTU 8-Year Cooling** | | **40,000 MWD/MTU 9-Year Cooling** | |
|---|---|---|---|---|---|
| (MeV) | (MeV) | (MeV/s) | (Photons/s) | (MeV/s) | (Photons/s) |
| 4.5e-01 | 7.0e-01 | 1.37e+15 | 2.38e+15 | 1.28E+15 | 2.22E+15 |
| 7.0e-01 | 1.0 | 2.47e+14 | 2.91e+14 | 1.86E+14 | 2.19E+14 |
| 1.0 | 1.5 | 4.59e+14 | 3.67e+14 | 4.02E+14 | 3.21E+14 |
| 1.5 | 2.0 | 3.99e+12 | 2.28e+12 | 3.46E+12 | 1.98E+12 |
| 2.0 | 2.5 | 5.85e+11 | 2.60e+11 | 2.69E+11 | 1.20E+11 |
| 2.5 | 3.0 | 3.44e+10 | 1.25e+10 | 1.77E+10 | 6.44E+09 |
| Totals | | 2.08e+15 | 3.04e+15 | 1.87E+15 | 2.76E+15 |

Note: These source terms were calculated for a 144-inch fuel length. The limits in Section 2.1.9 are based on the actual 122-inch active fuel length.

Table 5.2.10

SCALING FACTORS USED IN CALCULATING THE $^{60}Co$ SOURCE

| Region | PWR | BWR |
|---|---|---|
| Handle | N/A | 0.05 |
| Upper End Fitting | 0.1 | 0.1 |
| Gas Plenum Spacer | 0.1 | N/A |
| Expansion Springs | N/A | 0.1 |
| Gas Plenum Springs | 0.2 | 0.2 |
| Incore Grid Spacer | 1.0 | 1.0 |
| Lower End Fitting | 0.2 | 0.15 |

Table 5.2.11

CALCULATED MPC-32 $^{60}Co$ SOURCE PER ASSEMBLY FOR DESIGN BASIS ZIRCALOY CLAD FUEL AT DESIGN BASIS BURNUP AND COOLING TIME

| Location | 45,000 MWD/MTU and 3-Year Cooling (curies) | 69,000 MWD/MTU and 5-Year Cooling (curies) |
|---|---|---|
| Lower End Fitting | 217.58 | 208.12 |
| Gas Plenum Springs | 16.60 | 15.88 |
| Gas Plenum Spacer | 9.52 | 9.11 |
| Expansion Springs | N/A | N/A |
| Incore Grid Spacers | 563.50 | 539.00 |
| Upper End Fitting | 106.72 | 102.08 |
| Handle | N/A | N/A |

Table 5.2.12

CALCULATED MPC-24 $^{60}$Co SOURCE PER ASSEMBLY FOR DESIGN BASIS ZIRCALOY CLAD FUEL AT DESIGN BASIS BURNUP AND COOLING TIME

| **Location** | **60,000 MWD/MTU and 3-Year Cooling (curies)** | **75,000 MWD/MTU and - 5 Year Cooling (curies)** |
|---|---|---|
| Lower End Fitting | 249.74 | 219.47 |
| Gas Plenum Springs | 19.05 | 16.74 |
| Gas Plenum Spacer | 10.93 | 9.61 |
| Expansion Springs | N/A | N/A |
| Incore Grid Spacers | 646.80 | 568.40 |
| Upper End Fitting | 122.50 | 107.65 |
| Handle | N/A | N/A |

Table 5.2.13

CALCULATED MPC-68 $^{60}Co$ SOURCE PER ASSEMBLY FOR DESIGN BASIS ZIRCALOY CLAD FUEL AT DESIGN BASIS BURNUP AND COOLING TIME

| Location | 50,000 MWD/MTU and 3-Year Cooling (curies) |
|---|---|
| Lower End Fitting | 90.55 |
| Gas Plenum Springs | 27.67 |
| Gas Plenum Spacer | N/A |
| Expansion Springs | 5.03 |
| Grid Spacer Springs | 41.50 |
| Upper End Fitting | 25.15 |
| Handle | 3.14 |

Table 5.2.14

THIS TABLE INTENTIONALLY DELETED

Table 5.2.15

CALCULATED MPC-32 PWR NEUTRON SOURCE PER ASSEMBLY
FOR DESIGN BASIS ZIRCALOY CLAD FUEL
FOR VARYING BURNUPS AND COOLING TIMES

| Lower Energy (MeV) | Upper Energy (MeV) | 45,000 MWD/MTU 3-Year Cooling (Neutrons/s) | 69,000 MWD/MTU 5-Year Cooling (Neutrons/s) |
|---|---|---|---|
| 1.0e-01 | 4.0e-01 | 1.77E+07 | 5.31E+07 |
| 4.0e-01 | 9.0e-01 | 9.03E+07 | 2.71E+08 |
| 9.0e-01 | 1.4 | 8.27E+07 | 2.48E+08 |
| 1.4 | 1.85 | 6.09E+07 | 1.82E+08 |
| 1.85 | 3.0 | 1.08E+08 | 3.21E+08 |
| 3.0 | 6.43 | 9.77E+07 | 2.92E+08 |
| 6.43 | 20.0 | 8.66E+06 | 2.60E+07 |
| Totals | | 4.65E+08 | 1.39E+09 |

Table 5.2.16

CALCULATED MPC-24 PWR NEUTRON SOURCE PER ASSEMBLY
FOR DESIGN BASIS ZIRCALOY CLAD FUEL
FOR VARYING BURNUPS AND COOLING TIMES

| **Lower Energy (MeV)** | **Upper Energy (MeV)** | **60,000 MWD/MTU 3-Year Cooling (Neutrons/s)** | **75,000 MWD/MTU 5-Year Cooling (Neutrons/s)** |
|---|---|---|---|
| 1.0e-01 | 4.0e-01 | 3.76E+07 | 6.82E+07 |
| 4.0e-01 | 9.0e-01 | 1.92E+08 | 3.48E+08 |
| 9.0e-01 | 1.4 | 1.76E+08 | 3.18E+08 |
| 1.4 | 1.85 | 1.29E+08 | 2.34E+08 |
| 1.85 | 3.0 | 2.28E+08 | 4.11E+08 |
| 3.0 | 6.43 | 2.08E+08 | 3.75E+08 |
| 6.43 | 20.0 | 1.84E+07 | 3.34E+07 |
| Totals | | 9.89E+08 | 1.79E+09 |

Table 5.2.17

CALCULATED MPC-68 BWR NEUTRON SOURCE PER ASSEMBLY
FOR DESIGN BASIS ZIRCALOY CLAD FUEL
FOR VARYING BURNUPS AND COOLING TIMES

| **Lower Energy (MeV)** | **Upper Energy (MeV)** | **50,000 MWD/MTU 3-Year Cooling (Neutrons/s)** |
|---|---|---|
| 1.0e-01 | 4.0e-01 | 9.79E+06 |
| 4.0e-01 | 9.0e-01 | 5.00E+07 |
| 9.0e-01 | 1.4 | 4.57E+07 |
| 1.4 | 1.85 | 3.37E+07 |
| 1.85 | 3.0 | 5.93E+07 |
| 3.0 | 6.43 | 5.40E+07 |
| 6.43 | 20.0 | 4.79E+06 |
| Totals | | 2.57E+08 |

Table 5.2.18

CALCULATED MPC-68 BWR NEUTRON SOURCE PER ASSEMBLY
FOR DESIGN BASIS ZIRCALOY CLAD GE 6x6 FUEL

| **Lower Energy (MeV)** | **Upper Energy (MeV)** | **30,000 MWD/MTU 18-Year Cooling (Neutrons/s)** |
|---|---|---|
| 1.0e-01 | 4.0e-01 | 8.22e+5 |
| 4.0e-01 | 9.0e-01 | 4.20e+6 |
| 9.0e-01 | 1.4 | 3.87e+6 |
| 1.4 | 1.85 | 2.88e+6 |
| 1.85 | 3.0 | 5.18e+6 |
| 3.0 | 6.43 | 4.61e+6 |
| 6.43 | 20.0 | 4.02e+5 |
| Total | | 2.20e+7 |

Table 5.2.19

CALCULATED BWR NEUTRON SOURCE PER ASSEMBLY
FOR STAINLESS STEEL CLAD FUEL

| **Lower Energy (MeV)** | **Upper Energy (MeV)** | **22,500 MWD/MTU 10-Year Cooling (Neutrons/s)** |
|---|---|---|
| 1.0e-01 | 4.0e-01 | 2.23e+5 |
| 4.0e-01 | 9.0e-01 | 1.14e+6 |
| 9.0e-01 | 1.4 | 1.07e+6 |
| 1.4 | 1.85 | 8.20e+5 |
| 1.85 | 3.0 | 1.56e+6 |
| 3.0 | 6.43 | 1.30e+6 |
| 6.43 | 20.0 | 1.08e+5 |
| Total | | 6.22e+6 |

Note: These source terms were calculated for a 144-inch fuel length. The limits in Section 2.1.9 are based on the actual 83-inch active fuel length.

Table 5.2.20

CALCULATED PWR NEUTRON SOURCE PER ASSEMBLY
FOR STAINLESS STEEL CLAD FUEL

| Lower Energy (MeV) | Upper Energy (MeV) | 40,000 MWD/MTU 8-Year Cooling (Neutrons/s) | 40,000 MWD/MTU 9-Year Cooling (Neutrons/s) |
|---|---|---|---|
| 1.0e-01 | 4.0e-01 | 1.04e+7 | 1.01E+07 |
| 4.0e-01 | 9.0e-01 | 5.33e+7 | 5.14E+07 |
| 9.0e-01 | 1.4 | 4.89e+7 | 4.71E+07 |
| 1.4 | 1.85 | 3.61e+7 | 3.48E+07 |
| 1.85 | 3.0 | 6.41e+7 | 6.18E+07 |
| 3.0 | 6.43 | 5.79e+7 | 5.58E+07 |
| 6.43 | 20.0 | 5.11e+6 | 4.92E+06 |
| Totals | | 2.76e+8 | 2.66E+08 |

Note: These source terms were calculated for a 144-inch fuel length. The limits in Section 2.1.9 are based on the actual 122-inch active fuel length.

Table 5.2.21

DESCRIPTION OF DESIGN BASIS ZIRCALOY CLAD MIXED OXIDE FUEL

| | **BWR** |
|---|---|
| Fuel type | GE 6x6 |
| Active fuel length (in.) | 110 |
| No. of fuel rods | 36 |
| Rod pitch (in.) | 0.696 |
| Cladding material | Zircaloy-2 |
| Rod diameter (in.) | 0.5645 |
| Cladding thickness (in.) | 0.036 |
| Pellet diameter (in.) | 0.482 |
| Pellet material | $UO_2$ and $PuUO_2$ |
| No. of $UO_2$ Rods | 27 |
| No. of $PuUO_2$ rods | 9 |
| Pellet density (gm/cc) | 10.412 (95% of theoretical) |
| Enrichment (w/o $^{235}U$)† | 2.24 ($UO_2$ rods)<br>0.711 ($PuUO_2$ rods) |
| Burnup (MWD/MTU) | 30,000 |
| Cooling Time (years) | 18 |
| Specific power (MW/MTU) | 16.5 |
| Weight of $UO_2$,$PuUO_2$ (kg)†† | 123.3 |
| Weight of U,Pu (kg)†† | 108.7 |

† See Table 5.3.3 for detailed composition of $PuUO_2$ rods.

†† Derived from parameters in this table.

Table 5.2.22

CALCULATED MPC-68 BWR FUEL GAMMA SOURCE PER ASSEMBLY
FOR DESIGN BASIS ZIRCALOY CLAD MIXED OXIDE FUEL

| **Lower Energy** | **Upper Energy** | **30,000 MWD/MTU 18-Year Cooling** | |
|---|---|---|---|
| (MeV) | (MeV) | (MeV/s) | (Photons/s) |
| 4.5e-01 | 7.0e-01 | 1.45e+14 | 2.52e+14 |
| 7.0e-01 | 1.0 | 3.87e+12 | 4.56e+12 |
| 1.0 | 1.5 | 3.72e+12 | 2.98e+12 |
| 1.5 | 2.0 | 2.18e+11 | 1.25e+11 |
| 2.0 | 2.5 | 1.17e+9 | 5.22e+8 |
| 2.5 | 3.0 | 9.25e+7 | 3.36e+7 |
| Totals | | 1.53e+14 | 2.60e+14 |

Table 5.2.23

CALCULATED MPC-68 BWR NEUTRON SOURCE PER ASSEMBLY FOR DESIGN BASIS ZIRCALOY CLAD MIXED OXIDE FUEL

| **Lower Energy (MeV)** | **Upper Energy (MeV)** | **30,000 MWD/MTU 18-Year Cooling (Neutrons/s)** |
|---|---|---|
| 1.0e-01 | 4.0e-01 | 1.24e+6 |
| 4.0e-01 | 9.0e-01 | 6.36e+6 |
| 9.0e-01 | 1.4 | 5.88e+6 |
| 1.4 | 1.85 | 4.43e+6 |
| 1.85 | 3.0 | 8.12e+6 |
| 3.0 | 6.43 | 7.06e+6 |
| 6.43 | 20.0 | 6.07e+5 |
| Totals | | 3.37e+7 |

Table 5.2.24

INITIAL ENRICHMENTS USED IN THE SOURCE TERM CALCULATIONS

| Burnup Range (MWD/MTU) | Initial Enrichment (wt.% $^{235}U$) |
|---|---|
| **BWR Fuel** | |
| 20,000-25,000 | 2.1 |
| 25,000-30,000 | 2.4 |
| 30,000-35,000 | 2.6 |
| 35,000-40,000 | 2.9 |
| 40,000-45,000 | 3.0 |
| 45,000-50,000 | 3.2 |
| 50,000-55,000 | 3.6 |
| 55,000-60,000 | 4.0 |
| 60,000-65,000 | 4.4 |
| 65,000-70,000 | 4.8 |
| **PWR Fuel** | |
| 20,000-25,000 | 2.3 |
| 25,000-30,000 | 2.6 |
| 30,000-35,000 | 2.9 |
| 35,000-40,000 | 3.2 |
| 40,000-45,000 | 3.4 |
| 45,000-50,000 | 3.6 |
| 50,000-55,000 | 3.9 |
| 55,000-60,000 | 4.2 |
| 60,000-65,000 | 4.5 |
| 65,000-70,000 | 4.8 |
| 70,000-75,000 | 5.0 |

Note: The burnup ranges do not overlap. Therefore, 20,000-25,000 MWD/MTU means 20,000-24,999.9 MWD/MTU, etc. This note does not apply to the maximum burnups of 70,000 and 75,000 MWD/MTU.

Table 5.2.25 (page 1 of 2)

DESCRIPTION OF EVALUATED ZIRCALOY CLAD PWR FUEL

| Assembly | WE 14×14 | WE 14x14 | WE 15×15 | WE 17×17 | WE 17x17 |
|---|---|---|---|---|---|
| Fuel assembly array class | 14x14B | 14x14A | 15x15ABC | 17x17B | 17x17A |
| Active fuel length (in.) | 144 | 144 | 144 | 144 | 144 |
| No. of fuel rods | 179 | 179 | 204 | 264 | 264 |
| Rod pitch (in.) | 0.556 | 0.556 | 0.563 | 0.496 | 0.496 |
| Cladding material | Zr-4 | Zr-4 | Zr-4 | Zr-4 | Zr-4 |
| Rod diameter (in.) | 0.422 | 0.4 | 0.422 | 0.374 | 0.36 |
| Cladding thickness (in.) | 0.0243 | 0.0243 | 0.0245 | 0.0225 | 0.0225 |
| Pellet diameter (in.) | 0.3659 | 0.3444 | 0.3671 | 0.3232 | 0.3088 |
| Pellet material | $UO_2$ | $UO_2$ | $UO_2$ | $UO_2$ | $UO_2$ |
| Pellet density (gm/cc) (% of theoretical) | 10.522 (96%) | 10.522 (96%) | 10.522 (96%) | 10.522 (96%) | 10.522 (96%) |
| Enrichment (wt.% $^{235}U$) | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 |
| Burnup (MWD/MTU) | 40,000 | 40,000 | 40,000 | 40,000 | 40,000 |
| Cooling time (years) | 5 | 5 | 5 | 5 | 5 |
| Power/assembly (MW) | 15.0 | 15.0 | 18.6 | 20.4 | 20.4 |
| Specific power (MW/MTU) | 36.409 | 41.097 | 39.356 | 43.031 | 47.137 |
| Weight of $UO_2$ (kg)† | 467.319 | 414.014 | 536.086 | 537.752 | 490.901 |
| Weight of U (kg)† | 411.988 | 364.994 | 472.613 | 474.082 | 432.778 |
| No. of Guide Tubes | 17 | 17 | 21 | 25 | 25 |
| Guide Tube O.D. (in.) | 0.539 | 0.539 | 0.546 | 0.474 | 0.474 |
| Guide Tube Thickness (in.) | 0.0170 | 0.0170 | 0.0170 | 0.0160 | 0.0160 |

† Derived from parameters in this table.

Table 5.2.25 (page 2 of 2)

DESCRIPTION OF EVALUATED ZIRCALOY CLAD PWR FUEL

| Assembly | CE 14×14 | CE 16×16 | B&W 15×15 | B&W 17×17 |
|---|---|---|---|---|
| Fuel assembly array class | 14x14C | 16x16A | 15x15DEF H | 17x17C |
| Active fuel length (in.) | 144 | 150 | 144 | 144 |
| No. of fuel rods | 176 | 236 | 208 | 264 |
| Rod pitch (in.) | 0.580 | 0.5063 | 0.568 | 0.502 |
| Cladding material | Zr-4 | Zr-4 | Zr-4 | Zr-4 |
| Rod diameter (in.) | 0.440 | 0.382 | 0.428 | 0.377 |
| Cladding thickness (in.) | 0.0280 | 0.0250 | 0.0230 | 0.0220 |
| Pellet diameter (in.) | 0.3805 | 0.3255 | 0.3742 | 0.3252 |
| Pellet material | $UO_2$ | $UO_2$ | $UO_2$ | $UO_2$ |
| Pellet density (gm/cc) (95% of theoretical) | 10.522 (96%) | 10.522 (96%) | 10.412 (95%) | 10.522 (96%) |
| Enrichment (wt.% $^{235}U$) | 3.4 | 3.4 | 3.4 | 3.4 |
| Burnup (MWD/MTU) | 40,000 | 40,000 | 40,000 | 40,000 |
| Cooling time (years) | 5 | 5 | 5 | 5 |
| Power/assembly (MW) | 13.7 | 17.5 | 19.819 | 20.4 |
| Specific power (MW/MTU) | 31.275 | 39.083 | 40 | 42.503 |
| Weight of $UO_2$ (kg)† | 496.887 | 507.9 | 562.029 | 544.428 |
| Weight of U (kg)† | 438.055 | 447.764 | 495.485 | 479.968 |
| No. of Guide Tubes | 5 | 5 | 17 | 25 |
| Guide Tube O.D. (in.) | 1.115 | 0.98 | 0.53 | 0.564 |
| Guide Tube Thickness (in.) | 0.0400 | 0.0400 | 0.0160 | 0.0175 |

† Derived from parameters in this table.

Table 5.2.26 (page 1 of 2)

DESCRIPTION OF EVALUATED ZIRCALOY CLAD BWR FUEL

| Array Type | 7×7 | 8×8 | 8x8 | 9x9 | 9x9 |
|---|---|---|---|---|---|
| Fuel assembly array class | 7x7B | 8x8B | 8x8CDE | 9x9A | 9x9B |
| Active fuel length (in.) | 144 | 144 | 150 | 144 | 150 |
| No. of fuel rods | 49 | 64 | 62 | 74 | 72 |
| Rod pitch (in.) | 0.738 | 0.642 | 0.64 | 0.566 | 0.572 |
| Cladding material | Zr-2 | Zr-2 | Zr-2 | Zr-2 | Zr-2 |
| Rod diameter (in.) | 0.570 | 0.484 | 0.493 | 0.44 | 0.433 |
| Cladding thickness (in.) | 0.0355 | 0.02725 | 0.034 | 0.028 | 0.026 |
| Pellet diameter (in.) | 0.488 | 0.4195 | 0.416 | 0.376 | 0.374 |
| Pellet material | $UO_2$ | $UO_2$ | $UO_2$ | $UO_2$ | $UO_2$ |
| Pellet density (gm/cc) (% of theoretical) | 10.412 (95%) | 10.412 (95%) | 10.412 (95%) | 10.522 (96%) | 10.522 (96%) |
| Enrichment (wt.% $^{235}U$) | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Burnup (MWD/MTU) | 40,000 | 40,000 | 40,000 | 40,000 | 40,000 |
| Cooling time (years) | 5 | 5 | 5 | 5 | 5 |
| Power/assembly (MW) | 5.96 | 5.75 | 5.75 | 5.75 | 5.75 |
| Specific power (MW/MTU) | 30 | 30 | 30.24 | 31.97 | 31.88 |
| Weight of $UO_2$ (kg)† | 225.177 | 217.336 | 215.673 | 204.006 | 204.569 |
| Weight of U (kg)† | 198.516 | 191.603 | 190.137 | 179.852 | 180.348 |
| No. of Water Rods | 0 | 0 | 2 | 2 | 1 |
| Water Rod O.D. (in.) | n/a | n/a | 0.493 | 0.98 | 1.516 |
| Water Rod Thickness (in.) | n/a | n/a | 0.034 | 0.03 | 0.0285 |

† Derived from parameters in this table.

Table 5.2.26 (page 1 of 2)

DESCRIPTION OF EVALUATED ZIRCALOY CLAD BWR FUEL

| Array Type | 9x9 | 9×9 | 9x9 | 10×10 | 10x10 |
|---|---|---|---|---|---|
| Fuel assembly array class | 9x9CD | 9x9EF | 9x9G | 10x10AB | 10x10C |
| Active fuel length (in.) | 150 | 144 | 150 | 144 | 150 |
| No. of fuel rods | 80 | 76 | 72 | 92 | 96 |
| Rod pitch (in.) | 0.572 | 0.572 | 0.572 | 0.510 | 0.488 |
| Cladding material | Zr-2 | Zr-2 | Zr-2 | Zr-2 | Zr-2 |
| Rod diameter (in.) | 0.423 | 0.443 | 0.424 | 0.404 | 0.378 |
| Cladding thickness (in.) | 0.0295 | 0.0285 | 0.03 | 0.0260 | 0.0243 |
| Pellet diameter (in.) | 0.3565 | 0.3745 | 0.3565 | 0.345 | 0.3224 |
| Pellet material | $UO_2$ | $UO_2$ | $UO_2$ | $UO_2$ | $UO_2$ |
| Pellet density (gm/cc)<br>(% of theoretical) | 10.522<br>(96%) | 10.522<br>(96%) | 10.522<br>(96%) | 10.522<br>(96%) | 10.522<br>(96%) |
| Enrichment (wt.% $^{235}U$) | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Burnup (MWD/MTU) | 40,000 | 40,000 | 40,000 | 40,000 | 40,000 |
| Cooling time (years) | 5 | 5 | 5 | 5 | 5 |
| Power/assembly (MW) | 5.75 | 5.75 | 5.75 | 5.75 | 5.75 |
| Specific power (MW/MTU) | 31.58 | 31.38 | 35.09 | 30.54 | 32.18 |
| Weight of $UO_2$ (kg)† | 206.525 | 207.851 | 185.873 | 213.531 | 202.687 |
| Weight of U (kg)† | 182.073 | 183.242 | 163.865 | 188.249 | 178.689 |
| No. of Water Rods | 1 | 5 | 1 | 2 | 1 |
| Water Rod O.D. (in.) | 0.512 | 0.546 | 1.668 | 0.980 | Note 1 |
| Water Rod Thickness (in.) | 0.02 | 0.0120 | 0.032 | 0.0300 | Note 1 |

Note 1: 10x10C has a diamond shaped water rod with 4 additional segments dividing the fuel rods into four quadrants.

† Derived from parameters in this table.

Table 5.2.27

COMPARISON OF SOURCE TERMS FOR ZIRCALOY CLAD PWR FUEL
3.4 wt.% $^{235}U$ - 40,000 MWD/MTU - 5 years cooling

| Assembly | WE 14×14 | WE 14×14 | WE 15×15 | WE 17×17 | WE 17×17 | CE 14×14 | CE 16×16 | B&W 15×15 | B&W 17×17 |
|---|---|---|---|---|---|---|---|---|---|
| Array class | 14x14A | 14x14B | 15x15 ABC | 17x17A | 17x17B | 14x14C | 16x16A | 15x15 DEFH | 17x17C |
| Neutrons/sec | 1.76E+8<br>1.78E+8 | 2.32E+8<br>2.35E+8 | 2.70E+8<br>2.73E+8 | 2.18E+8 | 2.68E+8 | 2.32E+8 | 2.38E+8 | 2.94E+8 | 2.68E+8 |
| Photons/sec (0.45-3.0 MeV) | 2.88E+15<br>2.93E+15 | 3.28E+15<br>3.32E+15 | 3.80E+15<br>3.86E+15 | 3.49E+15 | 3.85E+15 | 3.37E+15 | 3.57E+15 | 4.01E+15 | 3.89E+15 |
| Thermal power (watts) | 809.5<br>820.7 | 923.5933.<br>7 | 10731086 | 985.6 | 1090 | 946.6 | 1005 | 1137 | 1098 |

Note:
The WE 14x14 and WE 15x15 have both zircaloy and stainless steel guide tubes. The first value presented is for the assembly with zircaloy guide tubes and the second value is for the assembly with stainless steel guide tubes.

Table 5.2.28

COMPARISON OF SOURCE TERMS FOR ZIRCALOY CLAD BWR FUEL
3.0 wt.% $^{235}U$ - 40,000 MWD/MTU - 5 years cooling

| Assembly | 7×7 | 8x8 | 8x8 | 9x9 | 9x9 | 9x9 | 9x9 | 9x9 | 10x10 | 10x10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Array Class | 7x7B | 8x8B | 8x8CDE | 9x9A | 9x9B | 9x9CD | 9x9EF | 9x9G | 10x10AB | 10x10C |
| Neutrons/sec | 1.33E+8 | 1.22E+8 | 1.22E+8 | 1.13E+8 | 1.06E+8 | 1.09E+8 | 1.24E+8 | 9.15E+7 | 1.24E+8 | 1.07E+8 |
| Photons/sec (0.45-3.0 MeV) | 1.55E+15 | 1.49E+15 | 1.48E+15 | 1.41E+15 | 1.40E+15 | 1.42E+15 | 1.45E+15 | 1.28E+15 | 1.48E+15 | 1.40E+15 |
| Thermal power (watts) | 435.5 | 417.3 | 414.2 | 394.2 | 389.8 | 395 | 405.8 | 356.9 | 413.5 | 389.2 |

Table 5.2.29

COMPARISON OF CALCULATED DECAY HEATS FOR DESIGN BASIS FUEL AND VALUES REPORTED IN THE DOE CHARACTERISTICS DATABASE† FOR 30,000 MWD/MTU AND 5-YEAR COOLING

| Fuel Assembly Class | Decay Heat from the DOE Database (watts/assembly) | Decay Heat from Source Term Calculations (watts/assembly) |
|---|---|---|
| **PWR Fuel** | | |
| B&W 15x15 | 752.0 | 827.5 |
| B&W 17x17 | 732.9 | 802.7 |
| CE 16x16 | 653.7 | 734.3 |
| CE 14x14 | 601.3 | 694.9 |
| WE 17x17 | 742.5 | 795.4 |
| WE 15x15 | 762.2 | 796.2 |
| WE 14x14 | 649.6 | 682.9 |
| **BWR Fuel** | | |
| 7x7 | 310.9 | 315.7 |
| 8x8 | 296.6 | 302.8 |
| 9x9 | 275.0 | 286.8 |

Notes:

1. The decay heat from the source term calculations is the maximum value calculated for that fuel assembly class.
2. The decay heat values from the database include contributions from in-core material (e.g. spacer grids).
3. Information on the 10x10 was not available in the DOE database. However, based on the results in Table 5.2.28, the actual decay heat values from the 10x10 would be very similar to the values shown above for the 8x8.
4. The enrichments used for the column labeled "Decay Heat from Source Term Calculations" were consistent with Table 5.2.24.

† Reference [5.2.7].

Table 5.2.30

DESCRIPTION OF DESIGN BASIS BURNABLE POISON ROD ASSEMBLY AND THIMBLE PLUG DEVICE

| **Region** | **BPRA** | **TPD** |
|---|---|---|
| Upper End Fitting (kg of steel) | 2.62 | 2.3 |
| Upper End Fitting (kg of inconel) | 0.42 | 0.42 |
| Gas Plenum Spacer (kg of steel) | 0.77488 | 1.71008 |
| Gas Plenum Springs (kg of steel) | 0.67512 | 1.48992 |
| In-core (kg of steel) | 13.2 | N/A |

Table 5.2.31

DESIGN BASIS COBALT-60 ACTIVITIES FOR BURNABLE POISON ROD ASSEMBLIES AND THIMBLE PLUG DEVICES

| **Region** | **BPRA** | **TPD** |
|---|---|---|
| Upper End Fitting (curies Co-60) | 32.7 | 25.21 |
| Gas Plenum Spacer (curies Co-60) | 5.0 | 9.04 |
| Gas Plenum Springs (curies Co-60) | 8.9 | 15.75 |
| In-core (curies Co-60) | 848.4 | N/A |

Table 5.2.32

DESCRIPTION OF DESIGN BASIS CONTROL ROD ASSEMBLY CONFIGURATIONS FOR SOURCE TERM CALCULATIONS

| **Axial Dimensions Relative to Bottom of Active Fuel** | | | **Flux Weighting Factor** | **Mass of cladding (kg Inconel)** | **Mass of absorber (kg AgInCd)** |
|---|---|---|---|---|---|
| **Start (in)** | **Finish (in)** | **Length (in)** | | | |
| **Configuration 1 - 10% Inserted** | | | | | |
| 0.0 | 15.0 | 15.0 | 1.0 | 1.32 | 7.27 |
| 15.0 | 18.8125 | 3.8125 | 0.2 | 0.34 | 1.85 |
| 18.8125 | 28.25 | 9.4375 | 0.1 | 0.83 | 4.57 |
| **Configuration 2 - Fully Removed** | | | | | |
| 0.0 | 3.8125 | 3.8125 | 0.2 | 0.34 | 1.85 |
| 3.8125 | 13.25 | 9.4375 | 0.1 | 0.83 | 4.57 |

Table 5.2.33

DESCRIPTION OF DESIGN BASIS AXIAL POWER SHAPING ROD CONFIGURATION S FOR SOURCE TERM CALCULATIONS

| Axial Dimensions Relative to Bottom of Active Fuel | | | Flux Weighting Factor | Mass of cladding (kg Steel) | Mass of absorber (kg Inconel) |
|---|---|---|---|---|---|
| Start (in) | Finish (in) | Length (in) | | | |
| **Configuration 1 - 10% Inserted** | | | | | |
| 0.0 | 15.0 | 15.0 | 1.0 | 1.26 | 5.93 |
| 15.0 | 18.8125 | 3.8125 | 0.2 | 0.32 | 1.51 |
| 18.8125 | 28.25 | 9.4375 | 0.1 | 0.79 | 3.73 |
| **Configuration 2 - Fully Removed** | | | | | |
| 0.0 | 3.8125 | 3.8125 | 0.2 | 0.32 | 1.51 |
| 3.8125 | 13.25 | 9.4375 | 0.1 | 0.79 | 3.73 |
| **Configuration 3 - Fully Inserted** | | | | | |
| 0.0 | 63.0 | 63.0 | 1.0 | 5.29 | 24.89 |
| 63.0 | 66.8125 | 3.8125 | 0.2 | 0.32 | 1.51 |
| 66.8125 | 76.25 | 9.4375 | 0.1 | 0.79 | 3.73 |

Table 5.2.34

DESIGN BASIS SOURCE TERMS FOR CONTROL ROD ASSEMBLY CONFIGURATIONS

| Axial Dimensions Relative to Bottom of Active Fuel | | | Photons/sec from AgInCd | | | Curies Co-60 from Inconel |
|---|---|---|---|---|---|---|
| Start (in) | Finish (in) | Length (in) | 0.3-0.45 MeV | 0.45-0.7 MeV | 0.7-1.0 MeV | |
| **Configuration 1 - 10% Inserted - 80.8 watts decay heat** | | | | | | |
| 0.0 | 15.0 | 15.0 | 1.91e+14 | 1.78e+14 | 1.42e+14 | 1111.38 |
| 15.0 | 18.8125 | 3.8125 | 9.71e+12 | 9.05e+12 | 7.20e+12 | 56.50 |
| 18.8125 | 28.25 | 9.4375 | 1.20e+13 | 1.12e+13 | 8.92e+12 | 69.92 |
| **Configuration 2 - Fully Removed - 8.25 watts decay heat** | | | | | | |
| 0.0 | 3.8125 | 3.8125 | 9.71e+12 | 9.05e+12 | 7.20e+12 | 56.50 |
| 3.8125 | 13.25 | 9.4375 | 1.20e+13 | 1.12e+13 | 8.92e+12 | 69.92 |

Table 5.2.35

DESIGN BASIS SOURCE TERMS FROM AXIAL POWER SHAPING ROD CONFIGURATIONS

| Axial Dimensions Relative to Bottom of Active Fuel | | | Curies of Co-60 |
|---|---|---|---|
| **Start (in)** | **Finish (in)** | **Length (in)** | |
| **Configuration 1 - 10% Inserted - 46.2 watts decay heat** | | | |
| 0.0 | 15.0 | 15.0 | 2682.57 |
| 15.0 | 18.8125 | 3.8125 | 136.36 |
| 18.8125 | 28.25 | 9.4375 | 168.78 |
| **Configuration 2 - Fully Removed - 4.72 watts decay heat** | | | |
| 0.0 | 3.8125 | 3.8125 | 136.36 |
| 3.8125 | 13.25 | 9.4375 | 168.78 |
| **Configuration 3 - Fully Inserted - 178.9 watts decay heat** | | | |
| 0.0 | 63.0 | 63.0 | 11266.80 |
| 63.0 | 66.8125 | 3.8125 | 136.36 |
| 66.8125 | 76.25 | 9.4375 | 168.78 |

Table 5.2.36

DESCRIPTION OF FUEL ASSEMBLY USED TO ANNALYZE THORIA RODS IN THE THORIA ROD CANISTER

| | **BWR** |
|---|---|
| Fuel type | 8x8 |
| Active fuel length (in.) | 110.5 |
| No. of $UO_2$ fuel rods | 55 |
| No. of $UO_2/ThO_2$ fuel rods | 9 |
| Rod pitch (in.) | 0.523 |
| Cladding material | zircaloy |
| Rod diameter (in.) | 0.412 |
| Cladding thickness (in.) | 0.025 |
| Pellet diameter (in.) | 0.358 |
| Pellet material | 98.2% $ThO_2$ and 1.8% $UO_2$ for $UO_2/ThO_2$ rods |
| Pellet density (gm/cc) | 10.412 |
| Enrichment (w/o $^{235}U$) | 93.5 in $UO_2$ for $UO_2/ThO_2$ rods<br>and<br>1.8 for $UO_2$ rods |
| Burnup (MWD/MTIHM) | 16,000 |
| Cooling Time (years) | 18 |
| Specific power (MW/MTIHM) | 16.5 |
| Weight of $THO_2$ and $UO_2$ (kg)† | 121.46 |
| Weight of U (kg)† | 92.29 |
| Weight of Th (kg)† | 14.74 |

† Derived from parameters in this table.

Table 5.2.37

CALCULATED FUEL GAMMA SOURCE FOR THORIA ROD CANISTER CONTAINING EIGHTEEN THORIA RODS

| **Lower Energy** | **Upper Energy** | **16,000 MWD/MTIHM 18-Year Cooling** | |
|---|---|---|---|
| (MeV) | (MeV) | (MeV/s) | (Photons/s) |
| 4.5e-01 | 7.0e-01 | 3.07e+13 | 5.34e+13 |
| 7.0e-01 | 1.0 | 5.79e+11 | 6.81e+11 |
| 1.0 | 1.5 | 3.79e+11 | 3.03e+11 |
| 1.5 | 2.0 | 4.25e+10 | 2.43e+10 |
| 2.0 | 2.5 | 4.16e+8 | 1.85e+8 |
| 2.5 | 3.0 | 2.31e+11 | 8.39e+10 |
| Totals | | 1.23e+12 | 1.09e+12 |

Table 5.2.38

CALCULATED FUEL NEUTRON SOURCE FOR THORIA ROD CANISTER CONTAINING EIGHTEEN THORIA RODS

| **Lower Energy (MeV)** | **Upper Energy (MeV)** | **16,000 MWD/MTIHM 18-Year Cooling (Neutrons/s)** |
|---|---|---|
| 1.0e-01 | 4.0e-01 | 5.65e+2 |
| 4.0e-01 | 9.0e-01 | 3.19e+3 |
| 9.0e-01 | 1.4 | 6.79e+3 |
| 1.4 | 1.85 | 1.05e+4 |
| 1.85 | 3.0 | 3.68e+4 |
| 3.0 | 6.43 | 1.41e+4 |
| 6.43 | 20.0 | 1.60e+2 |
| Totals | | 7.21e+4 |

## 5.3 MODEL SPECIFICATIONS

The shielding analysis of the HI-STORM 100 System was performed with MCNP-4A [5.1.1]. MCNP is a Monte Carlo transport code that offers a full three-dimensional combinatorial geometry modeling capability including such complex surfaces as cones and tori. This means that no gross approximations were required to represent the HI-STORM 100 System, including the HI-TRAC transfer casks, in the shielding analysis. A sample input file for MCNP is provided in Appendix 5.C.

As discussed in Section 5.1.1, off-normal conditions do not have any implications for the shielding analysis. Therefore, the MCNP models and results developed for the normal conditions also represent the off-normal conditions. Section 5.1.2 discussed the accident conditions and stated that the only accident that would impact the shielding analysis would be a loss of the neutron shield (water) in the HI-TRAC. Therefore, the MCNP model of the normal HI-TRAC condition has the neutron shield in place while the accident condition replaces the neutron shield with void. Section 5.1.2 also mentioned that there is no credible accident scenario that would impact the HI-STORM shielding analysis. Therefore, models and results for the normal and accident conditions are identical for the HI-STORM overpack.

### 5.3.1 Description of the Radial and Axial Shielding Configuration

Chapter 1 provides the drawings that describe the HI-STORM 100 System, including the HI-TRAC transfer casks. These drawings, using nominal dimensions, were used to create the MCNP models used in the radiation transport calculations. Modeling deviations from these drawings are discussed below. Figures 5.3.1 through 5.3.6 show cross sectional views of the HI-STORM 100 overpack and MPC as it was modeled in MCNP for each of the MPCs. Figures 5.3.1 through 5.3.3 were created with the MCNP two-dimensional plotter and are drawn to scale. The inlet and outlet vents were modeled explicitly, therefore, streaming through these components is accounted for in the calculations of the dose adjacent to the overpack and at 1 meter. Figure 5.3.7 shows a cross sectional view of the 100-ton HI-TRAC with the MPC-24 inside as it was modeled in MCNP. Since the fins and pocket trunnions were modeled explicitly, neutron streaming through these components is accounted for in the calculations of the dose adjacent to the overpack and 1 meter dose. In Section 5.4.1, the dose effect of localized streaming through these compartments is analyzed.

Figure 5.3.10 shows a cross sectional view of the HI-STORM 100 overpack with the as-modeled thickness of the various materials. The dimensions for the HI-STORM 100S and HI-STORM 100S Version B overpacks are also shown on Figure 5.3.10. This figure notes two different dimensions for the inner and outer shells. These values apply only to the HI-STORM 100 and 100S. In these overpacks, the inner and outer shells can be manufactured from 1.25 and 0.75 inch thick steel, respectively, or both shells can be manufactured from 1 inch thick steel. The HI-STORM 100 and 100S were modeled as 1.25 and 0.75 inch thick shells.

Figures 5.3.11, 5.3.18, and 5.3.22 are axial representations of the HI-STORM 100, HI-STORM 100S, and HI-STORM 100S Version B overpacks, respectively, with the various as-modeled dimensions indicated.

Only the HI-STORM 100S Version B is analyzed in this chapter. This is reasonable because the HI-STORM 100S Version B overpack is shorter than the other overpacks, and the MPC is positioned closer to the inlet vent which results in higher dose rates at the inlet vent compared to the other overpacks. In addition, the HI-STORM 100S Version B has slightly higher offsite dose than the other overpacks.

Figures 5.3.12, 5.3.13, and 5.3.23 show axial cross-sectional views of the 100-, 125-ton, and 100D HI-TRAC transfer casks, respectively, with the as-modeled dimensions and materials specified. Figures 5.3.14, 5.3.15, and 5.3.20 show fully labeled radial cross-sectional views of the HI-TRAC 100, 125, and 125D transfer casks, respectively. Figure 5.3.14 also provides the information for the HI-TRAC 100D. Finally, Figures 5.3.16 and 5.3.17 show fully labeled diagrams of the transfer lids for the HI-TRAC 100 and 125 transfer casks. Since lead plate may be used instead of poured lead in the pool and transfer lids, there exists the possibility of a gap between the lead plate and the surrounding steel walls. This gap was accounted for in the analysis as depicted on Figures 5.3.16 and 5.3.17. The gap was not modeled in the pool lid since the gap will only exist on the outer edges of the pool lid and the highest dose rate is in the center. (All results presented in this chapter were calculated with the gap with the exception of the results presented in Figures 5.1.6, 5.1.7, and 5.1.11 which did not include the gap.) The HI-TRAC 100D and 125D do not utilize the transfer lid, rather they utilize the pool lid in conjunction with the mating device. Therefore the dose rates reported for the pool lid in this chapter are applicable to both the HI-TRAC 125 and 125D and the HI-TRAC 100 and 100D while the dose rates reported for the transfer lid are applicable only to the HI-TRAC 100 and 125. Consistent with the analysis of the transfer lid in which only the portion of the lid directly below the MPC was modeled, the structure of the mating device which surrounds the pool lid was not modeled.

Since the HI-TRAC 125D has fewer radial ribs, the dose rate at the midplane of the HI-TRAC 125D is higher than the dose rate at the midplane of the HI-TRAC 125. The HI-TRAC 125D has steel ribs in the lower water jacket while the HI-TRAC 125 does not. These additional ribs in the lower water jacket reduce the dose rate in the vicinity of the pool lid for the HI-TRAC 125D compared to the HI-TRAC 125. Since the dose rates at the midplane of the HI-TRAC 125D are higher than the HI-TRAC 125, the results on the radial surface are only presented for the HI-TRAC 125D in this chapter.

To reduce the gamma dose around the inlet and outlet vents, stainless steel cross plates, designated gamma shield cross plates† (see Figures 5.3.11 and 5.3.18), have been installed inside

† This design embodiment, formally referred to as "Duct Photon Attenuator," has been disclosed as an invention by Holtec International for consideration by the US Patent Office for issuance of a patent under U.S. law.

all vents in all overpacks. The steel in these plates effectively attenuates the fuel and $^{60}Co$ gammas that dominated the dose at these locations prior to their installation. Figure 5.3.19 shows three designs for the gamma shield cross plates to be used in the inlet and outlet vents. The designs in the top portion of the figure are mandatory for use in the HI-STORM 100 and 100S overpacks during normal storage operations and were assumed to be in place in the shielding analysis. The designs in the middle portion of the figure may be used instead of the mandatory designs in the HI-STORM 100S overpack to further reduce the radiation dose rates at the vents. These optional gamma shield cross plates could further reduce the dose rate at the vent openings by as much as a factor of two. The designs in the bottom portion of the figure are mandatory for use in the HI-STORM 100S Version B overpack during normal storage operations and were assumed to be in place in the shielding analysis.

Calculations were performed to determine the acceptability of homogenizing the fuel assembly versus explicit modeling. Based on these calculations it was concluded that it was acceptable to homogenize the fuel assembly without loss of accuracy. The width of the PWR and BWR homogenized fuel assembly is equal to 15 times the pitch and 7 times the pitch, respectively. Homogenization resulted in a noticeable decrease in run time.

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

1. The basket material in the top and bottom 0.9 inches where the MPC basket flow holes are located is not modeled. The length of the basket not modeled (0.9 inches) was determined by calculating the equivalent area removed by the flow holes. This method of approximation is conservative because no material for the basket shielding is provided in the 0.9-inch area at the top and bottom of the MPC basket.

2. The upper and lower fuel spacers are not modeled, as the fuel spacers are not needed on all fuel assembly types. However, most PWR fuel assemblies will have upper and lower fuel spacers. The fuel spacer length for the design basis fuel assembly type determines the positioning of the fuel assembly for the shielding analysis, but the fuel spacer materials are not modeled. This is conservative since it removes steel that would provide a small amount of additional shielding.

3. For the MPC-32, MPC-24, and MPC-68, the MPC basket supports are not modeled. This is conservative since it removes steel that would provide a small increase in shielding. The optional aluminum heat conduction elements are also conservatively not modeled.

4. The MPC-24 basket is fabricated from 5/16 inch thick cell plates. It is conservatively assumed for modeling purposes that the structural portion of the MPC-24 basket is uniformly fabricated from 9/32 inch thick steel. The Boral and

sheathing are modeled explicitly. This is conservative since it removes steel that would provide a small amount of additional shielding.

5. In the modeling of the BWR fuel assemblies, the zircaloy flow channels were not represented. This was done because it cannot be guaranteed that all BWR fuel assemblies will have an associated flow channel when placed in the MPC. The flow channel does not contribute to the source, but does provide some small amount of shielding. However, no credit is taken for this additional shielding.

6. In the MPC-24, conservatively, all Boral panels on the periphery were modeled with a reduced width of 5 inches compared to 6.25 inches or 7.5 inches.

7. The MPC-68 is designed for two lid thicknesses: 9.5 inches and 10 inches. Conservatively, all calculations reported in this chapter were performed with the 9.5 inch thick lid.

During this project several design changes occurred that affected the drawings, but did not significantly affect the MCNP models of the HI-STORM 100 and HI-TRAC. Therefore, the models do not exactly represent the drawings. The discrepancies between models and drawings are listed and discussed here.

MPC Modeling Discrepancies

1. In the MPCs, there is a sump in the baseplate to enhance draining of the MPC. This localized reduction in the thickness of the baseplate was not modeled. Since there is significant shielding and distance in both the HI-TRAC and the HI-STORM outside the MPC baseplate, this localized reduction in shielding will not affect the calculated dose rates outside the HI-TRAC or the HI-STORM.

2. The design configuration of the MPC-24 has been enhanced for criticality purposes. The general location of the 24 assemblies remains basically the same, therefore the shielding analysis continues to use the superseded configuration. Since the new MPC-24 configuration and the configuration of the MPC-24E are almost identical, the analysis of the earlier MPC-24 configuration is valid for the MPC-24E as well. Figure 5.3.21 shows the superseded and current configuration for the MPC-24 for comparison.

3. The sheathing thickness on the new MPC-24 configuration was reduced from 0.06 inches to 0.0235 inches. However, the model still uses 0.06 inches. This discrepancy is compensated for by the use of 9/32 inch cell walls and 5 inch boral on the periphery as described above. MCNP calculations were performed with the new MPC-24 configuration in the 100-ton HI-TRAC for comparison to the superceded configuration. These results indicate that on the side of the overpack, the dose rates decrease by approximately 12% on the surface for a burnup of

60,000 MWD/MTU and a cooling time of 3 years. These results demonstrate that using the superceded MPC-24 design is conservative.

4. The MPC lid can be made either entirely from stainless steel, or from a stainless steel / carbon steel combination. In MCNP, the lid is modeled entirely as stainless steel. The difference in material would have a negligible effect on dose rates.

HI-TRAC Modeling Discrepancies

1. The pocket trunnion on the HI-TRAC 125 was modeled as penetrating the lead. This is conservative for gamma dose rates as it reduces effective shielding thickness. The HI-TRAC 125D does not use pocket trunnions.

2. The lifting blocks in the top lid of the 125-ton HI-TRACs were not modeled. Holtite-A was modeled instead. This is a small, localized item and will not impact the dose rates.

3. The door side plates that are in the middle of the transfer lid of the HI-TRAC 125 are not modeled. This is acceptable because the dose location calculated on the bottom of the transfer lid is in the center.

4. The outside diameter of the Holtite-A portion of the top lid of the 125-ton HI-TRACs was modeled as 4 inches larger than it is due to a design enhancement. This is acceptable because the peak dose rates on the top lid occur on the inner portions of the lid.

HI-STORM Modeling Discrepancies

1. The steel channels in the cavity between the MPC and overpack were not modeled. This is conservative since it removes steel that would provide a small amount of additional shielding.

2. The bolt anchor blocks were not explicitly modeled. Concrete was used instead. These are small, localized items and will not impact the dose rates.

3. In the HI-STORM 100S model, the exit vents were modeled as being inline with the inlet vents. In practice, they are rotated 45 degrees and positioned above the short radial plates. Therefore, this modeling change has the exit vents positioned above the full length radial plates. This modeling change has minimal impact on the dose rates at the exit vents.

4. The short radial plates in the HI-STORM 100S overpack were modeled in MCNP even though they are optional.

5. The pedestal baseplate, which is steel with holes for pouring concrete, in the HI-STORM 100 and 100S overpacks was modeled as concrete rather than steel. This is acceptable because this piece of steel is positioned at the bottom of the pedestal below 5 inches of steel and a minimum of 11.5 inches of concrete and therefore will have no impact on the dose rates at the bottom vent.

6. Minor penetrations in the body of the overpack (e.g. holes for grounding straps) are not modeled as these are small localized effects which will not affect the off-site dose rates.

7. Deleted

8. The drawings in Section 1.5 indicate that the HI-STORM 100S has a variable height. This is achieved by adjusting the height of the body of the overpack. The pedestal height is not adjusted. Conservatively, all calculations in this chapter used the shorter height for the HI-STORM 100S.

9. In February 2002, the top plate on the HI-STORM 100 overpack was modified to be two pieces in a shear ring arrangement. The total thickness of the top plate was not changed. However, there is approximately a 0.5 inch gap between the two pieces of the top plate. This gap was not modeled in MCNP since it will result in a small increase in the dose rate on the overpack lid in an area where the dose rate is greatly reduced compared to other locations on the lid.

10. The MPC base support in the HI-STORM 100S Version B was conservatively modeled as a 1 inch thick plate resting on a two inch tall ring as shown in Figure 5.3.22. The design of the overpack utilizes a solid three inch plate.

11. The gussets in the inside lower corners of the HI-STORM 100S Version B overpack were not modeled. Concrete was modeled instead.

#### 5.3.1.1 Fuel Configuration

As described earlier, the active fuel region is modeled as a homogenous zone. The end fittings and the plenum regions are also modeled as homogenous regions of steel. The masses of steel used in these regions are shown in Table 5.2.1. The axial description of the design basis fuel assemblies is provided in Table 5.3.1. Figures 5.3.8 and 5.3.9 graphically depict the location of the PWR and BWR fuel assemblies within the HI-STORM 100 System. The axial locations of the Boral, basket, inlet vents, and outlet vents are shown in these figures.

### 5.3.1.2 Streaming Considerations

The MCNP model of the HI-STORM overpack completely describes the inlet and outlet vents, thereby properly accounting for their streaming effect. The gamma shield cross plates located in the inlet and outlet vents, which effectively reduce the gamma dose in these locations, are modeled explicitly.

The MCNP model of the HI-TRAC transfer cask describes the lifting trunnions, pocket trunnions, and the opening in the HI-TRAC top lid. The fins through the HI-TRAC water jacket are also modeled. Streaming considerations through these trunnions and fins are discussed in Section 5.4.1.

The design of the HI-STORM 100 System, as described in the drawings in Chapter 1, has eliminated all other possible streaming paths. Therefore, the MCNP model does not represent any additional streaming paths. A brief justification of this assumption is provided for each penetration.

- The lifting trunnions will remain installed in the HI-TRAC transfer cask.
- The pocket trunnions of the HI-TRAC are modeled as solid blocks of steel. No credit is taken for any part of the pocket trunnion that extends beyond the water jacket.
- The threaded holes in the MPC lid are plugged with solid plugs during storage and, therefore, do not create a void in the MPC lid.
- The drain and vent ports in the MPC lid are designed to eliminate streaming paths. The holes in the vent and drain port cover plates are filled with a set screw and plug weld. The steel lost in the MPC lid at the port location is replaced with a block of steel approximately 6 inches thick located directly below the port opening and attached to the underside of the lid. This design feature is shown on the drawings in Chapter 1. The MCNP model did not explicitly represent this arrangement but, rather, modeled the MPC lid as a solid plate.

### 5.3.2 Regional Densities

Composition and densities of the various materials used in the HI-STORM 100 System and HI-TRAC shielding analyses are given in Tables 5.3.2 and 5.3.3. All of the materials and their actual geometries are represented in the MCNP model.

The concrete density shown in Table 5.3.2 is the minimum concrete density analyzed in this chapter. The HI-STORM 100 overpacks are designed in such a way that the concrete density in the body of the overpack can be increased to approximately 3.2 gm/cc (200 lb/cu-ft). It is generally recommended to use concrete with a density of 155 lb/cu-ft or more. Increasing the density beyond this value would result in a significant reduction in the dose rates. This may be beneficial based on on-site and off-site ALARA considerations. Lower densities may be necessary to address weight restrictions at certain sites.

The water density inside the MPC corresponds to the maximum allowable water temperature within the MPC. The water density in the water jacket corresponds to the maximum allowable temperature at the maximum allowable pressure. As mentioned, the HI-TRAC transfer cask is equipped with a water jacket providing radial neutron shielding. Demineralized water will be utilized in the water jacket. To ensure operability for low temperature conditions, ethylene glycol (25% in solution) may be added to reduce the freezing point for low temperature operations. Calculations were performed to determine the effect of the ethylene glycol on the shielding effectiveness of the radial neutron shield. Based on these calculations, it was concluded that the addition of ethylene glycol (25% in solution) does not reduce the shielding effectiveness of the radial neutron shield.

The MPCs in the HI-STORM 100 System can be manufactured with one of two possible neutron absorbing materials: Boral or Metamic. Both materials are made of aluminum and $B_4C$ powder. The Boral contains an aluminum and $B_4C$ powder mixture sandwiched between two aluminum plates while the Metamic is a single plate. The minimum $^{10}B$ areal density is the same for Boral and Metamic while the thicknesses are essentially the same. Therefore, the mass of Aluminum and $B_4C$ are essentially equivalent and there is no distinction between the two materials from a shielding perspective. As a result, Table 5.3.2 identifies the composition for Boral and no explicit calculations were performed with Metamic.

Sections 4.4 and 4.5 demonstrate that all materials used in the HI-STORM and HI-TRAC remain below their design temperatures as specified in Table 2.2.3 during all normal conditions. Therefore, the shielding analysis does not address changes in the material density or composition as a result of temperature changes.

Section 4.4 indicates that there are localized areas in the concrete in the lid of the overpack which approach 390°F. An increase in temperature from 300°F to 390°F results in an approximate 0.666% overall density reduction due to the loss of chemically unbound water. This density reduction results in a reduction in the mass fraction of hydrogen from 0.6% to 0.529% in the area affected by the temperature excursion. This is a localized effect with the maximum loss occurring at the bottom center of the lid where the temperature is the hottest and reduced loss occurring as the temperature decreases to 300°F.

Based on these considerations, the presence of localized temperatures up to 390°F in the lid concrete has a negligible effect on the shielding effectiveness of the HI-STORM 100 overpack lid.

Chapter 11 discusses the effect of the various accident conditions on the temperatures of the shielding materials and the resultant impact on their shielding effectiveness. As stated in Section 5.1.2, there is only one accident that has any significant impact on the shielding configuration. This accident is the loss of the neutron shield (water) in the HI-TRAC as a result of fire or other damage. The change in the neutron shield was conservatively analyzed by assuming that the entire volume of the liquid neutron shield was replaced by void.

Table 5.3.1

DESCRIPTION OF THE AXIAL MCNP MODEL OF THE FUEL ASSEMBLIES†

| Region | Start (in.) | Finish (in.) | Length (in.) | Actual Material | Modeled Material |
|---|---|---|---|---|---|
| **PWR** | | | | | |
| Lower End Fitting | 0.0 | 7.375 | 7.375 | SS304 | SS304 |
| Space | 7.375 | 8.375 | 1.0 | zircaloy | void |
| Fuel | 8.375 | 152.375 | 144 | fuel & zircaloy | fuel |
| Gas Plenum Springs | 152.375 | 156.1875 | 3.8125 | SS304 & zircaloy | SS304 |
| Gas Plenum Spacer | 156.1875 | 160.5625 | 4.375 | SS304 & zircaloy | SS304 |
| Upper End Fitting | 160.5625 | 165.625 | 5.0625 | SS304 | SS304 |
| **BWR** | | | | | |
| Lower End Fitting | 0.0 | 7.385 | 7.385 | SS304 | SS304 |
| Fuel | 7.385 | 151.385 | 144 | fuel & zircaloy | fuel |
| Space | 151.385 | 157.385 | 6 | zircaloy | void |
| Gas Plenum Springs | 157.385 | 166.865 | 9.48 | SS304 & zircaloy | SS304 |
| Expansion Springs | 166.865 | 168.215 | 1.35 | SS304 | SS304 |
| Upper End Fitting | 168.215 | 171.555 | 3.34 | SS304 | SS304 |
| Handle | 171.555 | 176 | 4.445 | SS304 | SS304 |

† All dimensions start at the bottom of the fuel assembly. The length of the lower fuel spacer must be added to the distances to determine the distance from the top of the MPC baseplate.

Table 5.3.2

COMPOSITION OF THE MATERIALS IN THE HI-STORM 100 SYSTEM

| Component | Density ($g/cm^3$) | Elements | Mass Fraction (%) |
|---|---|---|---|
| Uranium Oxide | 10.412 | $^{235}U$ | 2.9971(BWR)<br>3.2615(PWR) |
| | | $^{238}U$ | 85.1529(BWR)<br>84.8885(PWR) |
| | | O | 11.85 |
| Boral[†] | 2.644 | $^{10}B$ | 4.4226 (MPC-68 and MPC-32 in HI-STORM & HI-TRAC; MPC-24 in HI-STORM)4.367 (MPC-24 in HI-TRAC) |
| | | $^{11}B$ | 20.1474 (MPC-68 and MPC-32 in HI-STORM & HI-TRAC; MPC-24 in HI-STORM)<br>19.893 (MPC-24 in HI-TRAC) |
| | | Al | 68.61 (MPC-68 and MPC-32 in HI-STORM & HI-TRAC; MPC-24 in HI-STORM)<br>69.01 (MPC-24 in HI-TRAC) |
| | | C | 6.82 (MPC-68 and MPC-32 in HI-STORM & HI-TRAC; MPC-24 in HI-STORM)<br>6.73 (MPC-24 in HI-TRAC) |
| SS304 | 7.92 | Cr | 19 |
| | | Mn | 2 |
| | | Fe | 69.5 |
| | | Ni | 9.5 |
| Carbon Steel | 7.82 | C | 0.5 |
| | | Fe | 99.5 |
| Zircaloy | 6.55 | Zr | 100 |

† All B-10 loadings in the Boral compositions are conservatively lower than the values defined in the Bill of Materials.

Table 5.3.2 (continued)

COMPOSITION OF THE MATERIALS IN THE HI-STORM 100 SYSTEM

| Component | Density (g/cm$^3$) | Elements | Mass Fraction (%) |
|---|---|---|---|
| Neutron Shield Holtite-A | 1.61 | C | 27.66039 |
| | | H | 5.92 |
| | | Al | 21.285 |
| | | N | 1.98 |
| | | O | 42.372 |
| | | $^{10}B$ | 0.14087 |
| | | $^{11}B$ | 0.64174 |
| BWR Fuel Region Mixture | 4.29251 | $^{235}U$ | 2.4966 |
| | | $^{238}U$ | 70.9315 |
| | | O | 9.8709 |
| | | Zr | 16.4046 |
| | | N | 8.35E-05 |
| | | Cr | 0.0167 |
| | | Fe | 0.0209 |
| | | Sn | 0.2505 |
| PWR Fuel Region Mixture | 3.869939 | $^{235}U$ | 2.7652 |
| | | $^{238}U$ | 71.9715 |
| | | O | 10.0469 |
| | | Zr | 14.9015 |
| | | Cr | 0.0198 |
| | | Fe | 0.0365 |
| | | Sn | 0.2587 |

Table 5.3.2 (continued)

COMPOSITION OF THE MATERIALS IN THE HI-STORM 100 SYSTEM

| Component | Density ($g/cm^3$) | Elements | Mass Fraction (%) |
|---|---|---|---|
| Lower End Fitting (PWR) | 1.0783 | SS304 | 100 |
| Gas Plenum Springs (PWR) | 0.1591 | SS304 | 100 |
| Gas Plenum Spacer (PWR) | 0.1591 | SS304 | 100 |
| Upper End Fitting (PWR) | 1.5410 | SS304 | 100 |
| Lower End Fitting (BWR) | 1.4862 | SS304 | 100 |
| Gas Plenum Springs (BWR) | 0.2653 | SS304 | 100 |
| Expansion Springs (BWR) | 0.6775 | SS304 | 100 |
| Upper End Fitting (BWR) | 1.3692 | SS304 | 100 |
| Handle (BWR) | 0.2572 | SS304 | 100 |
| Lead | 11.3 | Pb | 99.9 |
| | | Cu | 0.08 |
| | | Ag | 0.02 |
| Water | 0.9140 (water jacket) | H | 11.2 |
| | 0.9619 (inside MPC) | O | 88.8 |

Table 5.3.2 (continued)

COMPOSITION OF THE MATERIALS IN THE HI-STORM 100 SYSTEM

| Component | Density (g/cm$^3$) | Elements | Mass Fraction (%) |
|---|---|---|---|
| Concrete | 2.24 | H | 0.6 |
| | | O | 50.0 |
| | | Si | 31.5 |
| | | Al | 4.8 |
| | | Na | 1.7 |
| | | Ca | 8.3 |
| | | Fe | 1.2 |
| | | K | 1.9 |

Table 5.3.3

COMPOSITION OF THE FUEL PELLETS IN THE MIXED OXIDE FUEL ASSEMBLIES

| Component | Density (g/cm$^3$) | Elements | Mass Fraction (%) |
|---|---|---|---|
| Mixed Oxide Pellets | 10.412 | $^{238}U$ | 85.498 |
| | | $^{235}U$ | 0.612 |
| | | $^{238}Pu$ | 0.421 |
| | | $^{239}Pu$ | 1.455 |
| | | $^{240}Pu$ | 0.034 |
| | | $^{241}Pu$ | 0.123 |
| | | $^{242}Pu$ | 0.007 |
| | | O | 11.85 |
| Uranium Oxide Pellets | 10.412 | $^{238}U$ | 86.175 |
| | | $^{235}U$ | 1.975 |
| | | O | 11.85 |

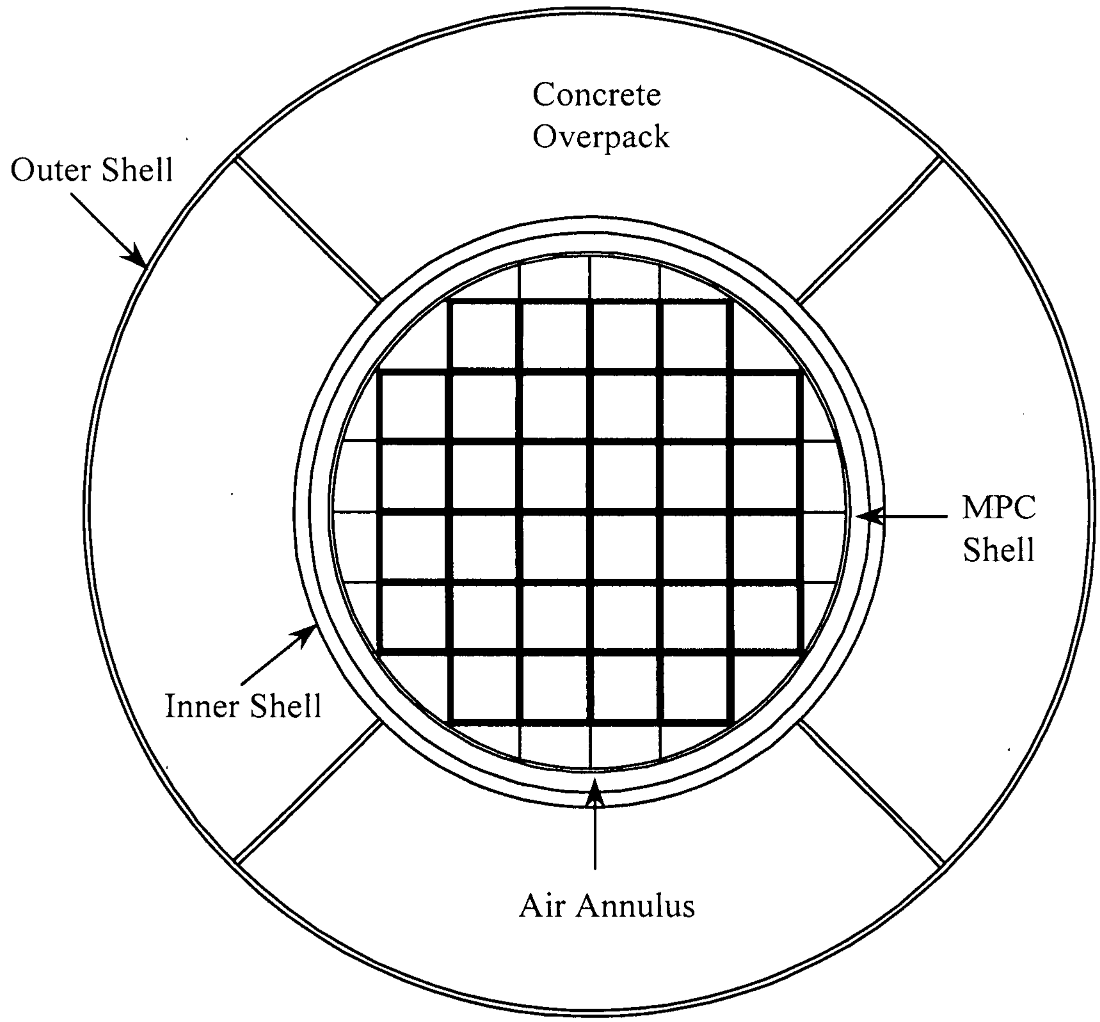


FIGURE 5.3.1; HI-STORM 100 OVERPACK WITH MPC-32 CROSS SECTIONAL VIEW AS MODELLED IN MCNP†

† This figure is drawn to scale using the MCNP plotter.

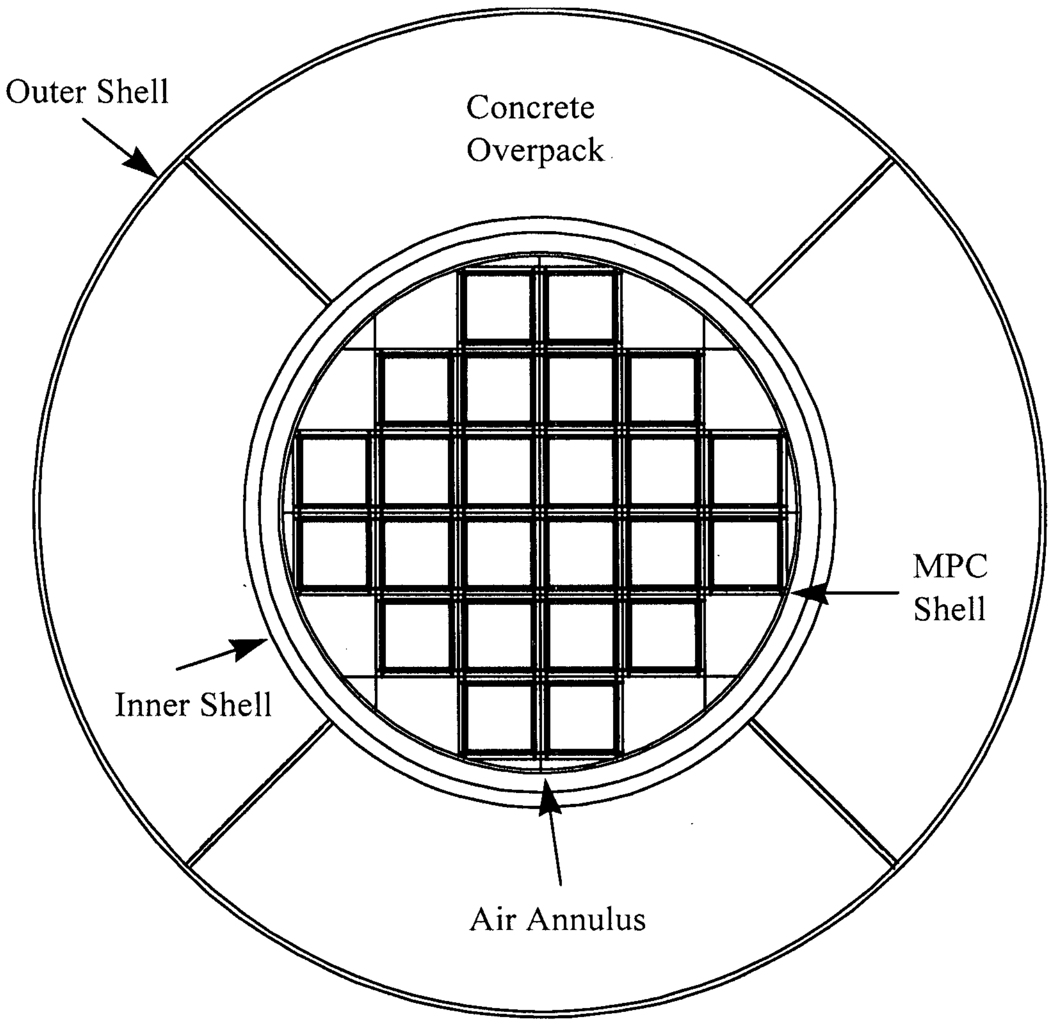


FIGURE 5.3.2; HI-STORM 100 OVERPACK WITH MPC-24 CROSS SECTIONAL VIEW AS MODELLED IN MCNP†

† This figure is drawn to scale using the MCNP plotter.

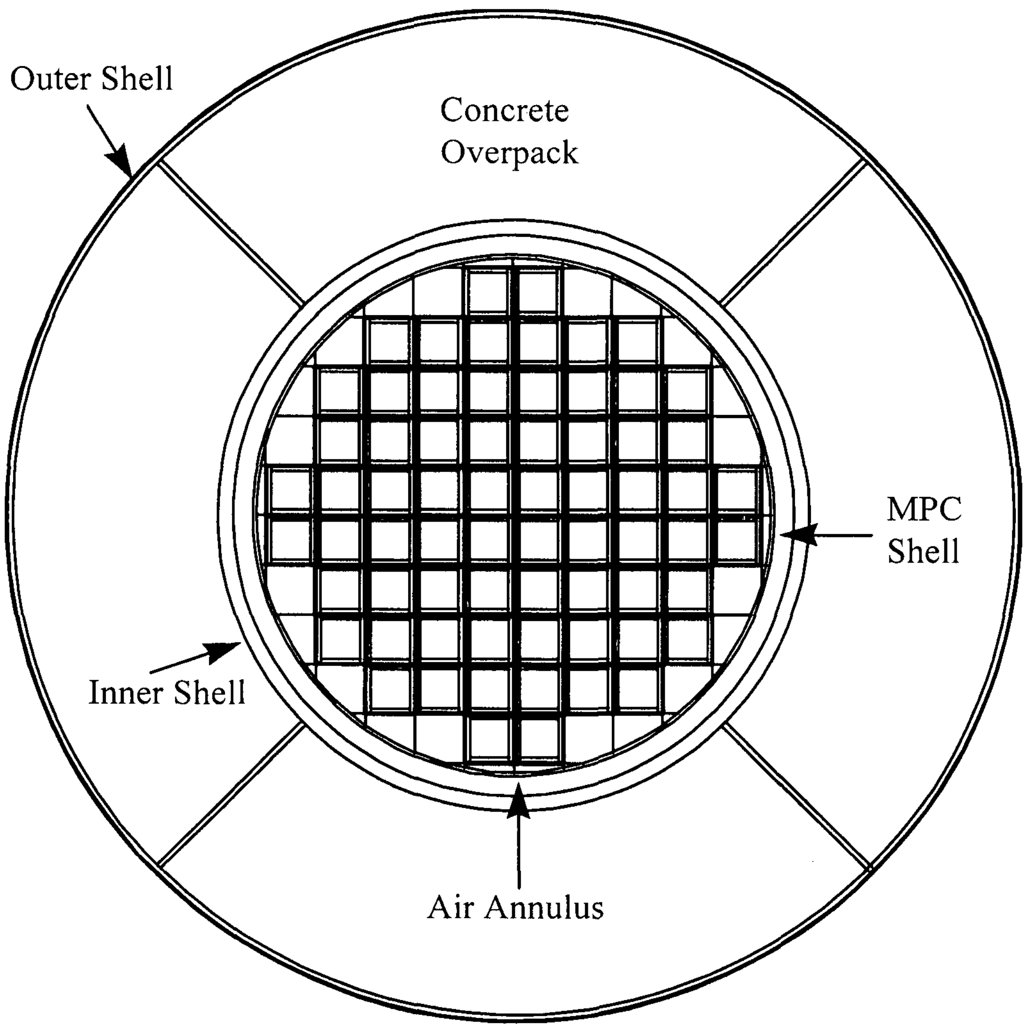


FIGURE 5.3.3; HI-STORM 100 OVERPACK WITH MPC-68 CROSS SECTIONAL VIEW AS MODELLED IN MCNP†

† This figure is drawn to scale using the MCNP plotter.

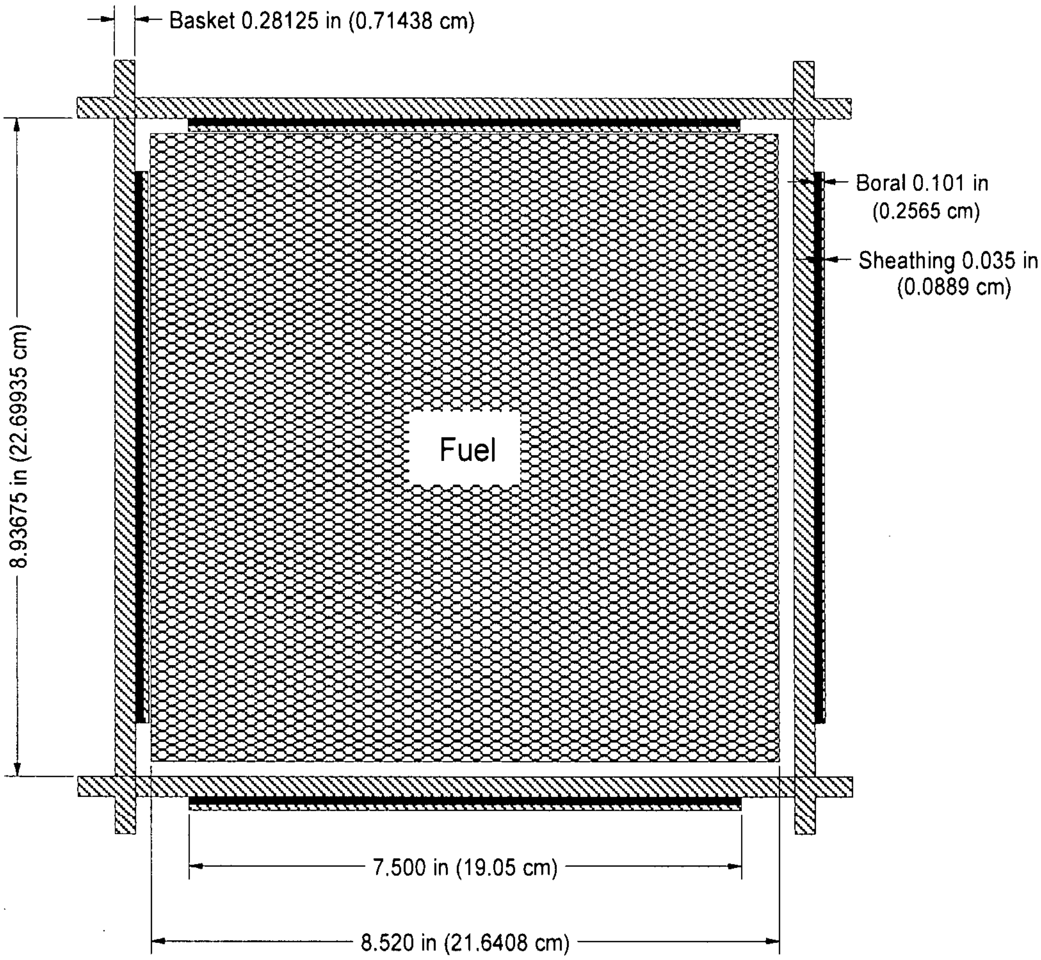


FIGURE 5.3.4; CROSS SECTIONAL VIEW OF AN MPC-32 BASKET CELL AS MODELED IN MCNP

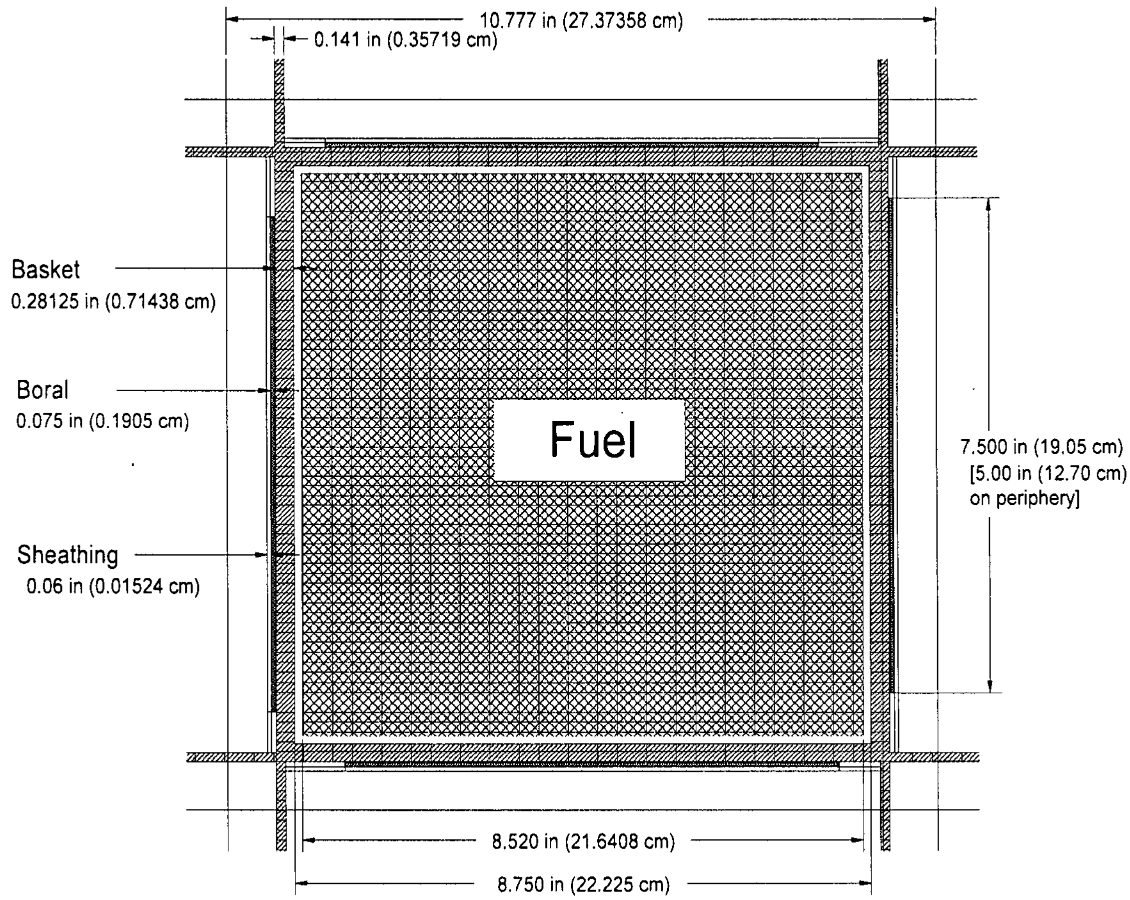


FIGURE 5.3.5; CROSS SECTIONAL VIEW OF AN MPC-24 BASKET CELL AS MODELED IN MCNP

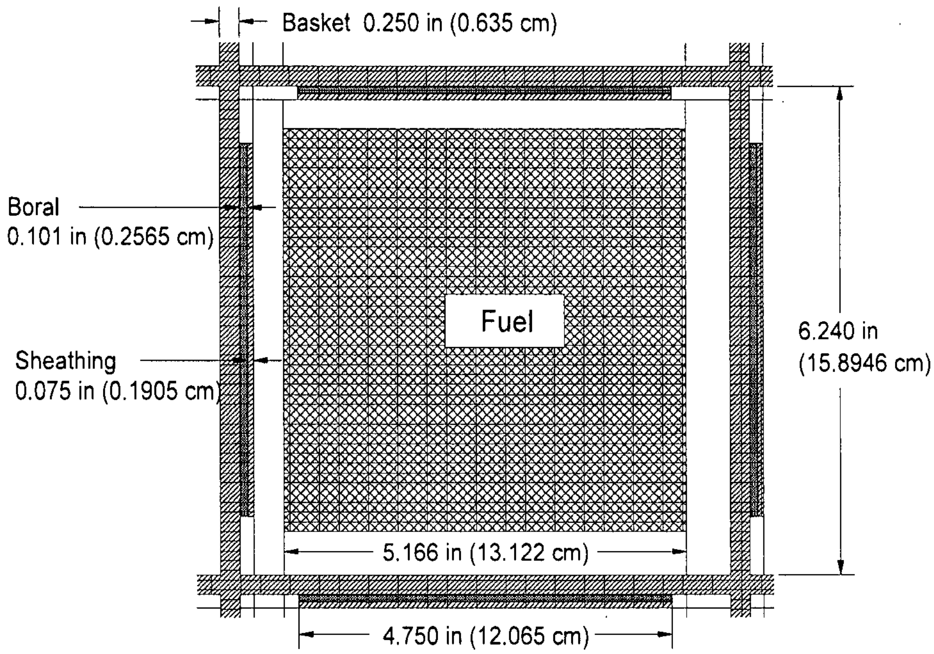


FIGURE 5.3.6; CROSS SECTIONAL VIEW OF AN MPC-68 BASKET CELL AS MODELED IN MCNP

# 100 TON HI-TRAC

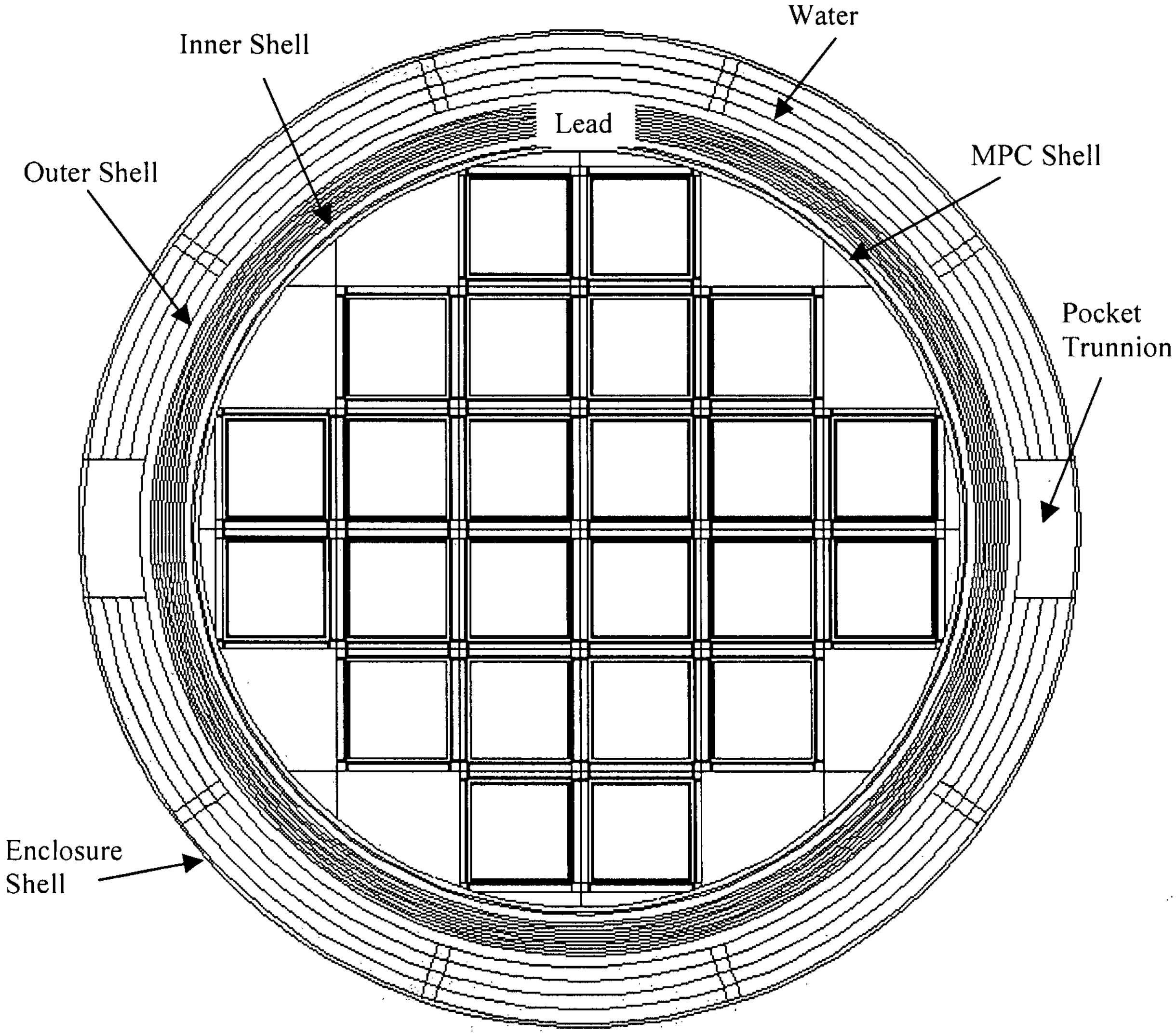


FIGURE 5.3.7; HI-TRAC OVERPACK WITH MPC-24 CROSS SECTIONAL VIEW AS MODELED IN MCNP†

† This figure is drawn to scale using the MCNP plotter.

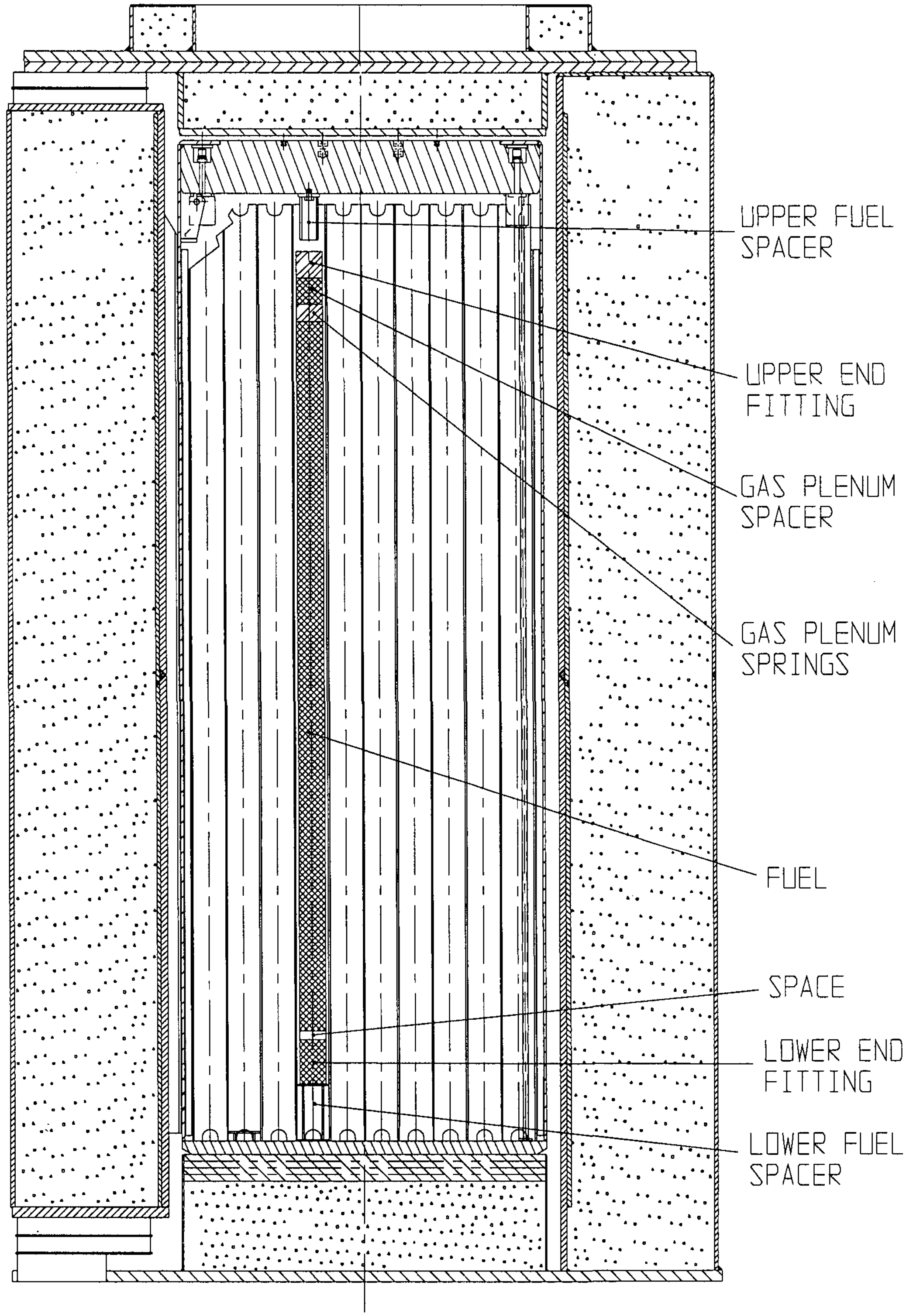


FIGURE 5.3.8; AXIAL LOCATION OF PWR DESIGN BASIS FUEL IN THE HI-STORM OVERPACK

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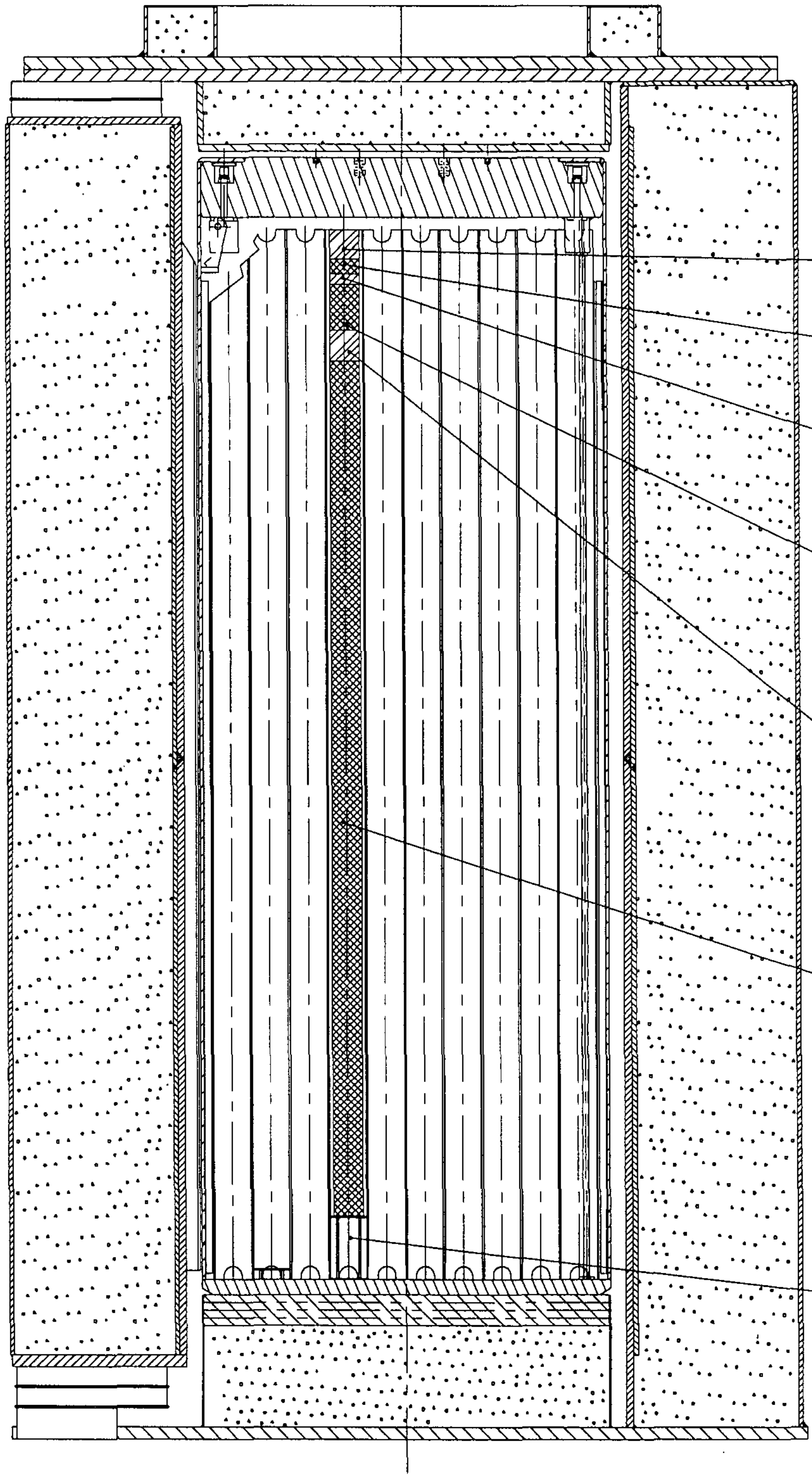


FIGURE 5.3.9; AXIAL LOCATION OF BWR DESIGN BASIS FUEL IN THE HI-STORM OVERPACK

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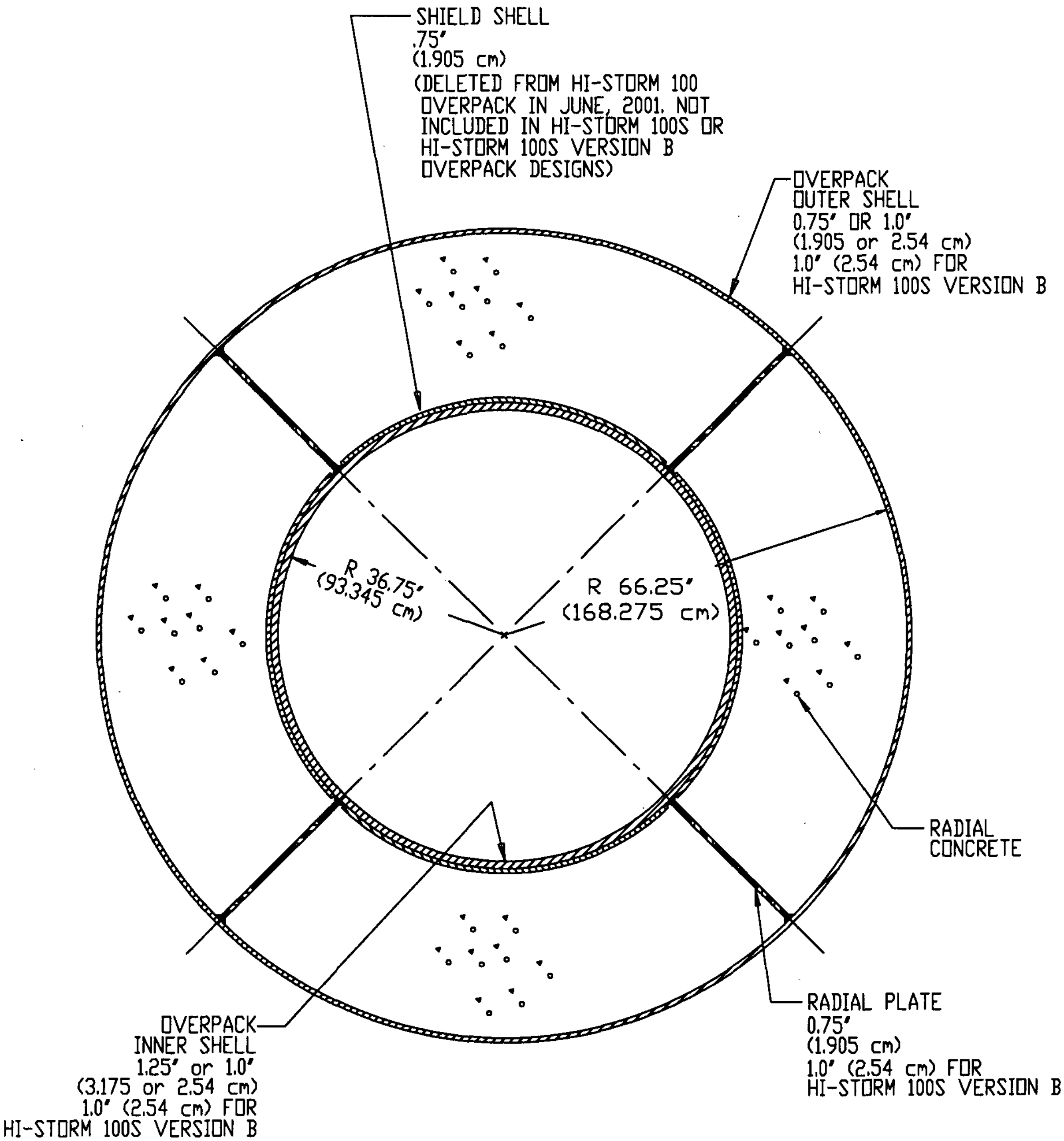



FIGURE 5.3.10; CROSS SECTION OF HI-STORM OVERPACK

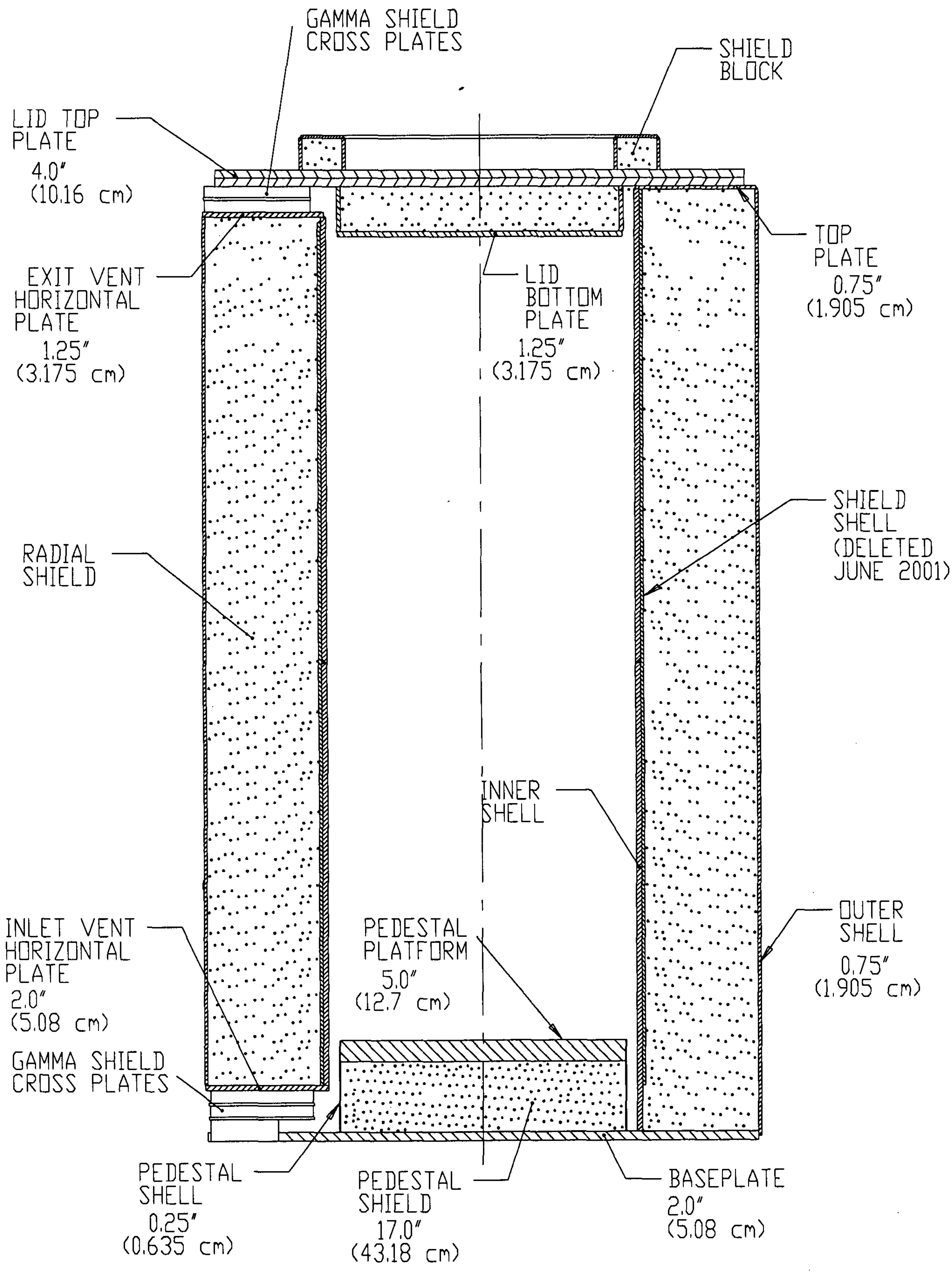



FIGURE 5.3.11; HI-STORM 100 OVERPACK CROSS SECTIONAL ELEVATION VIEW

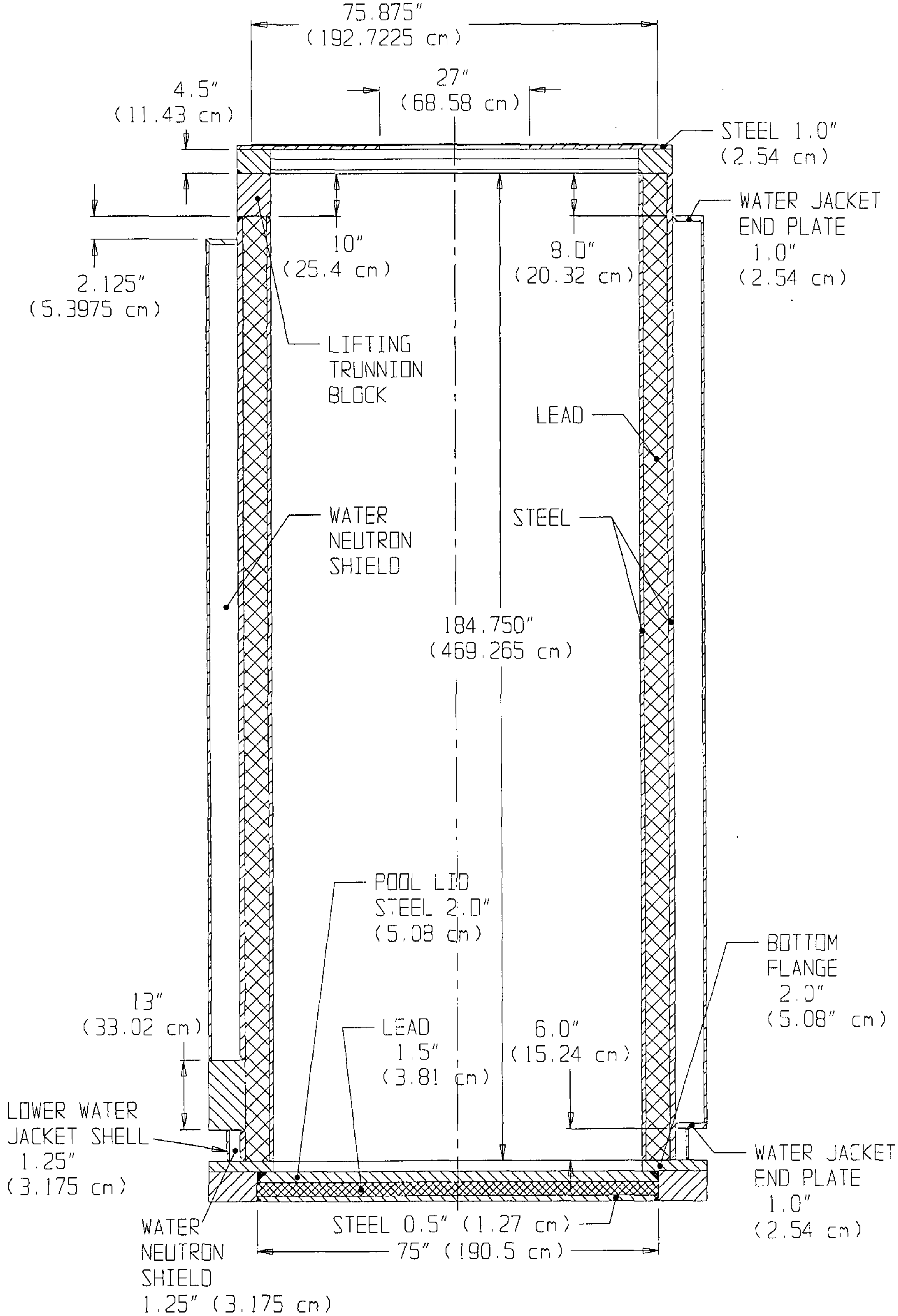



FIGURE 5.3.12; 100-TON HI-TRAC TRANSFER CASK WITH POOL LID CROSS SECTIONAL ELEVATION VIEW (AS MODELED)

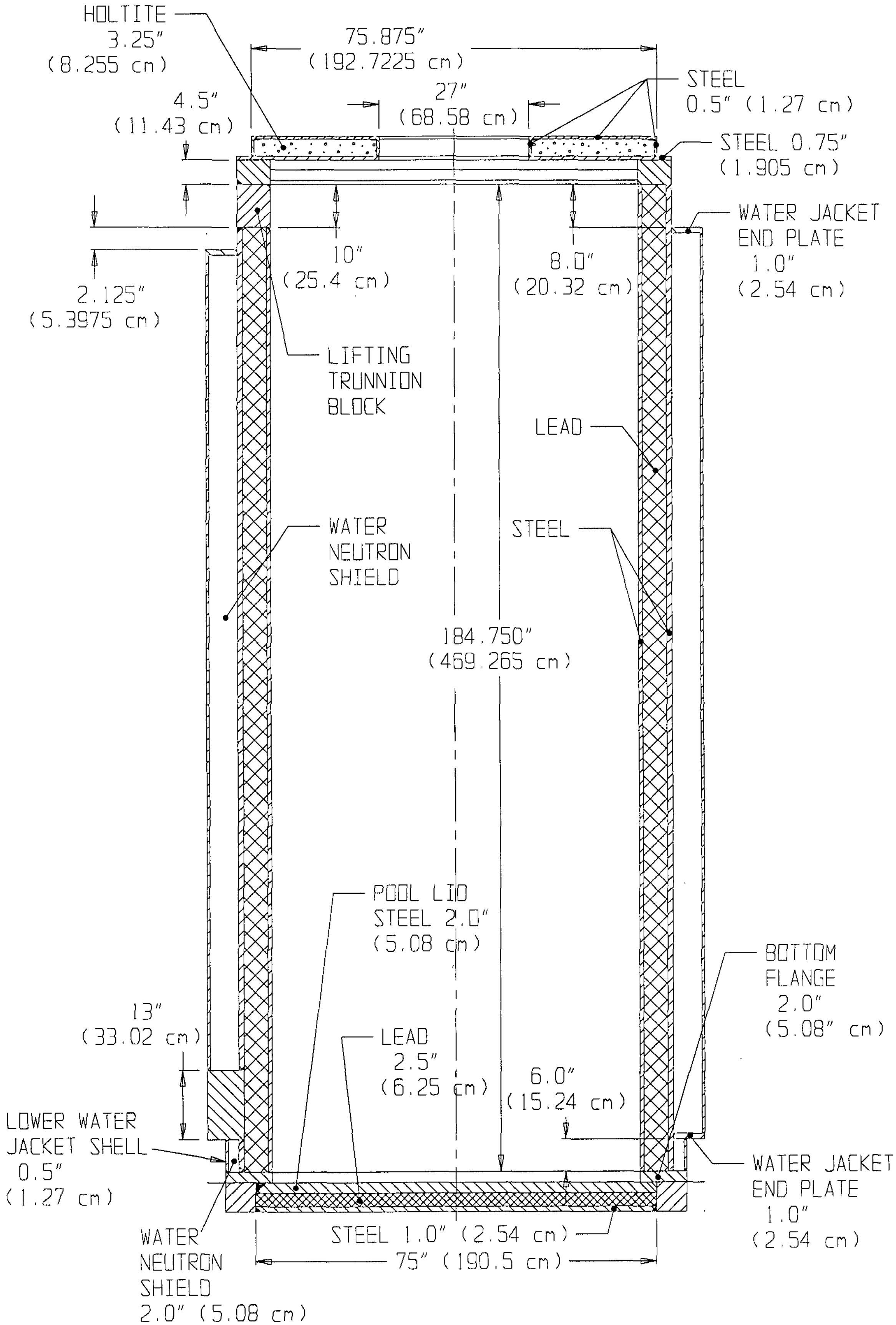
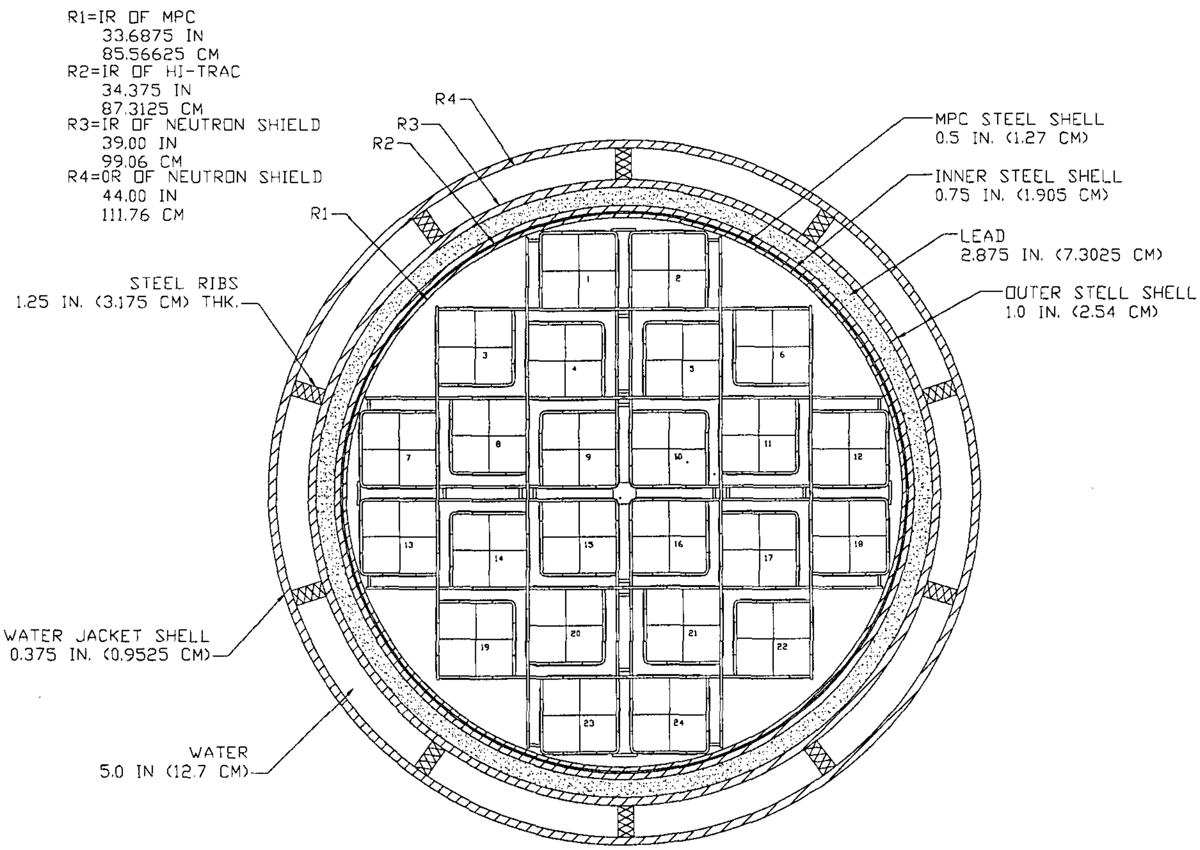



FIGURE 5.3.13; 125-TON HI-TRAC TRANSFER CASK WITH POOL LID CROSS SECTIONAL ELEVATION VIEW (AS MODELED)




Note: The HI-TRAC 100 has 10 steel ribs as shown. The HI-TRAC 100D has 8 steel ribs evenly spaced with thickness as shown.

FIGURE 5.3.14; HI-TRAC 100 AND 100D TRANSFER CASK CROSS SECTIONAL VIEW (AS MODELED)

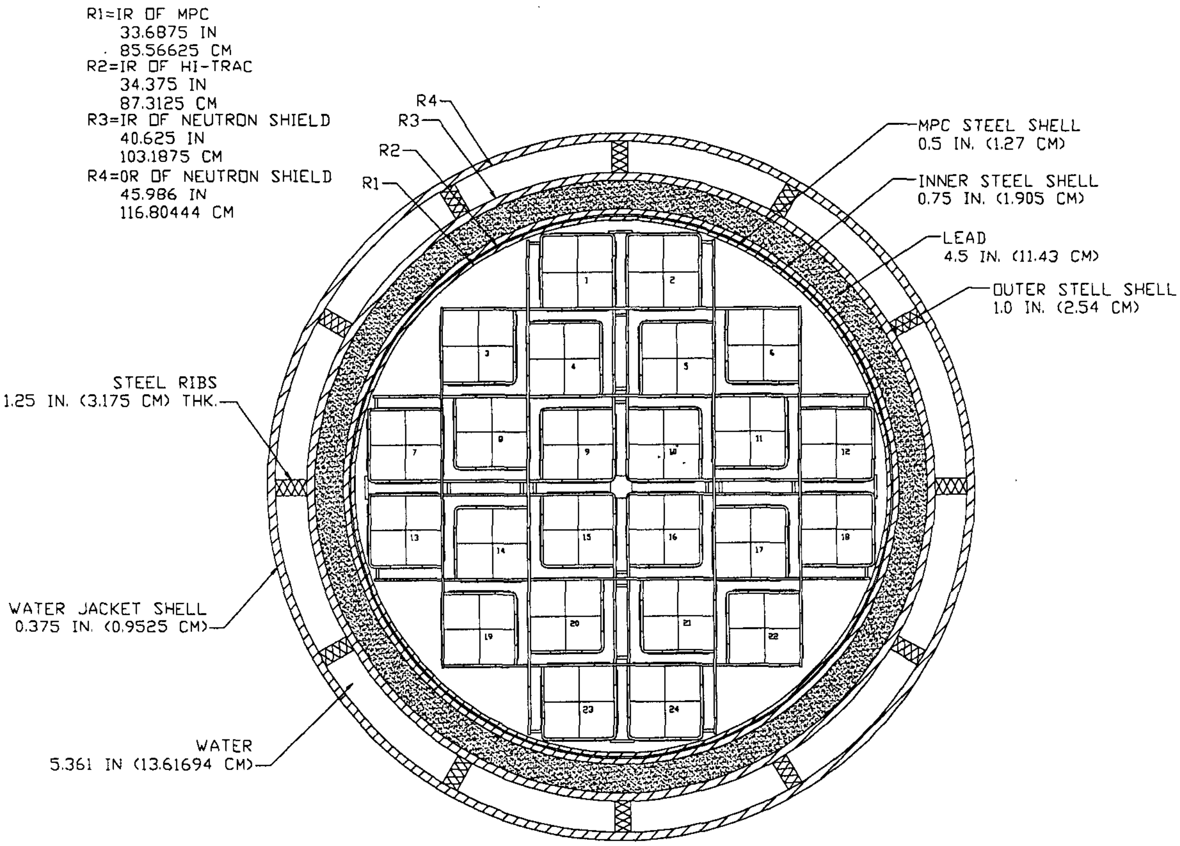



FIGURE 5.3.15; HI-TRAC 125 TRANSFER CASK CROSS SECTIONAL VIEW
(AS MODELED)

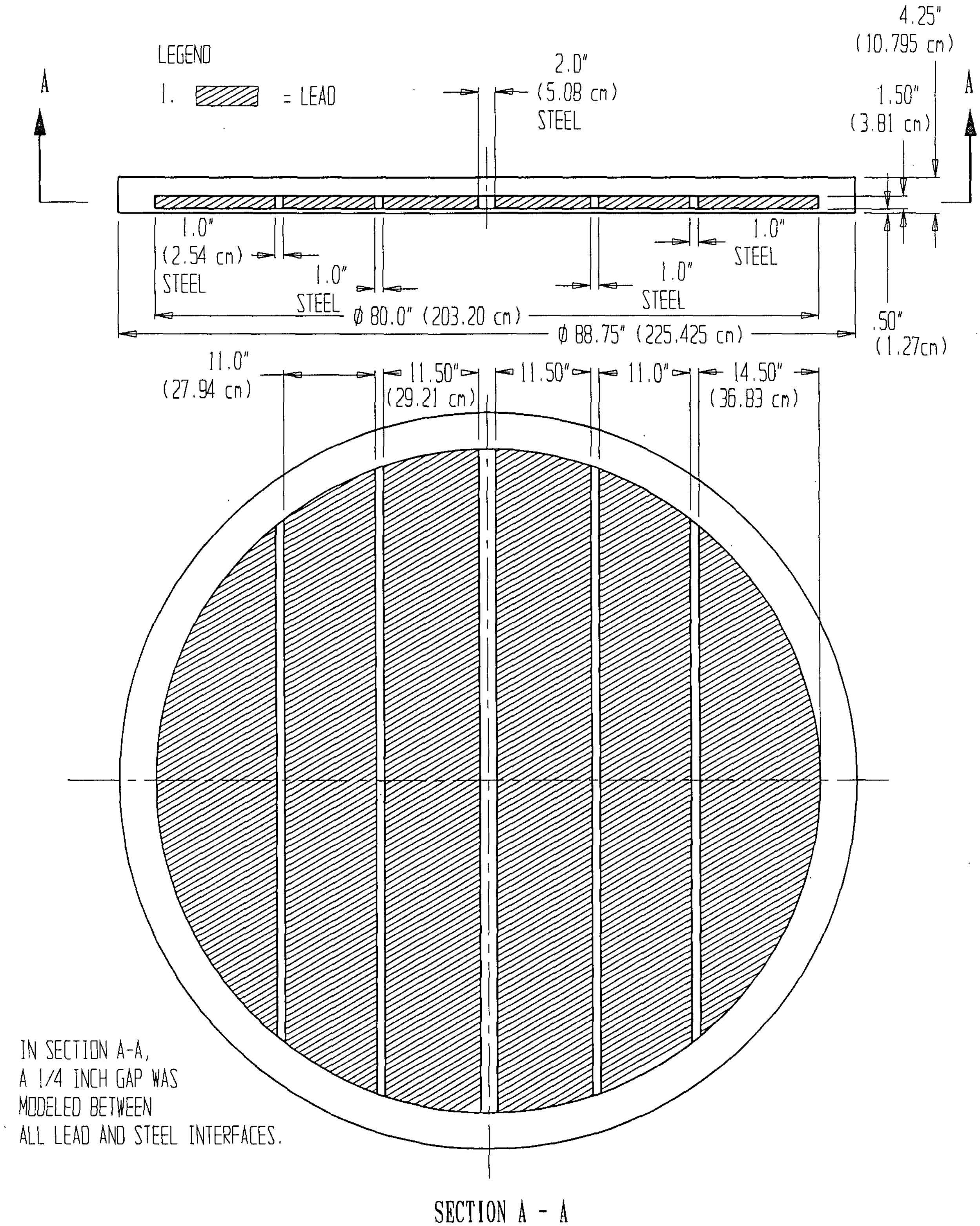



FIGURE 5.3.16; 100-TON HI-TRAC TRANSFER LID (AS MODELED)

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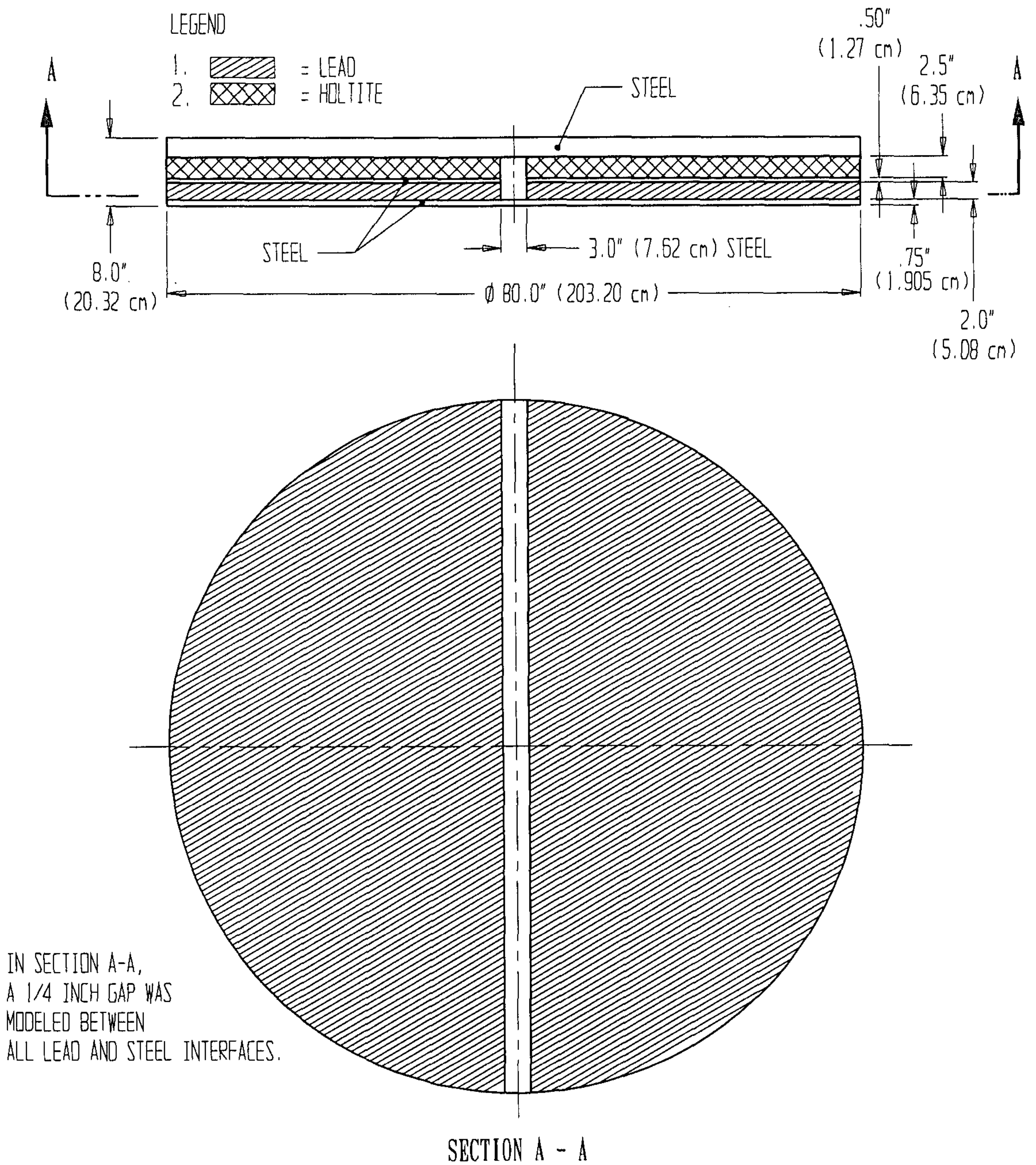


FIGURE 5.3.17; 125-TON HI-TRAC TRANSFER LID (AS MODELED)

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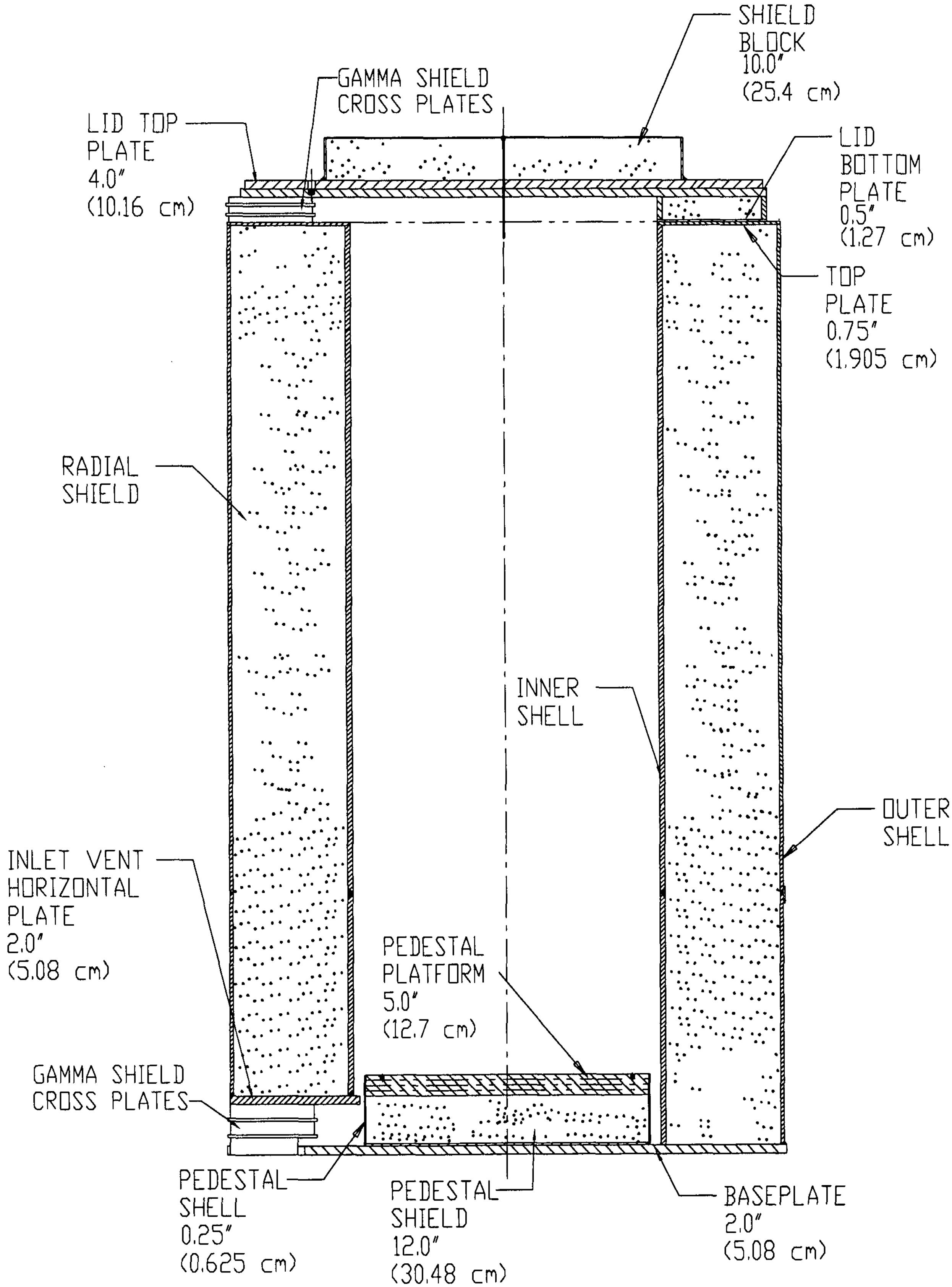
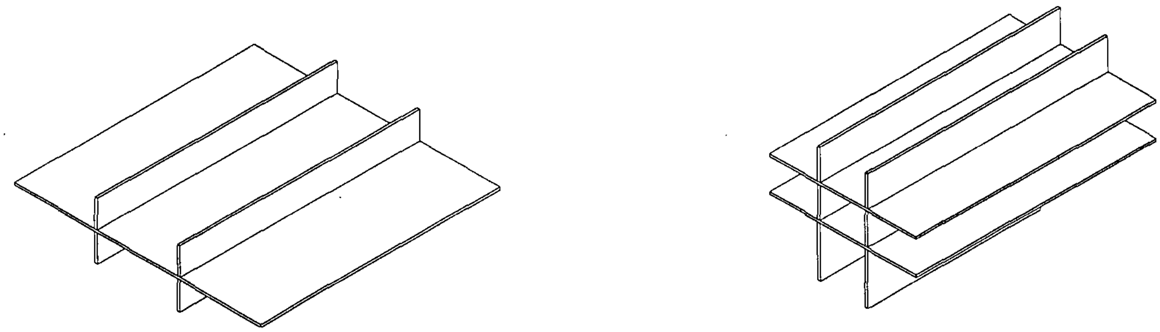
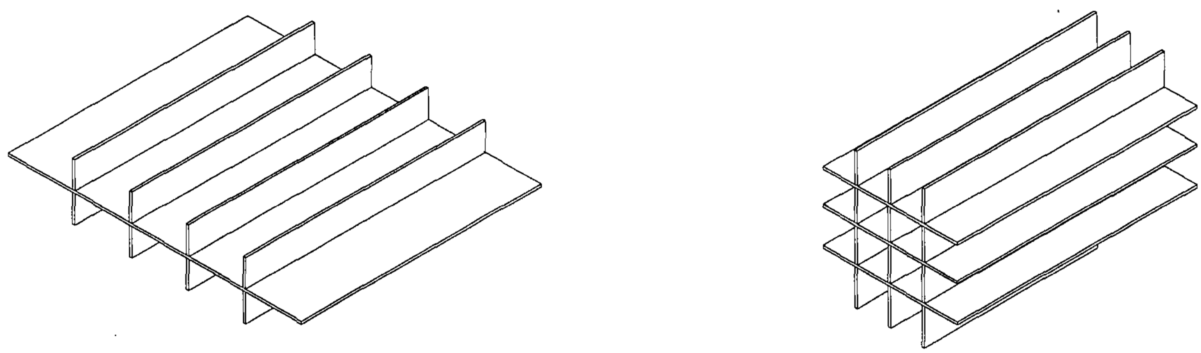



FIGURE 5.3.18; HI-STORM 100S OVERPACK CROSS SECTIONAL ELEVATION VIEW



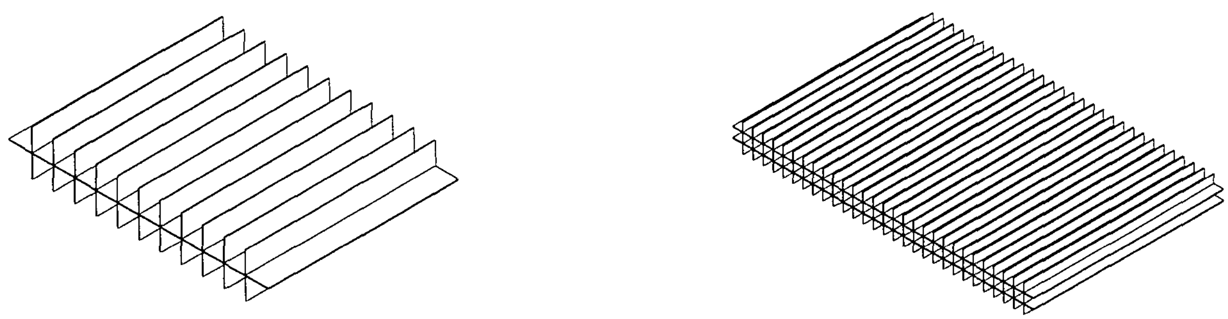
OUTLET VENT INLET VENT

MANDATORY GAMMA SHIELD CROSS PLATES FOR HI-STORM 100
AND HI-STORM 100S



OUTLET VENT INLET VENT

OPTIONAL GAMMA SHIELD CROSS PLATES FOR HI-STORM 100S
THAT MAY BE USED INSTEAD OF THE MANDATORY DEVICES.



OUTLET VENT INLET VENT

MANDATORY GAMMA SHIELD CROSS PLATES FOR HI-STORM 100S VERSION B

FIGURE 5.3.19: GAMMA SHIELD CROSS PLATE CONFIGURATION OF
HI-STORM 100, HI-STORM 100S, AND HI-STORM 100S VERSION B

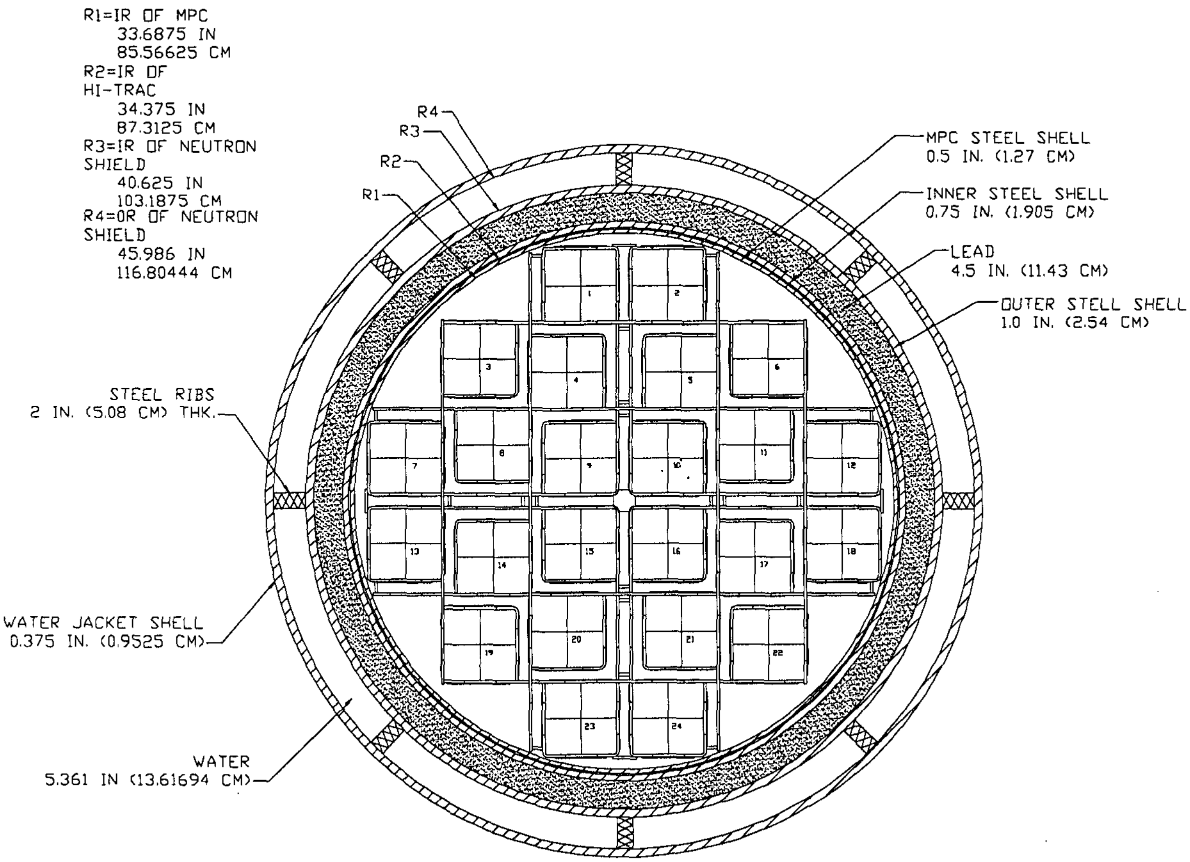



FIGURE 5.3.20; HI-TRAC 125D TRANSFER CASK CROSS SECTIONAL VIEW
(AS MODELED)

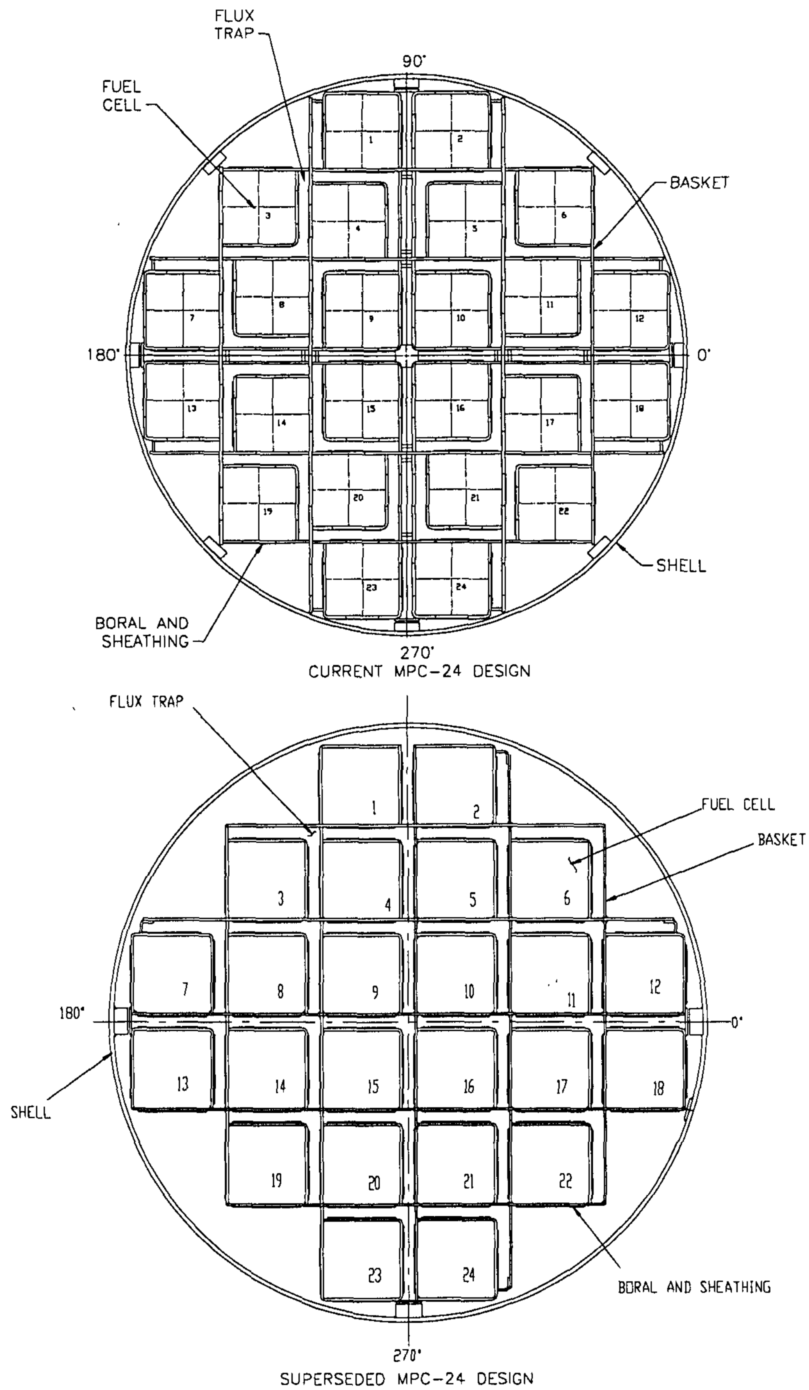



FIGURE 5.3.21; CROSS SECTIONAL VIEWS OF THE CURRENT MPC-24 DESIGN AND THE SUPERSEDED MPC-24 WHICH IS USED IN THE MCNP MODELS.

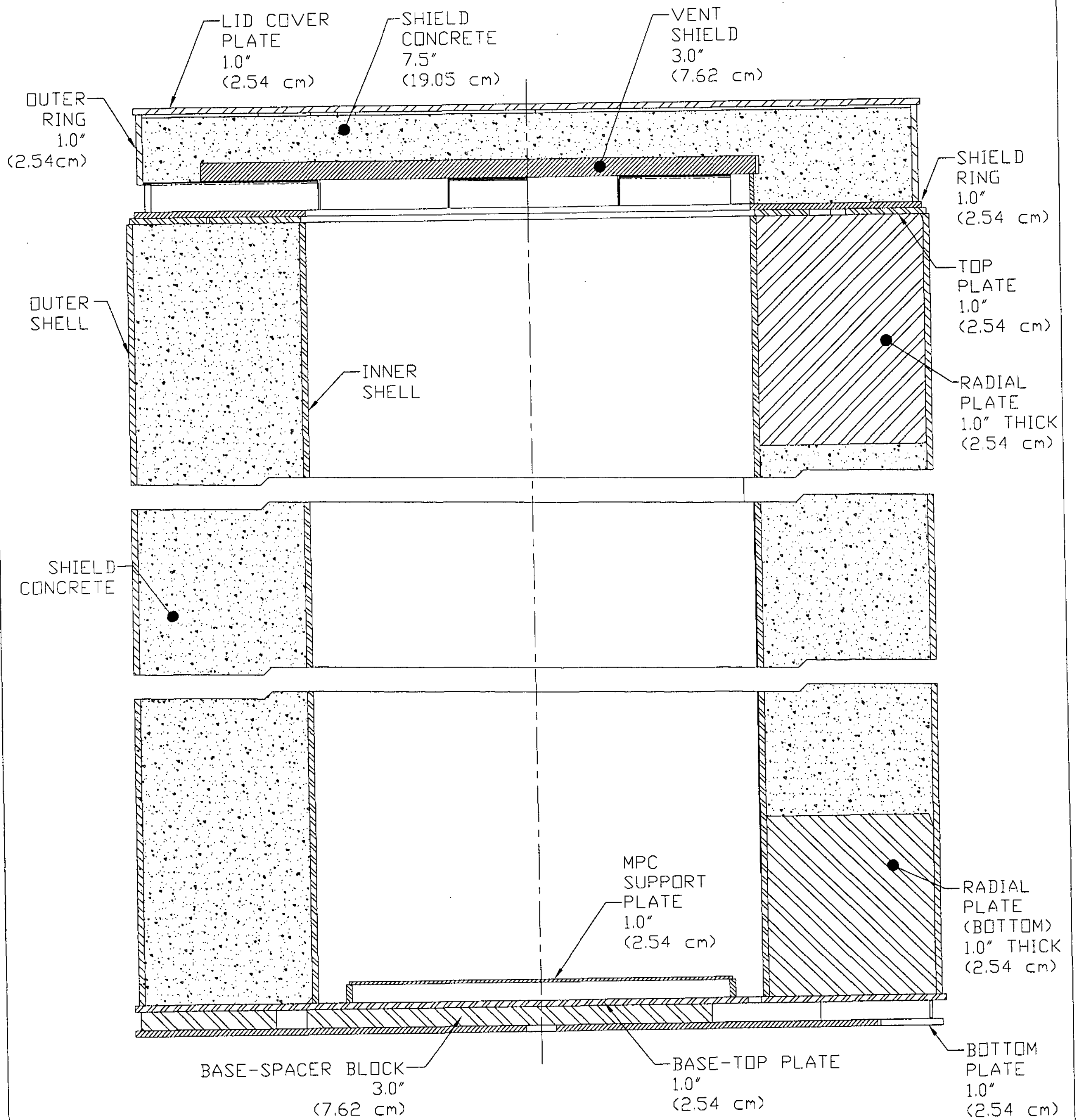



FIGURE 5.3.22; HI-STORM 100S VERSION B OVERPACK CROSS SECTIONAL ELEVATION VIEW

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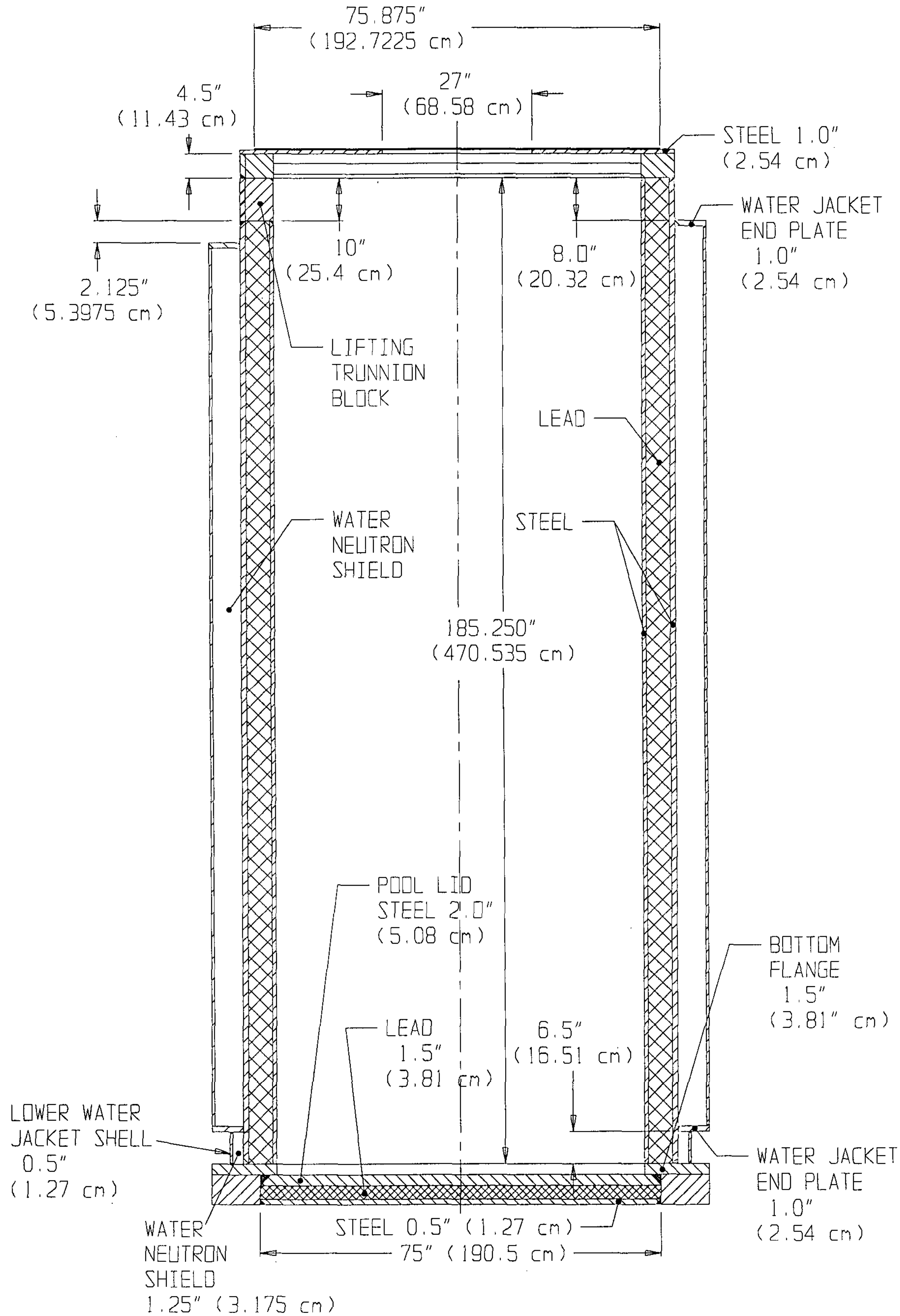


FIGURE 5.3.23; HI-TRAC 100D TRANSFER CASK WITH POOL LID CROSS SECTIONAL ELEVATION VIEW (AS MODELED)

## 5.4 SHIELDING EVALUATION

The MCNP-4A code was used for all of the shielding analyses [5.1.1]. MCNP is a continuous energy, three-dimensional, coupled neutron-photon-electron Monte Carlo transport code. Continuous energy cross section data are represented with sufficient energy points to permit linear-linear interpolation between points. The individual cross section libraries used for each nuclide are those recommended by the MCNP manual. All of these data are based on ENDF/B-V data. MCNP has been extensively benchmarked against experimental data by the large user community. References [5.4.2], [5.4.3], and [5.4.4] are three examples of the benchmarking that has been performed.

The energy distribution of the source term, as described earlier, is used explicitly in the MCNP model. A different MCNP calculation is performed for each of the three source terms (neutron, decay gamma, and $^{60}$Co). The axial distribution of the fuel source term is described in Table 2.1.11 and Figures 2.1.3 and 2.1.4. The PWR and BWR axial burnup distributions were obtained from References [5.4.5] and [5.4.6], respectively. These axial distributions were obtained from operating plants and are representative of PWR and BWR fuel with burnups greater than 30,000 MWD/MTU. The $^{60}$Co source in the hardware was assumed to be uniformly distributed over the appropriate regions.

It has been shown that the neutron source strength varies as the burnup level raised by the power of 4.2. Since this relationship is non-linear and since the burnup in the axial center of a fuel assembly is greater than the average burnup, the neutron source strength in the axial center of the assembly is greater than the relative burnup times the average neutron source strength. In order to account for this effect, the neutron source strength in each of the 10 axial nodes listed in Table 2.1.11 was determined by multiplying the average source strength by the relative burnup level raised to the power of 4.2. The peak relative burnups listed in Table 2.1.11 for the PWR and BWR fuels are 1.105 and 1.195 respectively. Using the power of 4.2 relationship results in a 37.6% ($1.105^{4.2}/1.105$) and 76.8% ($1.195^{4.2}/1.195$) increase in the neutron source strength in the peak nodes for the PWR and BWR fuel, respectively. The total neutron source strength increases by 15.6% for the PWR fuel assemblies and 36.9% for the BWR fuel assemblies.

MCNP was used to calculate doses at the various desired locations. MCNP calculates neutron or photon flux and these values can be converted into dose by the use of dose response functions. This is done internally in MCNP and the dose response functions are listed in the input file in Appendix 5.C. The response functions used in these calculations are listed in Table 5.4.1 and were taken from ANSI/ANS 6.1.1, 1977 [5.4.1].

The dose rates at the various locations were calculated with MCNP using a two step process. The first step was to calculate the dose rate for each dose location per starting particle for each neutron and gamma group in the fuel and each axial location in the end fittings. The second and last step was to multiply the dose rate per starting particle for each group or starting location by the source strength (i.e. particles/sec) in that group or location and sum the resulting dose rates for all groups in each dose location. The standard deviations of the various results were statistically combined to determine the standard deviation of the total dose in each dose location.

The HI-STORM shielding analysis was performed for conservative burnup and cooling time combinations which bound the uniform and regionalized loading specifications for zircaloy clad fuel specified in Section 2.1.9. Therefore, the HI-STORM shielding analysis presented in this chapter is conservatively bounding for the MPC-24, MPC-32, and MPC-68.

Tables 5.1.11 through 5.1.13 provide the maximum dose rates adjacent to the HI-STORM overpack during normal conditions for each of the MPCs. Tables 5.1.14 through 5.1.16 provide the maximum dose rates at one meter from the overpack. A detailed discussion of the normal, off-normal, and accident condition dose rates is provided in Sections 5.1.1 and 5.1.2.

Tables 5.1.7 and 5.1.8 provide dose rates for the 100-ton and 125-ton HI-TRAC transfer casks, respectively, with the MPC-24 loaded with design basis fuel in the normal condition, in which the MPC is dry and the HI-TRAC water jacket is filled with water. Table 5.4.2 shows the corresponding dose rates adjacent to and one meter away from the 100-ton HI-TRAC for the fully flooded MPC condition with an empty water-jacket (condition in which the HI-TRAC is removed from the spent fuel pool). Table 5.4.3 shows the dose rates adjacent to and one meter away from the 100-ton HI-TRAC for the fully flooded MPC condition with the water jacket filled with water (condition in which welding operations are performed). Dose locations 4 and 5, which are on the top and bottom of the HI-TRAC were not calculated at the one-meter distance for these configurations. For the conditions involving a fully flooded MPC, the internal water level was 10 inches below the MPC lid. These dose rates represent the various conditions of the HI-TRAC during operations. Comparing these results to Table 5.1.7 indicates that the dose rates in the upper and lower portions of the HI-TRAC are reduced by about 50% with the water in the MPC. The dose at the center of the HI-TRAC is reduced by approximately 50% when there is also water in the water jacket and is essentially unchanged when there is no water in the water jacket as compared to the normal condition results shown in Table 5.1.7.

The burnup and cooling time combination of 60,000 MWD/MTU and 3 years was selected for the 100-ton MPC-24 HI-TRAC analysis because this combination of burnup and cooling time results in the highest dose rates, and therefore, bounds all other requested combinations in the 100-ton HI-TRAC. The dose rate at 1 meter from the pool lid was not calculated because a concrete floor was placed 6 inches below the pool lid to account for potential ground scattering. These results in Table 5.1.7 clearly indicate that gammas are the dominant portion of the total dose rate. Therefore, as the burnup and cooling time increase, the reduction in the gamma dose rate due to the increased cooling time results in a net decrease in the total dose rate.

In contrast, the dose rates surrounding the HI-TRAC 125 and 125D transfer casks have significantly higher neutron component. Therefore, the dose rates at 75,000 MWD/MTU burnup and 5 year cooling are higher than the dose rates at 60,000 MWD/MTU burnup and 3 year cooling. The dose rates for the 125-ton HI-TRACs with the MPC-24 at 75,000 MWD/MTU and 5 year cooling are listed in Table 5.1.8 of Section 5.1.

Table 5.4.9 provides dose rates adjacent to and one meter away from the 100-ton HI-TRAC with the MPC-68 at a burnup and cooling time combination of 50,000 MWD/MTU and 3 years. The dose rate at 1 meter from the pool lid was not calculated because a concrete floor was placed 6 inches below the pool lid to account for potential ground scattering. These results demonstrate that the dose rates on contact at the top and bottom of the 100-ton HI-TRAC are somewhat higher in the MPC-68 case than in the MPC-24 case. However, the MPC-24 produces higher dose rates than the MPC-68 at the center of the HI-TRAC, on-contact, and at locations 1 meter away from the HI-TRAC. Therefore, the MPC-24 is still used for the exposure calculations in Chapter 10 of the FSAR.

Table 5.4.11 provides dose rates adjacent to and one meter away from the 100-ton HI-TRAC with the MPC-32 at burnup and cooling time combination of 45,000 MWD/MTU and 3 years. The dose rate at 1 meter from the pool lid was not calculated because a concrete floor was placed 6 inches below the pool lid to account for potential ground scattering. These results demonstrate that the dose rates on contact at the top of the 100-ton HI-TRAC are somewhat higher in the MPC-32 case than in the MPC-24 case. However, the MPC-24 produces higher dose rates than the MPC-32 at the center of the HI-TRAC, on-contact, and at locations 1 meter away from the HI-TRAC. Therefore, the MPC-24 is still used for the exposure calculations in Chapter 10 of the FSAR.

Table 5.4.19 provides dose rates adjacent to and one meter away from the radial surface of the HI-TRAC 100D with the MPC-32 at a burnup of 35,000 MWD/MTU and a cooling time of 3 years. Results are presented only for dose locations 1 through 3 since the differences between the HI-TRAC 100 and the 100D will only affect the dose rates on the side of the transfer cask. A comparison of these results to those provided in Table 5.4.11 indicates that the dose rates at 1 meter from the transfer cask are very similar to the dose rates for the 100-ton HI-TRAC.

As mentioned in Section 5.0, all MPCs offer a regionalized loading pattern as described in Section 2.1.9. This loading pattern authorizes fuel of higher decay heat than uniform loading (i.e. higher burnups and shorter cooling times) to be stored in either the center region, region 1, of the MPC or the outer region, region 2. From a shielding perspective, placing the older fuel on the outside provides shielding for the inner fuel in the radial direction. Note that for the MPC-24 there are some inner region assemblies that have a corner area with a direct line of sight to the MPC shell and therefore the outer region will not provide quite as much additional shielding over the whole surface area of the cask as it does for the MPC-32 and MPC-68. Based on analysis for the MPC-32 and MPC-68 using the same burnup and cooling times in region 1 and 2 the following percentages were calculated for dose location 2 on the 100-ton HI-TRAC.

- Approximately 21% and 27% of the neutron dose at the edge of the water jacket comes from region 1 fuel assemblies in the MPC-32 and MPC-68, respectively.

Region 1 contains 12 (38% of total) and 32 (47% of total) assemblies in the MPC-32 and MPC-68, respectively. For the MPC-24, where region 1 contains 12 (50% of total) assemblies, the contribution would be similar.

- Approximately 1% and 2% of the photon dose at the edge of the water jacket comes from region 1 fuel assemblies in the MPC-32 and MPC-68, respectively. For the MPC-24, where some corners of the region 1 assemblies are not completely shielded by the outer assemblies, the contribution of the photon dose from region 1 would be slightly larger than for the MPC-32 and MPC-68, but the gamma dose rates would still be dominated by the outer assemblies.

These results clearly indicate that the outer fuel assemblies shield almost the entire gamma source from the inner assemblies in the radial direction and a significant percentage of the neutron source. The conclusion from this analysis is that the total dose rate on the external radial surfaces of the cask can be greatly reduced by placing longer cooled and lower burnup fuels on the outside of the basket. Note that for the MPC-24 there may be localized higher dose rates using regionalized loading, since the inner region is not totally surrounded by the outer region. However, the dose rates would always be bounded by the values presented in this chapter. In the axial direction, regionalized loading with higher burnup fuel on the inside results in higher dose rates in the center portion of the cask since the region 2 assemblies are not shielding the region 1 assemblies for axial dose locations.

Note that the regionalized loading scheme also allows placing higher burned or shorter cooled assemblies on the periphery of the basket. In this case, dose rate would be closer to the bounding values presented here. This configuration should only be used if it is not feasible to place such assemblies in the center of the cask.

Burnup and cooling time combinations which bound both regionalized loading and uniform loading patterns were analyzed. Therefore, dose rates for specific regionalized loading patterns are not presented in this chapter. Section 5.4.9 provides a brief additional discussion on regionalized loading dose rates.

Unless otherwise stated all tables containing dose rates for design basis fuel refer to design basis intact zircaloy clad fuel.

Since MCNP is a statistical code, there is an uncertainty associated with the calculated values. In MCNP the uncertainty is expressed as the relative error which is defined as the standard deviation of the mean divided by the mean. Therefore, the standard deviation is represented as a percentage of the mean. The relative error for the total dose rates presented in this chapter were typically less than 5% and the relative error for the individual dose components was typically less than 10%.

### 5.4.1 Streaming Through Radial Steel Fins and Pocket Trunnions and Azimuthal Variations

The HI-STORM 100 overpack and the HI-TRAC utilize radial steel fins for structural support and cooling. The attenuation of neutrons through steel is substantially less than the attenuation of neutrons through concrete and water. Therefore, it is possible to have neutron streaming through the fins that could result in a localized dose peak. The reverse is true for photons, which would result in a localized reduction in the photon dose. In addition to the fins, the pocket trunnions in the HI-TRAC 100 and 125 are essentially blocks of steel that are approximately 12 inches wide and 12 inches high. The effect of the pocket trunnion on neutron streaming and photon transmission will be more substantial than the effect of a single fin.

Analysis of the pocket trunnions in the HI-TRAC 100 and 125 and the steel fins in the HI-TRAC 100, 125, and 125D indicate that neutron streaming is noticeable at the surface of the transfer cask. The neutron dose rate on the surface of the pocket trunnion is approximately 5 times higher than the circumferential average dose rate at that location. The gamma dose rate is approximately 10 times lower than the circumferential average dose rate at that location. The streaming at the rib location is the largest in the HI-TRAC 125D because the ribs are thicker than in the HI-TRAC 100 or 125. The neutron dose rate on the surface of the rib in the 125D is approximately 3 times higher than the circumferential average dose rate at that location. The gamma dose rate on the surface of the rib in the 125D is approximately 3 times lower than the circumferential average dose rate at that location. At one meter from the cask surface there is little difference between the dose rates calculated over the fins and the pocket trunnions compared to the other areas of the water jackets.

These conclusions indicate that localized neutron streaming is noticeable on the surface of the transfer casks. However, at one meter from the surface the streaming has dissipated. Since most HI-TRAC operations will involve personnel moving around the transfer cask at some distance from the cask only surface average dose rates are reported in this chapter.

Below each lifting trunnion, there is a localized area where the water jacket has been reduced in height by 4.125 inches to accommodate the lift yoke (see Figures 5.3.12 and 5.3.13). This area experiences a significantly higher than average dose rate on contact of the HI-TRAC. The peak dose in this location is 2.9 Rem/hr for the MPC-32, 2.0 Rem/hr for the MPC-68 and 2.4 Rem/hr for the MPC-24 in the 100-ton HI-TRAC and 1.7 Rem/hr for the MPC-24 in the HI-TRAC 125D. At a distance of 1 to 2 feet from the edge of the HI-TRAC the localized effect is greatly reduced. This dose rate is acceptable because during lifting operations the lift yoke will be in place, which, due to the additional lift yoke steel (~3 inches), will greatly reduce the dose rate. However, more importantly, people will be prohibited from being in the vicinity of the lifting trunnions during lifting operations as a standard rigging practice. In addition the lift yoke is remote in its attachment and detachment, further minimizing personnel exposure. Immediately following the detachment of the lift yoke, in preparation for closure operations, temporary shielding may be placed in this area. Any temporary shielding (e.g., lead bricks, water tanks, lead blankets, steel plates, etc.) is sufficient to attenuate the localized hot spot. The operating procedure in Chapter 8 discusses the placement of temporary shielding in this area. For the 100-ton HI-TRAC, the optional temporary shield ring will replace the water that was lost from the axial reduction in the water jacket thereby eliminating the localized hot spot. When the HI-TRAC is in the horizontal position, during transport operations, it will (at a minimum) be positioned a few feet off the ground by the transport vehicle and therefore this location below the lifting trunnions will be positioned above people which will minimize the effect on personnel exposure. In addition, good operating practice will dictate that personnel remain at least a few feet away from the transport vehicle. During vertical transport of a loaded HI-TRAC, the localized hot spot will be even further from the operating personnel. Based on these considerations, the conclusion is that this localized hot spot does not significantly impact the personnel exposure.

### 5.4.2 Damaged Fuel Post-Accident Shielding Evaluation

#### 5.4.2.1 Dresden 1 and Humboldt Bay Damaged Fuel

As discussed in Section 5.2.5.2, the analysis presented below, even though it is for damaged fuel, demonstrates the acceptability of storing intact Humboldt Bay 6x6 and intact Dresden 1 6x6 fuel assemblies.

For the damaged fuel and fuel debris accident condition, it is conservatively assumed that the damaged fuel cladding ruptures and all the fuel pellets fall and collect at the bottom of the damaged fuel container. The inner dimension of the damaged fuel container, specified in the Design Drawings of Chapter 1, and the design basis damaged fuel and fuel debris assembly dimensions in Table 5.2.2 are used to calculate the axial height of the rubble in the damaged fuel container assuming 50% compaction. Neglecting the fuel pellet to cladding inner diameter gap, the volume of cladding and fuel pellets available for deposit is calculated assuming the fuel rods are solid. Using the volume in conjunction with the damaged fuel container, the axial height of rubble is calculated to be 80 inches.

Dividing the total fuel gamma source for a 6x6 fuel assembly in Table 5.2.7 by the 80 inch rubble height provides a gamma source per inch of 3.41E+12 photon/s. Dividing the total neutron source for a 6x6 fuel assembly in Table 5.2.18 by 80 inches provides a neutron source per inch of 2.75E+05 neutron/s. These values are both bounded by the BWR design basis fuel gamma source per inch and neutron source per inch values of 1.08E+13 photon/s and 9.17E+05 neutron/s, respectively, for a burnup and cooling time of 40,000 MWD/MTU and 5 years. These BWR design basis values were calculated by dividing the total source strengths for 40,000 MWD/MTU and 5 year cooling by the active fuel length of 144 inches. Therefore, damaged Dresden 1 and Humboldt Bay fuel assemblies are bounded by the design basis intact BWR fuel assembly for accident conditions. No explicit analysis of the damaged fuel dose rates from Dresden 1 or Humboldt Bay fuel assemblies are provided as they are bounded by the intact fuel analysis.

### 5.4.2.2 Generic PWR and BWR Damaged Fuel

The Holtec Generic PWR and BWR DFCs are designed to accommodate any PWR or BWR fuel assembly that can physically fit inside the DFC. Damaged fuel assemblies under normal conditions, for the most part, resemble intact fuel assemblies from a shielding perspective. Under accident conditions, it can not be guaranteed that the damaged fuel assembly will remain intact. As a result, the damaged fuel assembly may begin to resemble fuel debris in its possible configuration after an accident.

Since damaged fuel is identical to intact fuel from a shielding perspective no specific analysis is required for damaged fuel under normal conditions. However, a generic shielding evaluation was performed to demonstrate that fuel debris under normal or accident conditions, or damaged fuel in a post-accident configuration, will not result in a significant increase in the dose rates around the 100-ton HI-TRAC. Only the 100-ton HI-TRAC was analyzed because it can be concluded that if the dose rate change is not significant for the 100-ton HI-TRAC then the change will not be significant for the 125-ton HI-TRACs or the HI-STORM overpacks.

Fuel debris or a damaged fuel assembly which has collapsed can have an average fuel density which is higher than the fuel density for an intact fuel assembly. If the damaged fuel assembly was to fully or partially collapse, the fuel density in one portion of the assembly would increase and the density in the other portion of the assembly would decrease. This scenario was analyzed with MCNP-4A in a conservative bounding fashion to determine the potential change in dose rate as a result of fuel debris or a damaged fuel assembly collapse. The analysis consisted of modeling the fuel assemblies in the damaged fuel locations in the MPC-24 (4 peripheral locations in the MPC-24E or MPC-24EF) and the MPC-68 (16 peripheral locations) with a fuel density that was twice the normal fuel density and correspondingly increasing the source rate for these locations by a factor of two. A flat axial power distribution was used which is approximately representative of the source distribution if the top half of an assembly collapsed into the bottom half of the assembly. Increasing the fuel density over the entire fuel length, rather than in the top half or bottom half of the fuel assembly, is conservative and provides the dose rate change in both the top and bottom portion of the cask.

Tables 5.4.13 and 5.4.14 provide the results for the MPC-24 and MPC-68, respectively. Only the radial dose rates are provided since the axial dose rates will not be significantly affected because the damaged fuel assemblies are located on the periphery of the baskets. A comparison of these results to the results in Tables 5.1.7 and 5.4.9 indicate that the dose rates in the top and bottom portion of the 100-ton HI-TRAC increase by less than 27% while the dose rate in the center of the HI-TRAC actually decreases a little bit. The increase in the bottom and top is due to the assumed flat power distribution. The dose rates shown in Tables 5.4.13 and 5.4.14 were averaged over the circumference of the cask. Since almost all of the peripheral cells in the MPC-68 are filled with DFCs, an azimuthal variation would not be expected for the MPC-68. However, since there are only 4 DFCs in the MPC-24E, an azimuthal variation in dose due to the damaged fuel/fuel debris might be expected. Therefore, the dose rates were evaluated in four smaller regions, one outside each DFC, that encompass about 44% of the circumference. There was no significant change in the dose rate as a result of the localized dose calculation. These results indicate that the potential effect on the dose rate is not very significant for the storage of damaged fuel and/or fuel debris. This conclusion is further reinforced by the fact that the majority of the significantly damaged fuel assemblies in the spent fuel inventories are older assemblies from the earlier days of nuclear plant operations. Therefore, these assemblies will have a considerably lower burnup and longer cooling times than the assemblies analyzed in this chapter.

The MPC-32 was not explicitly analyzed for damaged fuel or fuel debris in this chapter. However, based on the analysis described above for the MPC-24 and the MPC-68, it can be concluded that the shielding performance of the MPC-32 will not be significantly affected by the storage of damaged fuel.

### 5.4.3 Site Boundary Evaluation

NUREG-1536 [5.2.1] states that detailed calculations need not be presented since SAR Chapter 12 assigns ultimate compliance responsibilities to the site licensee. Therefore, this subsection describes, by example, the general methodology for performing site boundary dose calculations. The site-specific fuel characteristics, burnup, cooling time, and the site characteristics would be factored into the evaluation performed by the licensee.

As an example of the methodology, the dose from a single HI-STORM overpack loaded with an MPC-24 and various arrays of loaded HI-STORMs at distances equal to and greater than 100 meters were evaluated with MCNP. In the model, the casks were placed on an infinite slab of dirt to account for earth-shine effects. The atmosphere was represented by dry air at a uniform density corresponding to 20 degrees C. The height of air modeled was 700 meters. This is more than sufficient to properly account for skyshine effects. The models included either 500 or 1050 meters of air around the cask. Based on the behavior of the dose rate as a function of distance, 50 meters of air, beyond the detector locations, is sufficient to account for back-scattering. Therefore, the HI-STORM MCNP off-site dose models account for back scattering by including more than 50 meters of air beyond the detector locations for all cited dose rates. Since gamma back-scattering has an effect on the off-site dose, it is recommended that the site-specific evaluation under 10CFR72.212 include at least 50 to 100 meters of air, beyond the detector locations, in the calculational models.

The MCNP calculations of the off-site dose used a two-stage process. In the first stage a binary surface source file (MCNP terminology) containing particle track information was written for particles crossing the outer radial and top surfaces of the HI-STORM overpack. In the second stage of the calculation, this surface source file was used with the particle tracks originating on the outer edge of the overpack and the dose rate was calculated at the desired location (hundreds of meters away from the overpack). The results from this two-stage process are statistically the same as the results from a single calculation. However, the advantage of the two-stage process is that each stage can be optimized independently.

The annual dose, assuming 100% occupancy (8760 hours), at 350 meters from a single HI-STORM 100S Version B cask is presented in Table 5.4.6 for the design basis burnup and cooling time analyzed. This table indicates that the dose due to neutrons is 2.8 % of the total dose. This is an important observation because it implies that simplistic analytical methods such as point kernel techniques may not properly account for the neutron transmissions and could lead to low estimates of the site boundary dose.

The annual dose, assuming 8760 hour occupancy, at distance from an array of casks was calculated in three steps.

1. The annual dose from the radiation leaving the side of the HI-STORM 100S Version B overpack was calculated at the distance desired. Dose value = A.

2. The annual dose from the radiation leaving the top of the HI-STORM 100S Version B overpack was calculated at the distance desired. Dose value = B.

3. The annual dose from the radiation leaving the side of a HI-STORM 100S Version B overpack, when it is behind another cask, was calculated at the distance desired. The casks have an assumed 15-foot pitch. Dose value = C.

The doses calculated in the steps above are listed in Table 5.4.7 for the bounding burnup and cooling time of 60,000 MWD/MTU and 3-year cooling. Using these values, the annual dose (at the center of the long side) from an arbitrary 2 by Z array of HI-STORM 100S Version B overpacks can easily be calculated. The following formula describes the method.

Z = number of casks along long side

Dose = ZA + 2ZB + ZC

As an example, the dose from a 2x3 array at 450 meters is presented.

1. The annual dose from the side of a single cask: Dose A = 6.81
2. The annual dose from the top of a single cask: Dose B = 1.78E-2
3. The annual dose from the side of a cask positioned behind another cask: Dose C = 1.36

Using the formula shown above (Z=3), the total dose at 450 meters from a 2x3 array of HI-STORM overpacks is 24.62 mrem/year, assuming a 8760 hour occupancy.

An important point to notice here is that the dose from the side of the back row of casks is approximately 16 % of the total dose. This is a significant contribution and one that would probably not be accounted for properly by simpler methods of analysis.

The results for various typical arrays of HI-STORM overpacks can be found in Section 5.1. While the off-site dose analyses were performed for typical arrays of casks containing design basis fuel, compliance with the requirements of 10CFR72.104(a) can only be demonstrated on a site-specific basis. Therefore, a site-specific evaluation of dose at the controlled area boundary must be performed for each ISFSI in accordance with 10CFR72.212. The site-specific evaluation will consider the site-specific characteristics (such as exposure duration and the number of casks deployed), dose from other portions of the facility and the specifics of the fuel being stored (burnup and cooling time).

### 5.4.4 Stainless Steel Clad Fuel Evaluation

Table 5.4.8 presents the dose rates at the center of the HI-STORM 100 overpack, adjacent and at one meter distance, from the stainless steel clad fuel. These dose rates, when compared to Tables 5.1.1 through 5.1.6, are similar to the dose rates from the design basis zircaloy clad fuel, indicating that these fuel assemblies are acceptable for storage.

As described in Section 5.2.3, it would be incorrect to compare the total source strength from the stainless steel clad fuel assemblies to the source strength from the design basis zircaloy clad fuel assemblies since these assemblies do not have the same active fuel length and since there is a significant gamma source from Cobalt-60 activation in the stainless steel. Therefore it is necessary to calculate the dose rates from the stainless steel clad fuel and compare them to the dose rates from the zircaloy clad fuel. In calculating the dose rates, the source term for the stainless steel fuel was calculated with an artificial active fuel length of 144 inches to permit a simple comparison of dose rates from stainless steel clad fuel and zircaloy clad fuel at the center of the HI-STORM 100 overpack. Since the true active fuel length is shorter than 144 inches and since the end fitting masses of the stainless steel clad fuel are assumed to be identical to the end fitting masses of the zircaloy clad fuel, the dose rates at the other locations on the overpack are bounded by the dose rates from the design basis zircaloy clad fuel, and therefore, no additional dose rates are presented.

### 5.4.5 Mixed Oxide Fuel Evaluation

The source terms calculated for the Dresden 1 GE 6x6 MOX fuel assemblies can be compared to the source terms for the BWR design basis zircaloy clad fuel assembly (GE 7x7) which demonstrates that the MOX fuel source terms are bounded by the design basis source terms and no additional shielding analysis is needed.

Since the active fuel length of the MOX fuel assemblies is shorter than the active fuel length of the design basis fuel, the source terms must be compared on a per inch basis. Dividing the total fuel gamma source for the MOX fuel in Table 5.2.22 by the 110 inch active fuel height provides a gamma source per inch of 2.36E+12 photons/s. Dividing the total neutron source for the MOX fuel assemblies in Table 5.2.23 by 110 inches provides a neutron source strength per inch of 3.06E+5 neutrons/s. These values are both bounded by the BWR design basis fuel gamma source per inch and neutron source per inch values of 1.08E+13 photons/s and 9.17E+5 neutrons/s for 40,000 MWD/MTU and 5 year cooling. These BWR design basis values were calculated by dividing the total source strengths for 40,000 MWD/MTU and 5 year cooling by the active fuel length of 144 inches. This comparison shows that the MOX fuel source terms are bound by the design basis source terms. Therefore, no explicit analysis of dose rates is provided for MOX fuel.

Since the MOX fuel assemblies are Dresden Unit 1 6x6 assemblies, they can also be considered as damaged fuel. Using the same methodology as described in Section 5.4.2.1, the source term for the MOX fuel is calculated on a per inch basis assuming a post accident rubble height of 80 inches. The resulting gamma and neutron source strengths are 3.25E+12 photons/s and 4.21E+5 neutrons/s. These values are also bounded by the design basis fuel gamma source per inch and neutron source per inch. Therefore, no explicit analysis of dose rates is provided for MOX fuel in a post accident configuration.

### 5.4.6 Non-Fuel Hardware

As discussed in Section 5.2.4, non-fuel hardware in the form of BPRAs, TPDs, CRAs, and APSRs are permitted for storage, integral with a PWR fuel assembly, in the HI-STORM 100 System. Since each of these devices occupy the same location within an assembly (i.e., the guide tubes), only one of these devices will be present in a given assembly. ITTRs, which are installed after core discharge and do not contain radioactive material, may also be stored in the assembly. BPRAs, TPDs, and ITTRs are authorized for unrestricted storage in an MPC. The CRAs are restricted to the center twelve locations in an MPC while the APSRs are restricted to the center four locations in the MPC-24, MPC-24E, MPC-24EF and the center twelve locations in the MPC-32. The calculation of the source term and a description of the bounding fuel devices was provided in Section 5.2.4. The dose rate due to BPRAs and TPDs being stored in a fuel assembly was explicitly calculated. Table 5.4.15 provides the dose rates at various locations on the surface and one meter from the 100-ton HI-TRAC due to the BPRAs and TPDs for the MPC-24 and MPC-32. These results were added to the totals in the other table to provide the total dose rate with BPRAs. Table 5.4.15 indicates that the dose rates from BPRAs bound the dose rates from TPDs.

As discussed in Section 5.2.4, two different configurations were analyzed for CRAs and three different configurations were analyzed for APSRs. The dose rate due to CRAs and APSRs was explicitly calculated for dose locations around the 100-ton HI-TRAC. Tables 5.4.16 and 5.4.17 provide the results for the different configurations of CRAs and APSRs, respectively, in the MPC-24 and MPC-32. These results indicate the dose rate on the radial surfaces of the overpack due to the storage of these devices is less than the dose rate from BPRAs (except for the surface dose rate at the bottom, where the value for the CRA is comparable to or higher than the value from the BPRA, depending on the CRA configuration) and the dose rate out the top of the overpack is essentially 0. The latter is due to the fact that CRAs and APSRs do not achieve significant activation in the upper portion of the devices due to the manner in which they are utilized during normal reactor operations. In contrast, the dose rate out the bottom of the overpack is substantial due to these devices. However, these dose rates occur in an area (below the pool lid and transfer doors) which is not normally occupied. Therefore, even though the dose rates calculated (using a very conservative source term evaluation) are very high, they do not pose a risk from an operations perspective because they are localized in nature. Section 5.1.1 provides additional discussion on the acceptability of the relatively high localized doses on the bottom of the HI-TRACs.

It has to be noted that when twelve CRAs or APSRs are placed in a basket, not all of them are shielded equally well: the components placed in the center four locations have a better shielding than the eight components placed around them. The dose contribution per component will therefore be lower for components placed in the center four locations. It is therefore recommended from an ALARA perspective to minimize the number of CRAs and APSRs per basket if possible, and place the components close to the center of the basket.

### 5.4.7 Dresden Unit 1 Antimony-Beryllium Neutron Sources

Dresden Unit 1 has antimony-beryllium neutron sources which are placed in the water rod location of their fuel assemblies. These sources are steel rods which contain a cylindrical antimony-beryllium source which is 77.25 inches in length. The steel rod is approximately 95 inches in length. Information obtained from Dresden Unit 1 characterizes these sources in the following manner: "About one-quarter pound of beryllium will be employed as a special neutron source material. The beryllium produces neutrons upon gamma irradiation. The gamma rays for the source at initial start-up will be provided by neutron-activated antimony (about 865 curies). The source strength is approximately 1E+8 neutrons/second."

As stated above, beryllium produces neutrons through gamma irradiation and in this particular case antimony is used as the gamma source. The threshold gamma energy for producing neutrons from beryllium is 1.666 MeV. The outgoing neutron energy increases as the incident gamma energy increases. Sb-124, which decays by Beta decay with a half life of 60.2 days, produces a gamma of energy 1.69 MeV which is just energetic enough to produce a neutron from beryllium. Approximately 54% of the Beta decays for Sb-124 produce gammas with energies greater than or equal to 1.69 MeV. Therefore, the neutron production rate in the neutron source can be specified as 5.8E-6 neutrons per gamma (1E+8/865/3.7E+10/0.54) with energy greater than 1.666 MeV or 1.16E+5 neutrons/curie (1E+8/865) of Sb-124.

With the short half life of 60.2 days all of the initial Sb-124 is decayed and any Sb-124 that was produced while the neutron source was in the reactor is also decayed since these neutron sources are assumed to have the same minimum cooling time as the Dresden 1 fuel assemblies (array classes 6x6A, 6x6B, 6x6C, and 8x8A) of 18 years. Therefore, there are only two possible gamma sources which can produce neutrons from this antimony-beryllium source. The first is the gammas from the decay of fission products in the fuel assemblies in the MPC. The second gamma source is from Sb-124 which is being produced in the MPC from neutron activation from neutrons from the decay of fission products.

MCNP calculations were performed to determine the gamma source as a result of decay gammas from fuel assemblies and Sb-124 activation. The calculations explicitly modeled the 6x6 fuel assembly described in Table 5.2.2. A single fuel rod was removed and replaced by a guide tube. In order to determine the amount of Sb-124 that is being activated from neutrons in the MPC it was necessary to estimate the amount of antimony in the neutron source. The O.D. of the source was assumed to be the I.D. of the steel rod encasing the source (0.345 in.). The length of the source is 77.25 inches. The beryllium is assumed to be annular in shape encompassing the antimony. Using the assumed O.D. of the beryllium and the mass and length, the I.D. of the beryllium was calculated to be 0.24 inches. The antimony is assumed to be a solid cylinder with an O.D. equal to the I.D. of the beryllium. These assumptions are conservative since the antimony and beryllium are probably encased in another material which would reduce the mass of antimony. A larger mass of antimony is conservative since the calculated activity of Sb-124 is directly proportional to the initial mass of antimony.

The number of gammas from fuel assemblies with energies greater than 1.666 MeV entering the 77.25 inch long neutron source was calculated to be 1.04E+8 gammas/sec which would produce a neutron source of 603.2 neutrons/sec (1.04E+8 * 5.8E-6). The steady state amount of Sb-124 activated in the antimony was calculated to be 39.9 curies. This activity level would produce a neutron source of 4.63E+6 neutrons/sec (39.9 * 1.16E+5) or 6.0E+4 neutrons/sec/inch (4.63E+6/77.25). These calculations conservatively neglect the reduction in antimony and beryllium which would have occurred while the neutron sources were in the core and being irradiated at full reactor power.

Since this is a localized source (77.25 inches in length) it is appropriate to compare the neutron source per inch from the design basis Dresden Unit 1 fuel assembly, 6x6, containing an Sb-Be neutron source to the design basis fuel neutron source per inch. This comparison, presented in Table 5.4.18, demonstrates that a Dresden Unit 1 fuel assembly containing an Sb-Be neutron source is bounded by the design basis fuel.

As stated above, the Sb-Be source is encased in a steel rod. Therefore, the gamma source from the activation of the steel was considered assuming a burnup of 120,000 MWD/MTU which is the maximum burnup assuming the Sb-Be source was in the reactor for the entire 18 year life of Dresden Unit 1. The cooling time assumed was 18 years which is the minimum cooling time for Dresden Unit 1 fuel. The source from the steel was bounded by the design basis fuel assembly. In conclusion, storage of a Dresden Unit 1 Sb-Be neutron source in a Dresden Unit 1 fuel assembly is acceptable and bounded by the current analysis.

### 5.4.8 Thoria Rod Canister

Based on a comparison of the gamma spectra from Tables 5.2.37 and 5.2.7 for the thoria rod canister and design basis 6x6 fuel assembly, respectively, it is difficult to determine if the thoria rods will be bounded by the 6x6 fuel assemblies. However, it is obvious that the neutron spectra from the 6x6, Table 5.2.18, bounds the thoria rod neutron spectra, Table 5.2.38, with a significant margin. In order to demonstrate that the gamma spectrum from the single thoria rod canister is bounded by the gamma spectrum from the design basis 6x6 fuel assembly, the gamma dose rate on the outer radial surface of the 100-ton HI-TRAC and the HI-STORM overpack was estimated conservatively assuming an MPC full of thoria rod canisters. This gamma dose rate was compared to an estimate of the dose rate from an MPC full of design basis 6x6 fuel assemblies. The gamma dose rate from the 6x6 fuel was higher for the 100-ton HI-TRAC and only 15% lower for the HI-STORM overpack than the dose rate from an MPC full of thoria rod canisters. This in conjunction with the significant margin in neutron spectrum and the fact that there is only one thoria rod canister clearly demonstrates that the thoria rod canister is acceptable for storage in the MPC-68 or the MPC-68F.

### 5.4.9 Regionalized Loading Dose Rate Evaluation

Section 2.1.9 describes the regionalized loading scheme available in the HI-STORM 100 system. Depending on the choice of X (the ratio of inner region assembly heat load to outer region assembly heat load), higher heat load fuel (higher burnup and shorter cooling time) may be placed in either region 1 or region 2. If X is greater than 1, the higher heat load fuel is placed in region 1 and shielded by lower heat load fuel in region 2. This configuration produces the lowest dose rates since the older colder fuel is being used as shielding for the younger hotter fuel. If X is less than 1, then the younger hotter fuel is placed on the periphery of the basket and the older colder fuel is placed on the interior of the basket. This configuration will result in higher radial dose rates than for configurations with X greater than or equal to 1. In order to perform a bounding shielding analysis, the burnup and cooling time combinations listed in Section 5.1 were chosen to bound all values of X. All fuel assemblies in an MPC were assumed to have the same burnup and cooling time in the shielding analysis. This approach results in dose rates calculated in this chapter that bound all allowable regionalized and uniform loading burnup and cooling time combinations.

Table 5.4.1

FLUX-TO-DOSE CONVERSION FACTORS
(FROM [5.4.1])

| Gamma Energy (MeV) | (rem/hr)/ (photon/cm$^2$-s) |
|---|---|
| 0.01 | 3.96E-06 |
| 0.03 | 5.82E-07 |
| 0.05 | 2.90E-07 |
| 0.07 | 2.58E-07 |
| 0.1 | 2.83E-07 |
| 0.15 | 3.79E-07 |
| 0.2 | 5.01E-07 |
| 0.25 | 6.31E-07 |
| 0.3 | 7.59E-07 |
| 0.35 | 8.78E-07 |
| 0.4 | 9.85E-07 |
| 0.45 | 1.08E-06 |
| 0.5 | 1.17E-06 |
| 0.55 | 1.27E-06 |
| 0.6 | 1.36E-06 |
| 0.65 | 1.44E-06 |
| 0.7 | 1.52E-06 |
| 0.8 | 1.68E-06 |
| 1.0 | 1.98E-06 |
| 1.4 | 2.51E-06 |
| 1.8 | 2.99E-06 |
| 2.2 | 3.42E-06 |

Table 5.4.1 (continued)

FLUX-TO-DOSE CONVERSION FACTORS
(FROM [5.4.1])

| **Gamma Energy (MeV)** | **(rem/hr)/ (photon/cm$^2$-s)** |
|---|---|
| 2.6 | 3.82E-06 |
| 2.8 | 4.01E-06 |
| 3.25 | 4.41E-06 |
| 3.75 | 4.83E-06 |
| 4.25 | 5.23E-06 |
| 4.75 | 5.60E-06 |
| 5.0 | 5.80E-06 |
| 5.25 | 6.01E-06 |
| 5.75 | 6.37E-06 |
| 6.25 | 6.74E-06 |
| 6.75 | 7.11E-06 |
| 7.5 | 7.66E-06 |
| 9.0 | 8.77E-06 |
| 11.0 | 1.03E-05 |
| 13.0 | 1.18E-05 |
| 15.0 | 1.33E-05 |

Table 5.4.1 (continued)

FLUX-TO-DOSE CONVERSION FACTORS
(FROM [5.4.1])

| Neutron Energy (MeV) | Quality Factor | $(rem/hr)^{\dagger}/(n/cm^2\text{-}s)$ |
|---|---|---|
| 2.5E-8 | 2.0 | 3.67E-6 |
| 1.0E-7 | 2.0 | 3.67E-6 |
| 1.0E-6 | 2.0 | 4.46E-6 |
| 1.0E-5 | 2.0 | 4.54E-6 |
| 1.0E-4 | 2.0 | 4.18E-6 |
| 1.0E-3 | 2.0 | 3.76E-6 |
| 1.0E-2 | 2.5 | 3.56E-6 |
| 0.1 | 7.5 | 2.17E-5 |
| 0.5 | 11.0 | 9.26E-5 |
| 1.0 | 11.0 | 1.32E-4 |
| 2.5 | 9.0 | 1.25E-4 |
| 5.0 | 8.0 | 1.56E-4 |
| 7.0 | 7.0 | 1.47E-4 |
| 10.0 | 6.5 | 1.47E-4 |
| 14.0 | 7.5 | 2.08E-4 |
| 20.0 | 8.0 | 2.27E-4 |

† Includes the Quality Factor.

Table 5.4.2

DOSE RATES FOR THE 100-TON HI-TRAC FOR THE FULLY FLOODED MPC CONDITION WITH AN EMPTY NEUTRON SHIELD
MPC-24 DESIGN BASIS ZIRCALOY CLAD FUEL AT
60,000 MWD/MTU AND 3-YEAR COOLING

| Dose Point† Location | Fuel Gammas†† (mrem/hr) | $^{60}$Co Gammas (mrem/hr) | Neutrons (mrem/hr) | Totals (mrem/hr) | Totals with BPRAs (mrem/hr) |
|---|---|---|---|---|---|
| **ADJACENT TO THE 100-TON HI-TRAC** | | | | | |
| 1 | 44.75 | 370.31 | 55.57 | 470.63 | 473.46 |
| 2 | 2649.74 | 0.79 | 810.25 | 3460.78 | 3664.65 |
| 3 | 9.98 | 484.21 | 11.35 | 505.54 | 637.13 |
| 4 | 39.13 | 367.92 | 2.10 | 409.15 | 511.41 |
| 5 (pool lid) | 126.99 | 2071.23 | 5.62 | 2203.84††† | 2214.03 |
| **ONE METER FROM THE 100-TON HI-TRAC** | | | | | |
| 1 | 351.97 | 74.73 | 115.53 | 542.22 | 568.65 |
| 2 | 1171.07 | 7.08 | 265.57 | 1443.73 | 1533.97 |
| 3 | 140.14 | 117.78 | 47.64 | 305.55 | 349.87 |

Note: MPC internal water level is 10 inches below the MPC lid.

† Refer to Figures 5.1.2 and 5.1.4.

†† Gammas generated by neutron capture are included with fuel gammas.

††† Cited dose rates correspond to the cask center. Figures 5.1.6, 5.1.7, and 5.1.11 illustrate the substantial reduction in dose rates moving radially outward from the axial center of the HI-TRAC.

Table 5.4.3

DOSE RATES FOR THE 100-TON HI-TRAC FOR THE FULLY FLOODED MPC CONDITION WITH A FULL NEUTRON SHIELD
MPC-24 DESIGN BASIS ZIRCALOY CLAD FUEL AT
60,000 MWD/MTU AND 3-YEAR COOLING

| **Dose Point† Location** | **Fuel Gammas†† (mrem/hr)** | **$^{60}$Co Gammas (mrem/hr)** | **Neutrons (mrem/hr)** | **Totals (mrem/hr)** | **Totals with BPRAs (mrem/hr)** |
|---|---|---|---|---|---|
| **ADJACENT TO THE 100-TON HI-TRAC** | | | | | |
| 1 | 34.56 | 318.37 | 6.08 | 359.01 | 361.11 |
| 2 | 1565.21 | 0.50 | 53.06 | 1618.77 | 1734.33 |
| 3 | 6.38 | 483.03 | 1.07 | 490.48 | 621.41 |
| 4 | 39.09 | 367.91 | 1.93 | 408.92 | 511.18 |
| 5 (pool lid) | 126.63 | 2071.47 | 5.41 | 2203.51††† | 2213.68 |
| **ONE METER FROM THE 100-TON HI-TRAC** | | | | | |
| 1 | 202.31 | 49.47 | 7.09 | 258.86 | 273.65 |
| 2 | 681.82 | 3.93 | 19.97 | 705.72 | 756.28 |
| 3 | 80.54 | 81.26 | 2.41 | 164.21 | 193.09 |

Note: MPC internal water level is 10 inches below the MPC lid.

† Refer to Figures 5.1.2 and 5.1.4.

†† Gammas generated by neutron capture are included with fuel gammas.

††† Cited dose rates correspond to the cask center. Figures 5.1.6, 5.1.7, and 5.1.11 illustrate the substantial reduction in dose rates moving radially outward from the axial center of the HI-TRAC.

Table 5.4.4

[INTENTIONALLY DELETED]

Table 5.4.5

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Table 5.4.6

ANNUAL DOSE AT 350 METERS FROM A SINGLE
HI-STORM 100S VERSION B OVERPACK WITH AN MPC-24 WITH DESIGN BASIS
ZIRCALOY CLAD FUEL†

| Dose Component | 60,000 MWD/MTU 3-Year Cooling (mrem/yr) |
|---|---|
| Fuel gammas†† | 17.54 |
| $^{60}Co$ Gammas | 1.18 |
| Neutrons | 0.54 |
| Total | 19.26 |

† 8760 hour annual occupancy is assumed.

†† Gammas generated by neutron capture are included with fuel gammas.

Table 5.4.7

DOSE VALUES USED IN CALCULATING ANNUAL DOSE FROM VARIOUS HI-STORM 100S VERSION B ISFSI CONFIGURATIONS 60,000 MWD/MTU AND 3-YEAR COOLING ZIRCALOY CLAD FUEL†

| **Distance** | **A Side of Overpack (mrem/yr)** | **B Top of Overpack (mrem/yr)** | **C Side of Shielded Overpack (mrem/yr)** |
|---|---|---|---|
| 100 meters | 880.47 | 2.79 | 176.09 |
| 150 meters | 299.26 | 1.04 | 59.85 |
| 200 meters | 129.22 | 0.48 | 25.84 |
| 250 meters | 64.50 | 0.22 | 12.90 |
| 300 meters | 34.11 | 0.12 | 6.82 |
| 350 meters | 19.20 | 6.06E-02 | 3.84 |
| 400 meters | 11.26 | 3.25E-02 | 2.25 |
| 450 meters | 6.81 | 1.78E-02 | 1.36 |
| 500 meters | 4.22 | 1.07E-02 | 0.84 |
| 550 meters | 2.71 | 6.94E-03 | 0.54 |
| 600 meters | 1.74 | 4.13E-03 | 0.35 |

† 8760 hour annual occupancy is assumed.

Table 5.4.8

DOSE RATES AT THE CENTERLINE OF THE OVERPACK FOR DESIGN BASIS STAINLESS STEEL CLAD FUEL WITHOUT BPRAs

| Dose Point† Location | Fuel Gammas†† (mrem/hr) | $^{60}Co$ Gammas (mrem/hr) | Neutrons (mrem/hr) | Totals (mrem/hr) |
|---|---|---|---|---|
| **MPC-24 (40,000 MWD/MTU AND 8-YEAR COOLING)** | | | | |
| 2 (Adjacent) | 36.97 | 0.02 | 1.11 | 38.10 |
| 2 (One Meter) | 18.76 | 0.17 | 0.50 | 19.43 |
| **MPC-32 (40,000 MWD/MTU AND 9-YEAR COOLING)** | | | | |
| 2 (Adjacent) | 37.58 | 0.00 | 1.49 | 39.08 |
| 2 (One Meter) | 18.74 | 0.25 | 0.58 | 19.57 |
| **MPC-68 (22,500 MWD/MTU AND 10-YEAR COOLING)** | | | | |
| 2 (Adjacent) | 17.79 | 0.01 | 0.10 | 17.90 |
| 2 (One Meter) | 8.98 | 0.13 | 0.04 | 9.15 |

† Refer to Figure 5.1.1.

†† Gammas generated by neutron capture are included with fuel gammas.

Table 5.4.9

DOSE RATES FROM THE 100-TON HI-TRAC FOR NORMAL CONDITIONS
MPC-68 DESIGN BASIS ZIRCALOY CLAD FUEL AT
50,000 MWD/MTU AND 3-YEAR COOLING

| Dose Point Location | Fuel Gammas (mrem/hr) | (n,γ) Gammas (mrem/hr) | $^{60}$Co Gammas (mrem/hr) | Neutrons (mrem/hr) | Totals (mrem/hr) |
|---|---|---|---|---|---|
| **ADJACENT TO THE 100-TON HI-TRAC** | | | | | |
| 1 | 118.31 | 25.51 | 1260.91 | 340.66 | 1745.39 |
| 2 | 2638.99 | 125.79 | 0.80 | 227.40 | 2992.98 |
| 3 | 7.38 | 2.57 | 833.34 | 147.88 | 991.17 |
| 3 (temp) | 4.33 | 4.53 | 408.34 | 2.70 | 419.89 |
| 4 | 25.26 | 0.90 | 494.35 | 195.30 | 715.82 |
| 4 (outer) | 7.49 | 0.70 | 132.37 | 124.46 | 265.02 |
| 5 (pool lid) | 351.88 | 31.12 | 5646.34 | 2040.15 | 8069.50 |
| 5 (transfer lid) | 509.02 | 1.43 | 8507.35 | 1288.83 | 10306.63 |
| 5 (t-outer) | 187.09 | 0.61 | 750.08 | 479.11 | 1416.90 |
| **ONE METER FROM THE 100-TON HI-TRAC** | | | | | |
| 1 | 359.24 | 15.46 | 117.76 | 60.21 | 552.67 |
| 2 | 1134.59 | 35.59 | 8.69 | 78.41 | 1257.27 |
| 3 | 88.49 | 6.19 | 178.43 | 16.85 | 289.97 |
| 3 (temp) | 88.38 | 6.52 | 142.94 | 8.14 | 245.97 |
| 4 | 7.94 | 0.52 | 151.01 | 47.61 | 207.07 |
| 5 (transfer lid) | 260.67 | 0.62 | 3774.45 | 344.08 | 4379.82 |
| 5 (t-outer) | 32.63 | 1.12 | 318.78 | 97.39 | 449.92 |

Notes:

- Refer to Figures 5.1.2 and 5.1.4 for dose locations.
- Dose location 3(temp) represents dose location 3 with temporary shielding installed.
- Dose location 4(outer) is the radial segment at dose location 4 which is 18-30 inches from the center of the overpack.
- Dose location 5 (t-outer) is the radial segment at dose location 5 (transfer lid) which is 30-42 and 54-66 inches from the center of the lid for the adjacent and one meter locations, respectively. The inner radius of the HI-TRAC is 34.375 in. and the outer radius of the water jacket is 44.375 in.
- Dose rate based on no water within the MPC. For the majority of the duration that the HI-TRAC pool lid is installed, the MPC cavity will be flooded with water. The water within the MPC greatly reduces the dose rate.

Table 5.4.10

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Table 5.4.11

DOSE RATES FROM THE 100-TON HI-TRAC FOR NORMAL CONDITIONS
MPC-32 DESIGN BASIS ZIRCALOY CLAD FUEL
45,000 MWD/MTU AND 3-YEAR COOLING

| Dose Point Location | Fuel Gammas (mrem/hr) | (n,γ) Gammas (mrem/hr) | $^{60}$Co Gammas (mrem/hr) | Neutrons (mrem/hr) | Totals (mrem/hr) | Totals with BPRAs (mrem/hr) |
|---|---|---|---|---|---|---|
| **ADJACENT TO THE 100-TON HI-TRAC** | | | | | | |
| 1 | 123.09 | 17.99 | 1134.82 | 253.68 | 1529.57 | 1539.91 |
| 2 | 3059.28 | 77.64 | 1.63 | 145.58 | 3284.12 | 3576.87 |
| 3 | 42.51 | 3.43 | 703.72 | 203.47 | 953.12 | 1178.63 |
| 4 | 102.68 | 1.55 | 527.34 | 253.44 | 885.02 | 1064.21 |
| 4 (outer) | 28.17 | 0.91 | 132.30 | 174.27 | 335.65 | 380.68 |
| 5 (pool) | 745.11 | 26.66 | 6237.41 | 1665.29 | 8674.47 | 8757.27 |
| 5 (transfer) | 1366.50 | 1.04 | 9401.97 | 966.70 | 11736.20 | 11837.01 |
| 5 (t-outer) | 246.52 | 0.48 | 787.00 | 363.83 | 1397.82 | 1418.02 |
| **ONE METER FROM THE 100-TON HI-TRAC** | | | | | | |
| 1 | 407.43 | 10.23 | 168.91 | 42.45 | 629.02 | 667.20 |
| 2 | 1350.21 | 24.30 | 12.79 | 54.21 | 1441.51 | 1571.36 |
| 3 | 176.77 | 5.64 | 144.81 | 19.97 | 347.18 | 414.23 |
| 4 | 31.95 | 0.40 | 157.25 | 63.15 | 252.75 | 305.95 |
| 5 (transfer) | 567.40 | 0.23 | 3723.34 | 260.88 | 4551.86 | 4598.19 |
| 5 (t-outer) | 58.97 | 0.96 | 330.25 | 76.48 | 466.67 | 471.29 |

Notes:

- Refer to Figures 5.1.2 and 5.1.4 for dose locations.
- Dose location 4(outer) is the radial segment at dose location 4 which is 18-30 inches from the center of the overpack.
- Dose location 5 (t-outer) is the radial segment at dose location 5 (transfer lid) which is 30-42 and 54-66 inches from the center of the lid for the adjacent and one meter locations, respectively. The inner radius of the HI-TRAC is 34.375 in. and the outer radius of the water jacket is 44.375 in.
- Dose rate based on no water within the MPC. For the majority of the duration that the HI-TRAC pool lid is installed, the MPC cavity will be flooded with water. The water within the MPC greatly reduces the dose rate.

Table 5.4.12

[INTENTIONALLY DELETED]

Table 5.4.13

DOSE RATES FROM THE 100-TON HI-TRAC FOR ACCIDENT CONDITIONS
WITH FOUR DAMAGED FUEL CONTAINERS
MPC-24 DESIGN BASIS ZIRCALOY CLAD FUEL
60,000 MWD/MTU AND 3-YEAR COOLING
WITHOUT BPRAs

| Dose Point† Location | Fuel Gammas (mrem/hr) | (n,γ) Gammas (mrem/hr) | $^{60}$Co Gammas (mrem/hr) | Neutrons (mrem/hr) | Totals (mrem/hr) |
|---|---|---|---|---|---|
| **ADJACENT TO THE 100-TON HI-TRAC** | | | | | |
| 1 | 162.53 | 40.07 | 958.00 | 607.90 | 1768.50 |
| 2 | 3154.37 | 145.11 | 1.14 | 264.13 | 3564.75 |
| 3 | 47.06 | 9.00 | 528.22 | 583.57 | 1167.85 |
| **ONE METER FROM THE 100-TON HI-TRAC** | | | | | |
| 1 | 449.03 | 20.58 | 142.41 | 92.37 | 704.39 |
| 2 | 1404.60 | 44.91 | 11.27 | 99.48 | 1560.26 |
| 3 | 202.22 | 11.75 | 118.30 | 54.30 | 386.56 |

† Refer to Figures 5.1.2 and 5.1.4.

Table 5.4.14

DOSE RATES FROM THE 100-TON HI-TRAC FOR ACCIDENT CONDITIONS
WITH SIXTEEN DAMAGED FUEL CONTAINERS
MPC-68 DESIGN BASIS ZIRCALOY CLAD FUEL
50,000 MWD/MTU AND 3-YEAR COOLING

| Dose Point† Location | Fuel Gammas (mrem/hr) | (n,γ) Gammas (mrem/hr) | $^{60}$Co Gammas (mrem/hr) | Neutrons (mrem/hr) | Totals (mrem/hr) |
|---|---|---|---|---|---|
| **ADJACENT TO THE 100-TON HI-TRAC** | | | | | |
| 1 | 276.49 | 36.57 | 1260.91 | 629.42 | 2203.39 |
| 2 | 2488.31 | 126.39 | 0.80 | 213.81 | 2829.31 |
| 3 | 9.10 | 5.48 | 833.34 | 324.77 | 1172.69 |
| **ONE METER FROM THE 100-TON HI-TRAC** | | | | | |
| 1 | 417.32 | 19.09 | 117.76 | 90.45 | 644.62 |
| 2 | 1091.56 | 38.82 | 8.69 | 85.73 | 1224.79 |
| 3 | 121.49 | 8.49 | 178.43 | 33.62 | 342.02 |

† Refer to Figures 5.1.2 and 5.1.4.

Table 5.4.15

DOSE RATES DUE TO BPRAs AND TPDs FROM THE 100-TON HI-TRAC FOR NORMAL CONDITIONS

| | MPC-24 | | MPC-32 | |
|---|---|---|---|---|
| **Dose Point Location** | **BPRAs (mrem/hr)** | **TPDs (mrem/hr)** | **BPRAs (mrem/hr)** | **TPDs (mrem/hr)** |
| **ADJACENT TO THE 100-TON HI-TRAC** | | | | |
| 1 | 8.54 | 0.00 | 10.34 | 0.01 |
| 2 | 247.24 | 0.03 | 292.75 | 0.04 |
| 3 | 148.53 | 125.75 | 225.50 | 188.14 |
| 3 (temp) | 68.15 | 56.21 | 93.63 | 77.00 |
| 4 | 124.50 | 106.71 | 179.19 | 156.14 |
| 4 (outer) | 31.33 | 27.12 | 45.02 | 39.33 |
| 5 (pool lid) | 64.77 | 0.00 | 82.79 | 0.01 |
| 5 (transfer lid) | 96.84 | 0.00 | 100.81 | 0.00 |
| 5 (t-outer) | 21.47 | 0.00 | 20.20 | 0.00 |
| **ONE METER FROM THE 100-TON HI-TRAC** | | | | |
| 1 | 32.48 | 0.18 | 38.18 | 0.24 |
| 2 | 109.47 | 1.20 | 129.85 | 1.63 |
| 3 | 49.43 | 38.93 | 67.05 | 55.11 |
| 3 (temp) | 44.57 | 35.01 | 59.32 | 48.95 |
| 4 | 38.57 | 33.37 | 53.20 | 47.19 |
| 5 (transfer lid) | 39.13 | 0.00 | 46.33 | 0.00 |
| 5 (t-outer) | 3.90 | 0.00 | 4.63 | 0.00 |

Notes:

- Refer to Figures 5.1.2 and 5.1.4 for dose locations.
- Dose location 3(temp) represents dose location 3 with temporary shielding installed.
- Dose location 4(outer) is the radial segment at dose location 4 which is 18-30 inches from the center of the overpack.
- Dose location 5 (t-outer) is the radial segment at dose location 5 (transfer lid) which is 30-42 and 54-66 inches from the center of the lid for the adjacent and one meter locations, respectively. The inner radius of the HI-TRAC is 34.375 in. and the outer radius of the water jacket is 44.375 in.
- Dose rate based on no water within the MPC. For the majority of the duration that the HI-TRAC pool lid is installed, the MPC cavity will be flooded with water. The water within the MPC greatly reduces the dose rate.

Table 5.4.16

DOSE RATES DUE TO CRAs FROM THE 100-TON HI-TRAC
FOR NORMAL CONDITIONS

| | MPC-24 | | MPC-32 | |
|---|---|---|---|---|
| **Dose Point Location** | **Config. 1 (mrem/hr)** | **Config. 2 (mrem/hr)** | **Config. 1 (mrem/hr)** | **Config. 2 (mrem/hr)** |
| **ADJACENT TO THE 100-TON HI-TRAC** | | | | |
| 1 | 49.65 | 8.99 | 25.25 | 5.12 |
| 2 | 3.15 | 0.08 | 0.12 | 0.01 |
| 3 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5 (pool lid) | 1061.33 | 213.34 | 1504.83 | 300.86 |
| 5 (transfer lid) | 1846.04 | 349.09 | 2785.92 | 521.49 |
| 5 (t-outer) | 36.32 | 5.82 | 15.21 | 2.76 |
| **ONE METER FROM THE 100-TON HI-TRAC** | | | | |
| 1 | 28.42 | 3.59 | 5.11 | 0.97 |
| 2 | 13.64 | 1.19 | 0.67 | 0.09 |
| 3 | 0.20 | 0.02 | 0.02 | 0.00 |
| 4 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5 (transfer lid) | 545.93 | 100.60 | 638.62 | 119.05 |
| 5 (t-outer) | 29.81 | 5.51 | 30.89 | 5.88 |

Notes:
- Refer to Figures 5.1.2 and 5.1.4 for dose locations.
- Dose location 5 (t-outer) is the radial segment at dose location 5 (transfer lid) which is 30-42 and 54-66 inches from the center of the lid for the adjacent and one meter locations, respectively. The inner radius of the HI-TRAC is 34.375 in. and the outer radius of the water jacket is 44.375 in.
- Dose rate based on no water within the MPC. For the majority of the duration that the HI-TRAC pool lid is installed, the MPC cavity will be flooded with water. The water within the MPC greatly reduces the dose rate.

Table 5.4.17

DOSE RATES DUE TO APSRs FROM THE 100-TON HI-TRAC
FOR NORMAL CONDITIONS

| | MPC-24 | | | MPC-32 | | |
|---|---|---|---|---|---|---|
| **Dose Point Location** | **Config. 1 (mrem/hr)** | **Config. 2 (mrem/hr)** | **Config. 3 (mrem/hr)** | **Config. 1 (mrem/hr)** | **Config. 2 (mrem/hr)** | **Config. 3 (mrem/hr)** |
| **ADJACENT TO THE 100-TON HI-TRAC** | | | | | | |
| 1 | 12.42 | 2.35 | 12.25 | 57.80 | 11.73 | 56.80 |
| 2 | 0.21 | 0.01 | 9.12 | 0.29 | 0.02 | 17.70 |
| 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 |
| 5 (pool lid) | 1996.57 | 371.98 | 1941.51 | 3243.57 | 645.11 | 3698.77 |
| 5 (transfer) | 3021.08 | 572.85 | 2994.54 | 5522.01 | 1035.17 | 5664.10 |
| 5 (t-outer) | 3.41 | 0.54 | 3.57 | 33.25 | 5.97 | 31.46 |
| **ONE METER FROM THE 100-TON HI-TRAC** | | | | | | |
| 1 | 2.73 | 0.46 | 3.49 | 11.69 | 2.22 | 11.36 |
| 2 | 0.61 | 0.07 | 3.31 | 1.55 | 0.20 | 6.53 |
| 3 | 0.02 | 0.00 | 0.04 | 0.05 | 0.01 | 0.08 |
| 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 |
| 5 (transfer) | 458.06 | 84.81 | 444.44 | 1288.04 | 240.05 | 1211.44 |
| 5 (t-outer) | 17.11 | 3.19 | 17.36 | 64.18 | 12.16 | 62.83 |

Notes:
- Refer to Figures 5.1.2 and 5.1.4 for dose locations.
- Dose location 5 (t-outer) is the radial segment at dose location 5 (transfer lid) which is 30-42 and 54-66 inches from the center of the lid for the adjacent and one meter locations, respectively. The inner radius of the HI-TRAC is 34.375 in. and the outer radius of the water jacket is 44.375 in.
- Dose rate based on no water within the MPC. For the majority of the duration that the HI-TRAC pool lid is installed, the MPC cavity will be flooded with water. The water within the MPC greatly reduces the dose rate.

Table 5.4.18

COMPARISON OF NEUTRON SOURCE PER INCH PER SECOND FOR DESIGN BASIS 7X7 FUEL AND DESIGN BASIS DRESDEN UNIT 1 FUEL

| **Assembly** | **Active fuel length (inch)** | **Neutrons per sec per inch** | **Neutrons per sec per inch with Sb-Be source** | **Reference for neutrons per sec per inch** |
|---|---|---|---|---|
| 7x7 design basis | 144 | 9.17E+5 | N/A | 40 GWD/MTU and 5 year cooling |
| 6x6 design basis | 110 | 2.0E+5 | 2.6E+5 | Table 5.2.18 |
| 6x6 design basis MOX | 110 | 3.06E+5 | 3.66E+5 | Table 5.2.23 |

Table 5.4.19

DOSE RATES FROM THE HI-TRAC 100D FOR NORMAL CONDITIONS
MPC-32 DESIGN BASIS ZIRCALOY CLAD FUEL
35,000 MWD/MTU AND 3-YEAR COOLING

| Dose Point Location | Fuel Gammas (mrem/hr) | (n,γ) Gammas (mrem/hr) | $^{60}$Co Gammas (mrem/hr) | Neutrons (mrem/hr) | Totals (mrem/hr) | Totals with BPRAs (mrem/hr) |
|---|---|---|---|---|---|---|
| **ADJACENT TO THE 100-TON HI-TRAC** | | | | | | |
| 1 | 156.55 | 10.12 | 1558.18 | 77.72 | 1802.56 | 1818.78 |
| 2 | 2575.94 | 34.87 | 1.88 | 63.16 | 2675.84 | 2972.05 |
| 3 | 36.72 | 1.51 | 596.76 | 89.80 | 724.78 | 950.60 |
| **ONE METER FROM THE 100-TON HI-TRAC** | | | | | | |
| 1 | 349.37 | 4.72 | 192.55 | 16.34 | 562.97 | 602.58 |
| 2 | 1120.77 | 10.83 | 12.08 | 22.98 | 1166.66 | 1297.14 |
| 3 | 146.00 | 2.46 | 124.89 | 8.66 | 282.02 | 350.18 |

Notes:

- Refer to Figure 5.1.4 for dose locations.
- Dose rate based on no water within the MPC. For the majority of the duration that the HI-TRAC pool lid is installed, the MPC cavity will be flooded with water. The water within the MPC greatly reduces the dose rate.

## 5.5 REGULATORY COMPLIANCE

Chapters 1 and 2 and this chapter of this FSAR describe in detail the shielding structures, systems, and components (SSCs) important to safety.

This chapter has evaluated these shielding SSCs important to safety and has assessed the impact on health and safety resulting from operation of an independent spent fuel storage installation (ISFSI) utilizing the HI-STORM 100 System.

It has been shown that the design of the shielding system of the HI-STORM 100 System is in compliance with 10CFR72 and that the applicable design and acceptance criteria including 10CFR20 have been satisfied. Thus, this shielding evaluation provides reasonable assurance that the HI-STORM 100 System will allow safe storage of spent fuel.

## 5.6 REFERENCES


[5.1.1] J.F. Briesmeister, Ed., "MCNP - A General Monte Carlo N-Particle Transport Code, Version 4A." Los Alamos National Laboratory, LA-12625-M (1993).

[5.1.2] O.W. Hermann, C.V. Parks, "SAS2H: A Coupled One-Dimensional Depletion and Shielding Analysis Module," NUREG/CR-0200, Revision 5, (ORNL/NUREG/CSD-2/V2/R5), Oak Ridge National Laboratory, September 1995.

[5.1.3] O.W. Hermann, R.M. Westfall, "ORIGEN-S: SCALE System Module to Calculate Fuel Depletion, Actinide Transmutation, Fission Product Buildup and Decay, and Associated Radiation Source Terms," NUREG/CR-0200, Revision 5, (ORNL/NUREG/CSD-2/V2/R5), Oak Ridge National Laboratory, September 1995.

[5.2.1] NUREG-1536, SRP for Dry Cask Storage Systems, USNRC, Washington, DC, January 1997.

[5.2.2] A.G. Croff, M.A. Bjerke, G.W. Morrison, L.M. Petrie, "Revised Uranium-Plutonium Cycle PWR and BWR Models for the ORIGEN Computer Code," ORNL/TM-6051, Oak Ridge National Laboratory, September 1978.

[5.2.3] A. Luksic, "Spent Fuel Assembly Hardware: Characterization and 10CFR 61 Classification for Waste Disposal," PNL-6906-vol. 1, Pacific Northwest Laboratory, June 1989.

[5.2.4] J.W. Roddy et al., "Physical and Decay Characteristics of Commercial LWR Spent Fuel," ORNL/TM-9591/V1&R1, Oak Ridge National Laboratory, January 1996.

[5.2.5] "Characteristics of Spent Fuel, High Level Waste, and Other Radioactive Wastes Which May Require Long-Term Isolation," DOE/RW-0184, U.S. Department of Energy, December 1987.

[5.2.6] "Spent Nuclear Fuel Discharges from U.S. Reactors 1994," SR/CNEAF/96-01, Energy Information Administration, U.S. Department of Energy, February 1996.

[5.2.7] "Characteristics Database System LWR Assemblies Database," DOE/RW-0184-R1, U.S. Department of Energy, July 1992.

[5.2.8] O. W. Hermann, et al., "Validation of the Scale System for PWR Spent Fuel Isotopic Composition Analyses," ORNL/TM-12667, Oak Ridge National Laboratory, March 1995.

[5.2.9] M. D. DeHart and O. W. Hermann, "An Extension of the Validation of SCALE (SAS2H) Isotopic Predictions for PWR Spent Fuel," ORNL/TM-13317, Oak Ridge National Laboratory, September 1996.

[5.2.10] O. W. Hermann and M. D. DeHart, "Validation of SCALE (SAS2H) Isotopic Predictions for BWR Spent Fuel," ORNL/TM-13315, Oak Ridge National Laboratory, September 1998.

[5.2.11] "Summary Report of SNF Isotopic Comparisons for the Disposal Criticality Analysis Methodology," B00000000-01717-5705-00077 REV 00, CRWMS M&O, September 1997.

[5.2.12] "Isotopic and Criticality Validation of PWR Actinide-Only Burnup Credit," DOE/RW-0497, U.S. Department of Energy, May 1997.

[5.2.13] B. D. Murphy, "Prediction of the Isotopic Composition of $UO_2$ Fuel from a BWR: Analysis of the DU1 Sample from the Dodewaard Reactor," ORNL/TM-13687, Oak Ridge National Laboratory, October 1998.

[5.2.14] O. W. Hermann, et al., "Technical Support for a Proposed Decay Heat Guide Using SAS2H/ORIGEN-S Data," NUREG/CR-5625, ORNL-6698, Oak Ridge National Laboratory, September 1994.

[5.2.15] C. E. Sanders, I. C. Gauld, "Isotopic Analysis of High-Burnup PWR Spent Fuel Samples from the Takahama-3 Reactor," NUREG/CR-6798, ORNL/TM-2001/259, Oak Ridge National Laboratory, January 2003.

[5.2.16] T. Williams and C. Kelley, "gnuplot An Interactive Plotting Program", Version 3.7, December 1998.

[5.4.1] "American National Standard Neutron and Gamma-Ray Flux-to-Dose Rate Factors", ANSI/ANS-6.1.1-1977.

[5.4.2] D. J. Whalen, et al., "MCNP: Photon Benchmark Problems," LA-12196, Los Alamos National Laboratory, September 1991.

[5.4.3] D. J. Whalen, et al., "MCNP: Neutron Benchmark Problems," LA-12212, Los Alamos National Laboratory, November 1991.

[5.4.4] J. C. Wagner, et al., "MCNP: Criticality Safety Benchmark Problems," LA-12415, Los Alamos National Laboratory, October 1992.

[5.4.5] S. E. Turner, "Uncertainty Analysis - Axial Burnup Distribution Effects," presented in "Proceedings of a Workshop on the Use of Burnup Credit in Spent Fuel Transport Casks," SAND-89-0018, Sandia National Laboratory, Oct. 1989.

[5.4.6] Commonwealth Edison Company, Letter No. NFS-BND-95-083, Chicago, Illinois.

## APPENDIX 5.A

## SAMPLE INPUT FILE FOR SAS2H

```
=SAS2H     PARM='halt05,skipshipdata'
bw 15x15 PWR assembly
' fuel temp 923
44groupndf5    LATTICECELL
UO2 1 0.95 923 92234 0.03204 92235 3.6 92236 0.01656
    92238 96.3514 END
'
' Zirc 4 composition
ARBM-ZIRC4 6.55 4 1 0 0 50000 1.7 26000 0.24 24000 0.13 40000 97.93
          2 1.0 595 END
'
' water with 652.5 ppm boron
H2O       3 DEN=0.7135 1  579 END
ARBM-BORMOD  0.7135 1 1 0 0 5000 100 3 652.5E-6  579  END
'
co-59  3 0 1-20 579 end
kr-83  1 0 1-20 923 end
kr-84  1 0 1-20 923 end
kr-85  1 0 1-20 923 end
kr-86  1 0 1-20 923 end
sr-90  1 0 1-20 923 end
y-89   1 0 1-20 923 end
zr-94  1 0 1-20 923 end
zr-95  1 0 1-20 923 end
mo-94  1 0 1-20 923 end
mo-95  1 0 1-20 923 end
nb-94  1 0 1-20 923 end
nb-95  1 0 1-20 923 end
tc-99  1 0 1-20 923 end
ru-106  1 0 1-20 923 end
rh-103  1 0 1-20 923 end
rh-105  1 0 1-20 923 end
sb-124  1 0 1-20 923 end
sn-126  1 0 1-20 923 end
xe-131  1 0 1-20 923 end
xe-132  1 0 1-20 923 end
xe-134  1 0 1-20 923 end
'
xe-135  1 0 1-09 923 end
'
xe-136  1 0 1-20 923 end
cs-133  1 0 1-20 923 end
cs-134  1 0 1-20 923 end
cs-135  1 0 1-20 923 end
cs-137  1 0 1-20 923 end
ba-136  1 0 1-20 923 end
la-139  1 0 1-20 923 end
ce-144  1 0 1-20 923 end
pr-143  1 0 1-20 923 end
nd-143  1 0 1-20 923 end
nd-144  1 0 1-20 923 end
nd-145  1 0 1-20 923 end
nd-146  1 0 1-20 923 end
nd-147  1 0 1-20 923 end
nd-148  1 0 1-20 923 end
nd-150  1 0 1-20 923 end
pm-147  1 0 1-20 923 end
pm-148  1 0 1-20 923 end
```

```
pm-149  1 0 1-20 923 end
sm-147  1 0 1-20 923 end
sm-148  1 0 1-20 923 end
sm-149  1 0 1-20 923 end
sm-150  1 0 1-20 923 end
sm-151  1 0 1-20 923 end
sm-152  1 0 1-20 923 end
eu-151  1 0 1-20 923 end
eu-153  1 0 1-20 923 end
eu-154  1 0 1-20 923 end
eu-155  1 0 1-20 923 end
gd-154  1 0 1-20 923 end
gd-155  1 0 1-20 923 end
gd-157  1 0 1-20 923 end
gd-158  1 0 1-20 923 end
gd-160  1 0 1-20 923 end
'
END COMP
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'  FUEL-PIN-CELL GEOMETRY:
'
SQUAREPITCH  1.44272 0.950468 1 3 1.08712 2 0.97028 0 END
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'  MTU in this model is 0.495485 based on fuel dimensions provided
'
'  1 power cycle will be used and a library will be generated every
'  2500 MWD/MTU  power level is 40 MW/MTU
'  therefore 62.5 days per 2500 MWD/MTU
'  Below
'  BURN=62.5*NLIB/CYC
'  POWER=MTU*40
'
'  Number of libraries is 20 which is 50,000 MWD/MTU burnup (20*2500)
'
'  ASSEMBLY AND CYCLE PARAMETERS:
'
NPIN/ASSM=208 FUELNGTH=365.76 NCYCLES=1 NLIB/CYC=20
PRINTLEVEL=1
LIGHTEL=5  INPLEVEL=1   NUMHOLES=17
NUMINStr= 0  ORTUBE= 0.6731  SRTUBE=0.63246   END
POWER=19.81938  BURN=1250.0  END
'
 O  66.54421
 FE  0.24240868
 ZR 98.78151  CR  0.1311304   SN  1.714782
'
END
=SAS2H    PARM='restarts,halt10,skipshipdata'
bw 15x15 PWR assembly
END
=SAS2H    PARM='restarts,halt15,skipshipdata'
bw 15x15 PWR assembly
END
=SAS2H    PARM='restarts,halt20,skipshipdata'
```

```
bw 15x15 PWR assembly
END
```

## APPENDIX 5.B

## SAMPLE INPUT FILE FOR ORIGEN-S

```
#ORIGENS
0$$  A4 33 A8 26 A11 71  E
1$$  1 T
bw 15x15 FUEL -- FT33F001 -
'
' SUBCASE  1 LIBRARY POSITION  1
'
'   lib     pos      grms   photon group
3$$ 33  A3  1  0  A16 2   E T
35$$ 0 T
56$$  5  5  A6 3  A10  0  A13 9  A15 3 A19 1 E
57** 0.0 A3 1.E-5 0.05556 E T
 FUEL 3.6
BW 15x15 0.495485 MTU
58** 19.81938  19.81938 19.81938 19.81938  19.81938
60**  1.0000   3.0000  15.0000  30.0000  62.5
66$$ A1 2 A5 2 A9 2  E
73$$  922350  922340  922360  922380  80000  500000
      260000  240000  400000
74** 17837.45 158.7533 82.05225 477406.4 66544.21 1714.782
     242.0868 131.1304 98781.51
75$$  2  2  2  2  4  4  4  4  4  T
'
' SUBCASE  2 LIBRARY POSITION  2
'
3$$ 33  A3   2  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   5  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.05556 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE  3 LIBRARY POSITION  3
'
3$$ 33  A3   3  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.05556 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE  4 LIBRARY POSITION  4
'
3$$ 33  A3   4  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.05556 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
```

```
'
' SUBCASE  5 LIBRARY POSITION  5
'
3$$ 33  A3   5  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.05556 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE  6 LIBRARY POSITION  6
'
3$$ 33  A3   6  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.05556 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE  7 LIBRARY POSITION  7
'
3$$ 33  A3   7  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.05556 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE  8 LIBRARY POSITION  8
'
3$$ 33  A3   8  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.05556 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE  9 LIBRARY POSITION  9
'
3$$ 33  A3   9  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.05556 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
```

```
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE 10 LIBRARY POSITION 10
'
3$$ 33  A3  10  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.05556 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE 11 LIBRARY POSITION 11
'
3$$ 33  A3  11  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.05556 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE 12 LIBRARY POSITION 12
'
3$$ 33  A3  12  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.05556 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE 13 LIBRARY POSITION 13
'
3$$ 33  A3  13  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.05556 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE 14 LIBRARY POSITION 14
'
3$$ 33  A3  14  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.05556 E T
 fuel
```

```
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE 15 LIBRARY POSITION 15
'
3$$ 33  A3  15  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.05556 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE 16 LIBRARY POSITION 16
'
3$$ 33  A3  16  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.05556 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE 17 LIBRARY POSITION 17
'
3$$ 33  A3  17  0  A16 2  A33 0  E T
35$$ 0 T
56$$  3  3  A6 3  A10   3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.05556 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE 18 LIBRARY POSITION 18
'
3$$ 33  A3  18  A4 7 0  A16 2  A33 18  E T
35$$ 0 T
56$$  3  3  A6 1  A10  3  A15 3 A19 1 E
57** 0.0 A3 1.E-5  0.05556 E T
 fuel
BW 15X15
58** 19.81938 19.81938 19.81938
60** 18.5 37.0 62.5
66$$ A1 2 A5 2 A9 2  E T
'
' SUBCASE - decay
'
54$$ A8 1 E
56$$ 0 9 A6 1 A10 3 A14 3 A15 1 A19 1 E
57** 0.0 0 1.E-5  E T
```

```
 fuel enrichment above
60** 0.5 0.75 1.0 4.0 8.0 12.0 24.0 48.0 96.0
61** F0.1
65$$
'GRAM-ATOMS   GRAMS    CURIES     WATTS-ALL  WATTS-GAMMA
     3Z      0  1  0     0 0 0      1 0 0         3Z          6Z
     3Z      0  1  0     0 0 0      1 0 0         3Z          6Z
     3Z      0  1  0     0 0 0      1 0 0         3Z          6Z   T
'
' SUBCASE - decay
'
54$$ A8 1 E
56$$ 0 9 A6 1 A10 9 A14 4 A15 1 A19 1 E
57** 4.0 0 1.E-5  E T
 fuel enrichment above
60** 10.0 20.0 30.0 60.0 90.0 120.0 180.0 240.0 365.0
61** F0.1
65$$
'GRAM-ATOMS   GRAMS    CURIES     WATTS-ALL  WATTS-GAMMA
     3Z      0  1  0     0 0 0      1 0 0         3Z          6Z
     3Z      0  1  0     0 0 0      1 0 0         3Z          6Z
     3Z      0  1  0     0 0 0      1 0 0         3Z          6Z   T
'
' SUBCASE - decay
'
54$$ A8 0 E
56$$ 0 9 A6 1 A10 9 A14 5 A15 1 A19 1 E
57** 1.0 0 1.E-5  E T
 fuel enrichment above
60** 1.5 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0
61** F1.0e-5
65$$
'GRAM-ATOMS   GRAMS    CURIES     WATTS-ALL  WATTS-GAMMA
     3Z      0  1  0     1 0 0      1 0 0         3Z          6Z
     3Z      0  1  0     1 0 0      1 0 0         3Z          6Z
     3Z      0  1  0     1 0 0      1 0 0         3Z          6Z
81$$ 2 0 26 1 E
82$$ 0 2 2 2 2 2 2 2 2
83**  1.1E+7  8.0E+6 6.0E+6 4.0E+6 3.0E+6 2.5E+6 2.0E+6 1.5E+6
      1.0E+6  7.0E+5 4.5E+5 3.0E+5 1.5E+5 1.0E+5 7.0E+4 4.5E+4
      3.0E+4  2.0E+4 1.0E+4
84**  20.0E+6 6.43E+6 3.0E+6 1.85E+6 1.40E+6 9.00E+5 4.00E+5 1.0E+5 T
'
'
'
'
'
'
'
'
' SUBCASE - decay
'
54$$ A8 0 E
56$$ 0 10 A6 1 A10 9 A14 5 A15 1 A19 1 E
57** 10.0 0 1.E-5  E T
 fuel enrichment above
60** 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0
61** F1.0e-5
```

```
65$$
'GRAM-ATOMS   GRAMS    CURIES     WATTS-ALL  WATTS-GAMMA
     3Z      0  1  0     1 0 0      1 0 0        3Z         6Z
     3Z      0  1  0     1 0 0      1 0 0        3Z         6Z
     3Z      0  1  0     1 0 0      1 0 0        3Z         6Z
81$$ 2 0 26 1 E
82$$ 2 2 2 2 2 2 2 2 2 2
83**  1.1E+7  8.0E+6 6.0E+6 4.0E+6 3.0E+6 2.5E+6 2.0E+6 1.5E+6
      1.0E+6  7.0E+5 4.5E+5 3.0E+5 1.5E+5 1.0E+5 7.0E+4 4.5E+4
      3.0E+4  2.0E+4 1.0E+4
84**  20.0E+6 6.43E+6 3.0E+6 1.85E+6 1.40E+6 9.00E+5 4.00E+5 1.0E+5 T
'
'
'
'
'
'
'
'
'
'
' END
'
56$$ F0 T
END
```

## APPENDIX 5.C

## SAMPLE INPUT FILE FOR MCNP

```
message:   outp=hs24c11o  srctp=hs24c11s  runtpe=hs24c11r
           mctal=hs24c11m  wssa=hs24c11w  rssa=pt001w

hs24c11
c
c     origin is 6 inches below mpc
c
c     only cells that contain material are split axially
c     importance splitting is not done in cells with 0 material
c
c     axial segmentation is at the following boundaries
c     615, 620, 420, 430, 445, 455, 675, 651, 652 ,653
c     654, 655, 656, 657, 680
c
c     universe 1
c
301    0           (-40:41:-42:43)    -400 u=1
302    0   37 -38     -12          400 -410 u=1
303    0   37 -38  15              400 -410 u=1
304    0   35 -36              -20 400 -410 u=1
305    0   35 -36          23      400 -410 u=1
306    0   37 -38     -12          435 -460 u=1
307    0   37 -38  15              435 -460 u=1
308    0   35 -36              -20 435 -460 u=1
309    0   35 -36          23      435 -460 u=1
310    0   37 -38     -10          410 -435 u=1
311    0   37 -38  17              410 -435 u=1
312    0   35 -36              -18 410 -435 u=1
313    0   35 -36          25      410 -435 u=1
314    5 -7.92     10 -11 26 -27 410 -420 u=-1 $ left
315    6 -2.644    11 -12 26 -27 410 -420 u=-1 $ left
316    6 -2.644    15 -16 26 -27 410 -420 u=-1 $ right
317    5 -7.92     16 -17 26 -27 410 -420 u=-1 $ right
318    5 -7.92     28 -29 18 -19 410 -420 u=-1 $ bot
319    6 -2.644    28 -29 19 -20 410 -420 u=-1 $ bot
320    6 -2.644    28 -29 23 -24 410 -420 u=-1 $ top
321    5 -7.92     28 -29 24 -25 410 -420 u=-1 $ top
322    5 -7.92     10 -11 26 -27 420 -430 u=-1 $ left
323    6 -2.644    11 -12 26 -27 420 -430 u=-1 $ left
324    6 -2.644    15 -16 26 -27 420 -430 u=-1 $ right
325    5 -7.92     16 -17 26 -27 420 -430 u=-1 $ right
326    5 -7.92     28 -29 18 -19 420 -430 u=-1 $ bot
327    6 -2.644    28 -29 19 -20 420 -430 u=-1 $ bot
328    6 -2.644    28 -29 23 -24 420 -430 u=-1 $ top
329    5 -7.92     28 -29 24 -25 420 -430 u=-1 $ top
330    5 -7.92     10 -11 26 -27 430 -435 u=-1 $ left
331    6 -2.644    11 -12 26 -27 430 -435 u=-1 $ left
332    6 -2.644    15 -16 26 -27 430 -435 u=-1 $ right
333    5 -7.92     16 -17 26 -27 430 -435 u=-1 $ right
334    5 -7.92     28 -29 18 -19 430 -435 u=-1 $ bot
335    6 -2.644    28 -29 19 -20 430 -435 u=-1 $ bot
336    6 -2.644    28 -29 23 -24 430 -435 u=-1 $ top
337    5 -7.92     28 -29 24 -25 430 -435 u=-1 $ top
338    0           10 -12 27 -38 410 -435 u=-1 $ left
339    0           10 -12 37 -26 410 -435 u=-1 $ left
340    0           15 -17 27 -38 410 -435 u=-1 $ right
341    0           15 -17 37 -26 410 -435 u=-1 $ right
342    0           35 -28 18 -20 410 -435 u=-1 $ bot
343    0           29 -36 18 -20 410 -435 u=-1 $ bot
344    0           35 -28 23 -25 410 -435 u=-1 $ top
345    0           29 -36 23 -25 410 -435 u=-1 $ top
346    5 -7.92     12 -15 20 -23 (-13:-21:22:14) 400 -420 u=-1
347    5 -7.92     12 -15 20 -23 (-13:-21:22:14) 420 -430 u=-1
348    5 -7.92     12 -15 20 -23 (-13:-21:22:14) 430 -445 u=-1
349    5 -7.92     12 -15 20 -23 (-13:-21:22:14) 445 -460 u=-1
```

```
350    0           13 -14 21 -22 (-40:41:-42:43) 400 -455 u=-1
351    9 -1.17e-3                            460      u=1
c      fuel element
352    0           40 -41 42 -43     -415 u=1
353    5 -1.0783   40 -41 42 -43 415 -420 u=-1 $ lower nozzle
354    0           40 -41 42 -43 420 -425 u=-1 $ space
355    2 -3.8699   40 -41 42 -43 425 -430 u=-1 $ active fuel
356    5 -0.1591   40 -41 42 -43 430 -440 u=-1 $ space
357    5 -0.1591   40 -41 42 -43 440 -445 u=-1 $ plenum spacer
358    5 -1.5410   40 -41 42 -43 445 -455 u=-1 $ top nozzle
359    0           13 -14 21 -22 455 -460 u=-1
c
360    5 -7.92     38 -23 -12  400 -420 u=1
361    5 -7.92     20 -37 -12  400 -420 u=1
362    5 -7.92     12 -35  23  400 -420 u=1
363    5 -7.92     12 -35 -20  400 -420 u=1
364    5 -7.92     36 -15  23  400 -420 u=1
365    5 -7.92     36 -15 -20  400 -420 u=1
366    5 -7.92     38 -23  15  400 -420 u=1
367    5 -7.92     20 -37  15  400 -420 u=1
368    5 -7.92     38 -23 -12  420 -430 u=1
369    5 -7.92     20 -37 -12  420 -430 u=1
370    5 -7.92     12 -35  23  420 -430 u=1
371    5 -7.92     12 -35 -20  420 -430 u=1
372    5 -7.92     36 -15  23  420 -430 u=1
373    5 -7.92     36 -15 -20  420 -430 u=1
374    5 -7.92     38 -23  15  420 -430 u=1
375    5 -7.92     20 -37  15  420 -430 u=1
376    5 -7.92     38 -23 -12  430 -445 u=1
377    5 -7.92     20 -37 -12  430 -445 u=1
378    5 -7.92     12 -35  23  430 -445 u=1
379    5 -7.92     12 -35 -20  430 -445 u=1
380    5 -7.92     36 -15  23  430 -445 u=1
381    5 -7.92     36 -15 -20  430 -445 u=1
382    5 -7.92     38 -23  15  430 -445 u=1
383    5 -7.92     20 -37  15  430 -445 u=1
384    5 -7.92     38 -23 -12  445 -460 u=1
385    5 -7.92     20 -37 -12  445 -460 u=1
386    5 -7.92     12 -35  23  445 -460 u=1
387    5 -7.92     12 -35 -20  445 -460 u=1
388    5 -7.92     36 -15  23  445 -460 u=1
389    5 -7.92     36 -15 -20  445 -460 u=1
390    5 -7.92     38 -23  15  445 -460 u=1
391    5 -7.92     20 -37  15  445 -460 u=1
392    0           23 -12      400 -460 u=1
393    0           23  15      400 -460 u=1
394    0           15 -20      400 -460 u=1
395    0          -12 -20      400 -460 u=1
c
c     universe 2
c
401    0          (-40:41:-42:43)   -400 u=2
402    0    37 -38    -12          400 -410 u=2
403    0    37 -38  15             400 -410 u=2
404    0    35 -36            -20 400 -410 u=2
405    0    35 -36         23      400 -410 u=2
406    0    37 -38    -12          435 -460 u=2
407    0    37 -38  15             435 -460 u=2
408    0    35 -36            -20 435 -460 u=2
409    0    35 -36         23      435 -460 u=2
410    0    37 -38    -10          410 -435 u=2
411    0    37 -38  17             410 -435 u=2
412    0    35 -36            -18 410 -435 u=2
413    0    35 -36         25      410 -435 u=2
414    5 -7.92      10 -11 26 -27 410 -420 u=-2 $ left
```

```
415     6 -2.644     11 -12 26 -27 410 -420 u=-2 $ left
416     6 -2.644     15 -16 30 -31 410 -420 u=-2 $ right
417     5 -7.92      16 -17 30 -31 410 -420 u=-2 $ right
418     5 -7.92      28 -29 18 -19 410 -420 u=-2 $ bot
419     6 -2.644     28 -29 19 -20 410 -420 u=-2 $ bot
420     6 -2.644     32 -33 23 -24 410 -420 u=-2 $ top
421     5 -7.92      32 -33 24 -25 410 -420 u=-2 $ top
422     5 -7.92      10 -11 26 -27 420 -430 u=-2 $ left
423     6 -2.644     11 -12 26 -27 420 -430 u=-2 $ left
424     6 -2.644     15 -16 30 -31 420 -430 u=-2 $ right
425     5 -7.92      16 -17 30 -31 420 -430 u=-2 $ right
426     5 -7.92      28 -29 18 -19 420 -430 u=-2 $ bot
427     6 -2.644     28 -29 19 -20 420 -430 u=-2 $ bot
428     6 -2.644     32 -33 23 -24 420 -430 u=-2 $ top
429     5 -7.92      32 -33 24 -25 420 -430 u=-2 $ top
430     5 -7.92      10 -11 26 -27 430 -435 u=-2 $ left
431     6 -2.644     11 -12 26 -27 430 -435 u=-2 $ left
432     6 -2.644     15 -16 30 -31 430 -435 u=-2 $ right
433     5 -7.92      16 -17 30 -31 430 -435 u=-2 $ right
434     5 -7.92      28 -29 18 -19 430 -435 u=-2 $ bot
435     6 -2.644     28 -29 19 -20 430 -435 u=-2 $ bot
436     6 -2.644     32 -33 23 -24 430 -435 u=-2 $ top
437     5 -7.92      32 -33 24 -25 430 -435 u=-2 $ top
438     0            10 -12 27 -38 410 -435 u=-2 $ left
439     0            10 -12 37 -26 410 -435 u=-2 $ left
440     0            15 -17 31 -38 410 -435 u=-2 $ right
441     0            15 -17 37 -30 410 -435 u=-2 $ right
442     0            35 -28 18 -20 410 -435 u=-2 $ bot
443     0            29 -36 18 -20 410 -435 u=-2 $ bot
444     0            35 -32 23 -25 410 -435 u=-2 $ top
445     0            33 -36 23 -25 410 -435 u=-2 $ top
446     5 -7.92      12 -15 20 -23 (-13:-21:22:14) 400 -420 u=-2
447     5 -7.92      12 -15 20 -23 (-13:-21:22:14) 420 -430 u=-2
448     5 -7.92      12 -15 20 -23 (-13:-21:22:14) 430 -445 u=-2
449     5 -7.92      12 -15 20 -23 (-13:-21:22:14) 445 -460 u=-2
450     0            13 -14 21 -22 (-40:41:-42:43) 400 -455 u=-2
451     9 -1.17e-3                          460     u=2
c       fuel element
452     0            40 -41 42 -43     -415 u=2
453     5 -1.0783    40 -41 42 -43 415 -420 u=-2 $ lower nozzle
454     0            40 -41 42 -43 420 -425 u=-2 $ space
455     2 -3.8699    40 -41 42 -43 425 -430 u=-2 $ active fuel
456     5 -0.1591    40 -41 42 -43 430 -440 u=-2 $ space
457     5 -0.1591    40 -41 42 -43 440 -445 u=-2 $ plenum spacer
458     5 -1.5410    40 -41 42 -43 445 -455 u=-2 $ top nozzle
459     0            13 -14 21 -22 455 -460 u=-2
c
460     5 -7.92      38 -23 -12  400 -420 u=2
461     5 -7.92      20 -37 -12  400 -420 u=2
462     0            12 -35  23  400 -420 u=2
463     5 -7.92      12 -35 -20  400 -420 u=2
464     0            36 -15  23  400 -420 u=2
465     5 -7.92      36 -15 -20  400 -420 u=2
466     0            38 -23  15  400 -420 u=2
467     0            20 -37  15  400 -420 u=2
468     5 -7.92      38 -23 -12  420 -430 u=2
469     5 -7.92      20 -37 -12  420 -430 u=2
470     0            12 -35  23  420 -430 u=2
471     5 -7.92      12 -35 -20  420 -430 u=2
472     0            36 -15  23  420 -430 u=2
473     5 -7.92      36 -15 -20  420 -430 u=2
474     0            38 -23  15  420 -430 u=2
475     0            20 -37  15  420 -430 u=2
476     5 -7.92      38 -23 -12  430 -445 u=2
477     5 -7.92      20 -37 -12  430 -445 u=2
```

```
478     0              12 -35  23   430 -445 u=2  .
479     5 -7.92        12 -35 -20   430 -445 u=2
480     0              36 -15  23   430 -445 u=2
481     5 -7.92        36 -15 -20   430 -445 u=2
482     0              38 -23  15   430 -445 u=2
483     0              20 -37  15   430 -445 u=2
484     5 -7.92        38 -23 -12   445 -460 u=2
485     5 -7.92        20 -37 -12   445 -460 u=2
486     0              12 -35  23   445 -460 u=2
487     5 -7.92        12 -35 -20   445 -460 u=2
488     0              36 -15  23   445 -460 u=2
489     5 -7.92        36 -15 -20   445 -460 u=2
490     0              38 -23  15   445 -460 u=2
491     0              20 -37  15   445 -460 u=2
492     0              23 -12       400 -460 u=2
493     0              23  15       400 -460 u=2
494     0              15 -20       400 -460 u=2
495     0             -12 -20       400 -460 u=2
c
c     universe 3
c
501     0               (-40:41:-42:43)    -400 u=3
502     0    37 -38       -12           400 -410 u=3
503     0    37 -38    15               400 -410 u=3
504     0    35 -36                 -20 400 -410 u=3
505     0    35 -36             23      400 -410 u=3
506     0    37 -38       -12           435 -460 u=3
507     0    37 -38    15               435 -460 u=3
508     0    35 -36                 -20 435 -460 u=3
509     0    35 -36             23      435 -460 u=3
510     0    37 -38       -10           410 -435 u=3
511     0    37 -38    17               410 -435 u=3
512     0    35 -36                 -18 410 -435 u=3
513     0    35 -36             25      410 -435 u=3
514     5 -7.92        10 -11 30 -31 410 -420 u=-3 $ left
515     6 -2.644       11 -12 30 -31 410 -420 u=-3 $ left
516     6 -2.644       15 -16 26 -27 410 -420 u=-3 $ right
517     5 -7.92        16 -17 26 -27 410 -420 u=-3 $ right
518     5 -7.92        28 -29 18 -19 410 -420 u=-3 $ bot
519     6 -2.644       28 -29 19 -20 410 -420 u=-3 $ bot
520     6 -2.644       32 -33 23 -24 410 -420 u=-3 $ top
521     5 -7.92        32 -33 24 -25 410 -420 u=-3 $ top
522     5 -7.92        10 -11 30 -31 420 -430 u=-3 $ left
523     6 -2.644       11 -12 30 -31 420 -430 u=-3 $ left
524     6 -2.644       15 -16 26 -27 420 -430 u=-3 $ right
525     5 -7.92        16 -17 26 -27 420 -430 u=-3 $ right
526     5 -7.92        28 -29 18 -19 420 -430 u=-3 $ bot
527     6 -2.644       28 -29 19 -20 420 -430 u=-3 $ bot
528     6 -2.644       32 -33 23 -24 420 -430 u=-3 $ top
529     5 -7.92        32 -33 24 -25 420 -430 u=-3 $ top
530     5 -7.92        10 -11 30 -31 430 -435 u=-3 $ left
531     6 -2.644       11 -12 30 -31 430 -435 u=-3 $ left
532     6 -2.644       15 -16 26 -27 430 -435 u=-3 $ right
533     5 -7.92        16 -17 26 -27 430 -435 u=-3 $ right
534     5 -7.92        28 -29 18 -19 430 -435 u=-3 $ bot
535     6 -2.644       28 -29 19 -20 430 -435 u=-3 $ bot
536     6 -2.644       32 -33 23 -24 430 -435 u=-3 $ top
537     5 -7.92        32 -33 24 -25 430 -435 u=-3 $ top
538     0              10 -12 31 -38 410 -435 u=-3 $ left
539     0              10 -12 37 -30 410 -435 u=-3 $ left
540     0              15 -17 27 -38 410 -435 u=-3 $ right
541     0              15 -17 37 -26 410 -435 u=-3 $ right
542     0              35 -28 18 -20 410 -435 u=-3 $ bot
543     0              29 -36 18 -20 410 -435 u=-3 $ bot
544     0              35 -32 23 -25 410 -435 u=-3 $ top
```

```
545     0              33 -36 23 -25 410 -435 u=-3 $ top
546     5 -7.92        12 -15 20 -23 (-13:-21:22:14) 400 -420 u=-3
547     5 -7.92        12 -15 20 -23 (-13:-21:22:14) 420 -430 u=-3
548     5 -7.92        12 -15 20 -23 (-13:-21:22:14) 430 -445 u=-3
549     5 -7.92        12 -15 20 -23 (-13:-21:22:14) 445 -460 u=-3
550     0              13 -14 21 -22 (-40:41:-42:43) 400 -455 u=-3
551     9 -1.17e-3                               460      u=3
c       fuel element
552     0              40 -41 42 -43     -415 u=3
553     5 -1.0783      40 -41 42 -43 415 -420 u=-3 $ lower nozzle
554     0              40 -41 42 -43 420 -425 u=-3 $ space
555     2 -3.8699      40 -41 42 -43 425 -430 u=-3 $ active fuel
556     5 -0.1591      40 -41 42 -43 430 -440 u=-3 $ space
557     5 -0.1591      40 -41 42 -43 440 -445 u=-3 $ plenum spacer
558     5 -1.5410      40 -41 42 -43 445 -455 u=-3 $ top nozzle
559     0              13 -14 21 -22 455 -460 u=-3
c
560     0              38 -23 -12  400 -420 u=3
561     0              20 -37 -12  400 -420 u=3
562     0              12 -35  23  400 -420 u=3
563     5 -7.92        12 -35 -20  400 -420 u=3
564     0              36 -15  23  400 -420 u=3
565     5 -7.92        36 -15 -20  400 -420 u=3
566     5 -7.92        38 -23  15  400 -420 u=3
567     5 -7.92        20 -37  15  400 -420 u=3
568     5 -7.92        38 -23 -12  420 -430 u=3
569     5 -7.92        20 -37 -12  420 -430 u=3
570     0              12 -35  23  420 -430 u=3
571     0              12 -35 -20  420 -430 u=3
572     5 -7.92        36 -15  23  420 -430 u=3
573     0              36 -15 -20  420 -430 u=3
574     5 -7.92        38 -23  15  420 -430 u=3
575     5 -7.92        20 -37  15  420 -430 u=3
576     5 -7.92        38 -23 -12  430 -445 u=3
577     5 -7.92        20 -37 -12  430 -445 u=3
578     0              12 -35  23  430 -445 u=3
579     0              12 -35 -20  430 -445 u=3
580     5 -7.92        36 -15  23  430 -445 u=3
581     0              36 -15 -20  430 -445 u=3
582     5 -7.92        38 -23  15  430 -445 u=3
583     5 -7.92        20 -37  15  430 -445 u=3
584     5 -7.92        38 -23 -12  445 -460 u=3
585     5 -7.92        20 -37 -12  445 -460 u=3
586     0              12 -35  23  445 -460 u=3
587     0              12 -35 -20  445 -460 u=3
588     5 -7.92        36 -15  23  445 -460 u=3
589     0              36 -15 -20  445 -460 u=3
590     5 -7.92        38 -23  15  445 -460 u=3
591     5 -7.92        20 -37  15  445 -460 u=3
592     0              23 -12      400 -460 u=3
593     0              23  15      400 -460 u=3
594     0              15 -20      400 -460 u=3
595     0             -12 -20      400 -460 u=3
c
c      universe 4
c
601     0              (-40:41:-42:43)   -400 u=4
602     0    37 -38      -12          400 -410 u=4
603     0    37 -38  15               400 -410 u=4
604     0    35 -36              -20  400 -410 u=4
605     0    35 -36         23        400 -410 u=4
606     0    37 -38      -12          435 -460 u=4
607     0    37 -38  15               435 -460 u=4
608     0    35 -36              -20  435 -460 u=4
609     0    35 -36         23        435 -460 u=4
```

```
610     0    37 -38      -10          410 -435 u=4
611     0    37 -38   17              410 -435 u=4
612     0    35 -36              -18  410 -435 u=4
613     0    35 -36          25       410 -435 u=4
614     5 -7.92       10 -11 30 -31 410 -420 u=-4 $ left
615     6 -2.644      11 -12 30 -31 410 -420 u=-4 $ left
616     6 -2.644      15 -16 26 -27 410 -420 u=-4 $ right
617     5 -7.92       16 -17 26 -27 410 -420 u=-4 $ right
618     5 -7.92       32 -33 18 -19 410 -420 u=-4 $ bot
619     6 -2.644      32 -33 19 -20 410 -420 u=-4 $ bot
620     6 -2.644      28 -29 23 -24 410 -420 u=-4 $ top
621     5 -7.92       28 -29 24 -25 410 -420 u=-4 $ top
622     5 -7.92       10 -11 30 -31 420 -430 u=-4 $ left
623     6 -2.644      11 -12 30 -31 420 -430 u=-4 $ left
624     6 -2.644      15 -16 26 -27 420 -430 u=-4 $ right
625     5 -7.92       16 -17 26 -27 420 -430 u=-4 $ right
626     5 -7.92       32 -33 18 -19 420 -430 u=-4 $ bot
627     6 -2.644      32 -33 19 -20 420 -430 u=-4 $ bot
628     6 -2.644      28 -29 23 -24 420 -430 u=-4 $ top
629     5 -7.92       28 -29 24 -25 420 -430 u=-4 $ top
630     5 -7.92       10 -11 30 -31 430 -435 u=-4 $ left
631     6 -2.644      11 -12 30 -31 430 -435 u=-4 $ left
632     6 -2.644      15 -16 26 -27 430 -435 u=-4 $ right
633     5 -7.92       16 -17 26 -27 430 -435 u=-4 $ right
634     5 -7.92       32 -33 18 -19 430 -435 u=-4 $ bot
635     6 -2.644      32 -33 19 -20 430 -435 u=-4 $ bot
636     6 -2.644      28 -29 23 -24 430 -435 u=-4 $ top
637     5 -7.92       28 -29 24 -25 430 -435 u=-4 $ top
638     0             10 -12 31 -38 410 -435 u=-4 $ left
639     0             10 -12 37 -30 410 -435 u=-4 $ left
640     0             15 -17 27 -38 410 -435 u=-4 $ right
641     0             15 -17 37 -26 410 -435 u=-4 $ right
642     0             35 -32 18 -20 410 -435 u=-4 $ bot
643     0             33 -36 18 -20 410 -435 u=-4 $ bot
644     0             35 -28 23 -25 410 -435 u=-4 $ top
645     0             29 -36 23 -25 410 -435 u=-4 $ top
646     5 -7.92       12 -15 20 -23 (-13:-21:22:14) 400 -420 u=-4
647     5 -7.92       12 -15 20 -23 (-13:-21:22:14) 420 -430 u=-4
648     5 -7.92       12 -15 20 -23 (-13:-21:22:14) 430 -445 u=-4
649     5 -7.92       12 -15 20 -23 (-13:-21:22:14) 445 -460 u=-4
650     0             13 -14 21 -22 (-40:41:-42:43) 400 -455 u=-4
651     9 -1.17e-3                            460      u=4
c       fuel element
652     0             40 -41 42 -43     -415 u=4
653     5 -1.0783     40 -41 42 -43 415 -420 u=-4 $ lower nozzle
654     0             40 -41 42 -43 420 -425 u=-4 $ space
655     2 -3.8699     40 -41 42 -43 425 -430 u=-4 $ active fuel
656     5 -0.1591     40 -41 42 -43 430 -440 u=-4 $ space
657     5 -0.1591     40 -41 42 -43 440 -445 u=-4 $ plenum spacer
658     5 -1.5410     40 -41 42 -43 445 -455 u=-4 $ top nozzle
659     0             13 -14 21 -22 455 -460 u=-4
c
660     0             38 -23 -12  400 -420 u=4
661     0             20 -37 -12  400 -420 u=4
662     5 -7.92       12 -35  23  400 -420 u=4
663     0             12 -35 -20  400 -420 u=4
664     5 -7.92       36 -15  23  400 -420 u=4
665     0             36 -15 -20  400 -420 u=4
666     5 -7.92       38 -23  15  400 -420 u=4
667     5 -7.92       20 -37  15  400 -420 u=4
668     0             38 -23 -12  420 -430 u=4
669     0             20 -37 -12  420 -430 u=4
670     5 -7.92       12 -35  23  420 -430 u=4
671     0             12 -35 -20  420 -430 u=4
672     5 -7.92       36 -15  23  420 -430 u=4
```

```
673     0             36 -15 -20  420 -430 u=4
674     5 -7.92       38 -23  15  420 -430 u=4
675     5 -7.92       20 -37  15  420 -430 u=4
676     0             38 -23 -12  430 -445 u=4
677     0             20 -37 -12  430 -445 u=4
678     5 -7.92       12 -35  23  430 -445 u=4
679     0             12 -35 -20  430 -445 u=4
680     5 -7.92       36 -15  23  430 -445 u=4
681     0             36 -15 -20  430 -445 u=4
682     5 -7.92       38 -23  15  430 -445 u=4
683     5 -7.92       20 -37  15  430 -445 u=4
684     0             38 -23 -12  445 -460 u=4
685     0             20 -37 -12  445 -460 u=4
686     5 -7.92       12 -35  23  445 -460 u=4
687     0             12 -35 -20  445 -460 u=4
688     5 -7.92       36 -15  23  445 -460 u=4
689     0             36 -15 -20  445 -460 u=4
690     5 -7.92       38 -23  15  445 -460 u=4
691     5 -7.92       20 -37  15  445 -460 u=4
692     0             23 -12      400 -460 u=4
693     0             23  15      400 -460 u=4
694     0             15 -20      400 -460 u=4
695     0            -12 -20      400 -460 u=4
c
c     universe 5
c
701     0             (-40:41:-42:43)    -400 u=5
702     0    37 -38      -12          400 -410 u=5
703     0    37 -38   15              400 -410 u=5
704     0    35 -36              -20  400 -410 u=5
705     0    35 -36          23       400 -410 u=5
706     0    37 -38      -12          435 -460 u=5
707     0    37 -38   15              435 -460 u=5
708     0    35 -36              -20  435 -460 u=5
709     0    35 -36          23       435 -460 u=5
710     0    37 -38      -10          410 -435 u=5
711     0    37 -38   17              410 -435 u=5
712     0    35 -36              -18  410 -435 u=5
713     0    35 -36          25       410 -435 u=5
714     5 -7.92       10 -11 26 -27 410 -420 u=-5 $ left
715     6 -2.644      11 -12 26 -27 410 -420 u=-5 $ left
716     6 -2.644      15 -16 30 -31 410 -420 u=-5 $ right
717     5 -7.92       16 -17 30 -31 410 -420 u=-5 $ right
718     5 -7.92       32 -33 18 -19 410 -420 u=-5 $ bot
719     6 -2.644      32 -33 19 -20 410 -420 u=-5 $ bot
720     6 -2.644      28 -29 23 -24 410 -420 u=-5 $ top
721     5 -7.92       28 -29 24 -25 410 -420 u=-5 $ top
722     5 -7.92       10 -11 26 -27 420 -430 u=-5 $ left
723     6 -2.644      11 -12 26 -27 420 -430 u=-5 $ left
724     6 -2.644      15 -16 30 -31 420 -430 u=-5 $ right
725     5 -7.92       16 -17 30 -31 420 -430 u=-5 $ right
726     5 -7.92       32 -33 18 -19 420 -430 u=-5 $ bot
727     6 -2.644      32 -33 19 -20 420 -430 u=-5 $ bot
728     6 -2.644      28 -29 23 -24 420 -430 u=-5 $ top
729     5 -7.92       28 -29 24 -25 420 -430 u=-5 $ top
730     5 -7.92       10 -11 26 -27 430 -435 u=-5 $ left
731     6 -2.644      11 -12 26 -27 430 -435 u=-5 $ left
732     6 -2.644      15 -16 30 -31 430 -435 u=-5 $ right
733     5 -7.92       16 -17 30 -31 430 -435 u=-5 $ right
734     5 -7.92       32 -33 18 -19 430 -435 u=-5 $ bot
735     6 -2.644      32 -33 19 -20 430 -435 u=-5 $ bot
736     6 -2.644      28 -29 23 -24 430 -435 u=-5 $ top
737     5 -7.92       28 -29 24 -25 430 -435 u=-5 $ top
738     0             10 -12 27 -38 410 -435 u=-5 $ left
739     0             10 -12 37 -26 410 -435 u=-5 $ left
```

```
740     0           15 -17 31 -38 410 -435 u=-5 $ right
741     0           15 -17 37 -30 410 -435 u=-5 $ right
742     0           35 -32 18 -20 410 -435 u=-5 $ bot
743     0           33 -36 18 -20 410 -435 u=-5 $ bot
744     0           35 -28 23 -25 410 -435 u=-5 $ top
745     0           29 -36 23 -25 410 -435 u=-5 $ top
746     5 -7.92     12 -15 20 -23 (-13:-21:22:14) 400 -420 u=-5
747     5 -7.92     12 -15 20 -23 (-13:-21:22:14) 420 -430 u=-5
748     5 -7.92     12 -15 20 -23 (-13:-21:22:14) 430 -445 u=-5
749     5 -7.92     12 -15 20 -23 (-13:-21:22:14) 445 -460 u=-5
750     0           13 -14 21 -22 (-40:41:-42:43) 400 -455 u=-5
751     9 -1.17e-3                          460     u=5
c       fuel element
752     0           40 -41 42 -43     -415 u=5
753     5 -1.0783   40 -41 42 -43 415 -420 u=-5 $ lower nozzle
754     0           40 -41 42 -43 420 -425 u=-5 $ space
755     2 -3.8699   40 -41 42 -43 425 -430 u=-5 $ active fuel
756     5 -0.1591   40 -41 42 -43 430 -440 u=-5 $ space
757     5 -0.1591   40 -41 42 -43 440 -445 u=-5 $ plenum spacer
758     5 -1.5410   40 -41 42 -43 445 -455 u=-5 $ top nozzle
759     0           13 -14 21 -22 455 -460 u=-5
c
760     5 -7.92     38 -23 -12  400 -420 u=5
761     5 -7.92     20 -37 -12  400 -420 u=5
762     5 -7.92     12 -35  23  400 -420 u=5
763     0           12 -35 -20  400 -420 u=5
764     5 -7.92     36 -15  23  400 -420 u=5
765     0           36 -15 -20  400 -420 u=5
766     0           38 -23  15  400 -420 u=5
767     0           20 -37  15  400 -420 u=5
768     5 -7.92     38 -23 -12  420 -430 u=5
769     5 -7.92     20 -37 -12  420 -430 u=5
770     5 -7.92     12 -35  23  420 -430 u=5
771     0           12 -35 -20  420 -430 u=5
772     5 -7.92     36 -15  23  420 -430 u=5
773     0           36 -15 -20  420 -430 u=5
774     0           38 -23  15  420 -430 u=5
775     0           20 -37  15  420 -430 u=5
776     5 -7.92     38 -23 -12  430 -445 u=5
777     5 -7.92     20 -37 -12  430 -445 u=5
778     5 -7.92     12 -35  23  430 -445 u=5
779     0           12 -35 -20  430 -445 u=5
780     5 -7.92     36 -15  23  430 -445 u=5
781     0           36 -15 -20  430 -445 u=5
782     0           38 -23  15  430 -445 u=5
783     0           20 -37  15  430 -445 u=5
784     5 -7.92     38 -23 -12  445 -460 u=5
785     5 -7.92     20 -37 -12  445 -460 u=5
786     5 -7.92     12 -35  23  445 -460 u=5
787     0           12 -35 -20  445 -460 u=5
788     5 -7.92     36 -15  23  445 -460 u=5
789     0           36 -15 -20  445 -460 u=5
790     0           38 -23  15  445 -460 u=5
791     0           20 -37  15  445 -460 u=5
792     0           23 -12      400 -460 u=5
793     0           23  15      400 -460 u=5
794     0           15 -20      400 -460 u=5
795     0          -12 -20      400 -460 u=5
c
c       egg crate
c
c      storage locations
c
c      201   0  -301     -112 101       620 -675
202    0  -301 112 -113 101      620 -675
```

```
203    0  -301 113 -114 101       620 -675
c      204   0  -301 114       101       620 -675
c
205    0  -301      -111 102       620 -675
206    0  -301 111 -112 102 -101 620 -675
101    0  -301 112 -113 102 -101 620 -675
       fill=3 (-13.68679 68.43395 0.0)
102    0  -301 113 -114 102 -101 620 -675
       fill=2 ( 13.68679 68.43395 0.0)
207    0  -301 114 -115 102 -101 620 -675
208    0  -301 115       102       620 -675
c
c      209   0  -301      -110 103       620 -675
210    0  -301 110 -111 103 -102 620 -675
103    0       111 -112 103 -102 620 -675
       fill=3 (-41.06037 41.06037 0.0)
104    0       112 -113 103 -102 620 -675
       fill=1 (-13.68679 41.06037 0.0)
105    0       113 -114 103 -102 620 -675
       fill=1 ( 13.68679 41.06037 0.0)
106    0       114 -115 103 -102 620 -675
       fill=2 ( 41.06037 41.06037 0.0)
211    0  -301 115 -116 103 -102 620 -675
c      212   0  -301 116       103       620 -675
c
213    0  -301      -110 104 -103 620 -675
107    0  -301 110 -111 104 -103 620 -675
       fill=3 (-68.43395 13.68679 0.0)
108    0       111 -112 104 -103 620 -675
       fill=1 (-41.06037 13.68679 0.0)
109    0       112 -113 104 -103 620 -675
       fill=1 (-13.68679 13.68679 0.0)
110    0       113 -114 104 -103 620 -675
       fill=1 ( 13.68679 13.68679 0.0)
111    0       114 -115 104 -103 620 -675
       fill=1 ( 41.06037 13.68679 0.0)
112    0  -301 115 -116 104 -103 620 -675
       fill=2 ( 68.43395 13.68679 0.0)
214    0  -301 116       104 -103 620 -675
c
215    0  -301      -110 105 -104 620 -675
113    0  -301 110 -111 105 -104 620 -675
       fill=4 (-68.43395 -13.68679 0.0)
114    0       111 -112 105 -104 620 -675
       fill=1 (-41.06037 -13.68679 0.0)
115    0       112 -113 105 -104 620 -675
       fill=1 (-13.68679 -13.68679 0.0)
116    0       113 -114 105 -104 620 -675
       fill=1 ( 13.68679 -13.68679 0.0)
117    0       114 -115 105 -104 620 -675
       fill=1 ( 41.06037 -13.68679 0.0)
118    0  -301 115 -116 105 -104 620 -675
       fill=5 ( 68.43395 -13.68679 0.0)
216    0  -301 116       105 -104 620 -675
c
c      217   0  -301      -110      -105 620 -675
218    0  -301 110 -111 106 -105 620 -675
119    0       111 -112 106 -105 620 -675
       fill=4 (-41.06037 -41.06037 0.0)
120    0       112 -113 106 -105 620 -675
       fill=1 (-13.68679 -41.06037 0.0)
121    0       113 -114 106 -105 620 -675
       fill=1 ( 13.68679 -41.06037 0.0)
122    0       114 -115 106 -105 620 -675
       fill=5 ( 41.06037 -41.06037 0.0)
```

```
219     0  -301 115 -116 106 -105 620 -675
c       220    0  -301 116          -105 620 -675
c
221     0  -301     -111      -106 620 -675
222     0  -301 111 -112 107 -106 620 -675
123     0  -301 112 -113 107 -106 620 -675
        fill=4 (-13.68679 -68.43395 0.0)
124     0  -301 113 -114 107 -106 620 -675
        fill=5 ( 13.68679 -68.43395 0.0)
223     0  -301 114 -115 107 -106 620 -675
224     0  -301 115           -106 620 -675
c
c       225   0  -301      -112      -107 620 -675
226     0  -301 112 -113      -107 620 -675
227     0  -301 113 -114      -107 620 -675
c       228    0  -301 114          -107 620 -675
c
1001     5 -7.92 301 -302 610 -615  $ MPC shell
1003     5 -7.92 301 -302 615 -616  $ MPC shell
1005     5 -7.92 301 -302 616 -620  $ MPC shell
1007     5 -7.92 301 -302 620 -420  $ MPC shell
1009     5 -7.92 301 -302 420 -430  $ MPC shell
1011     5 -7.92 301 -302 430 -445  $ MPC shell
1013     5 -7.92 301 -302 445 -460  $ MPC shell
1014     5 -7.92 301 -302 460 -675  $ MPC shell
1015     5 -7.92 301 -302 675 -651  $ MPC shell
1017     5 -7.92 301 -302 651 -652  $ MPC shell
1019     5 -7.92 301 -302 652 -653  $ MPC shell
1021     5 -7.92 301 -302 653 -654  $ MPC shell
1023     5 -7.92 301 -302 654 -655  $ MPC shell
1025     5 -7.92 301 -302 655 -656  $ MPC shell
1027     5 -7.92 301 -302 656 -657  $ MPC shell
1028     5 -7.92 301 -302 657 -658  $ MPC shell
1029     5 -7.92 301 -302 658 -659  $ MPC shell
1031     5 -7.92 301 -302 659 -680  $ MPC shell
c
1051     5 -7.92      -301 610 -615  $ MPC baseplate
1052     5 -7.92      -301 615 -616  $ MPC baseplate
1053     5 -7.92      -301 616 -620  $ MPC baseplate
1060     5 -7.92      -301 675 -651  $ MPC lid
1061     5 -7.92      -301 651 -652  $ MPC lid
1062     5 -7.92      -301 652 -653  $ MPC lid
1063     5 -7.92      -301 653 -654  $ MPC lid
1064     5 -7.92      -301 654 -655  $ MPC lid
1065     5 -7.92      -301 655 -656  $ MPC lid
1066     5 -7.92      -301 656 -657  $ MPC lid
1067     5 -7.92      -301 657 -658  $ MPC lid
1068     5 -7.92      -301 658 -659  $ MPC lid
1069     5 -7.92      -301 659 -680  $ MPC lid
c
c        overpack universes
c
c       pedastal
c
2001     8 -7.82     -302 801 -610
2002     8 -7.82     -302 802 -801
2003     8 -7.82     -302 803 -802
2004     8 -7.82     -302 804 -803
2005     8 -7.82     -302 805 -804
c
2006     7 -2.35       -306 806 -805
2007     7 -2.35       -306 807 -806
2008     7 -2.35       -306 808 -807
2009     7 -2.35       -306 809 -808
2010     7 -2.35       -306 810 -809
```

```
2011   7 -2.35       -306 811 -810
2012   7 -2.35       -306 812 -811
2013   7 -2.35       -306 813 -812
2014   7 -2.35       -306 814 -813
c
2016   8 -7.82  306 -302 806 -805
2017   8 -7.82  306 -302 807 -806
2028   8 -7.82  306 -302 808 -807
2019   8 -7.82  306 -302 809 -808
2020   8 -7.82  306 -302 810 -809
2021   8 -7.82  306 -302 811 -810
2022   8 -7.82  306 -302 812 -811
2023   8 -7.82  306 -302 813 -812
2024   8 -7.82  306 -302 814 -813
c      overpack baseplate
2031   8 -7.82       -302 815 -814
2032   8 -7.82       -302 816 -815
2033   7 -2.35       -302 817 -816
c      gap between overpack and lid
3001   9 -1.17e-3 -302 680 -901
c
c     lid
c
3002   8 -7.82     -307 901 -902
3003   8 -7.82     -307 902 -903
c
3004   7 -2.35     -305 903 -904
3005   7 -2.35     -305 904 -905
3006   7 -2.35     -305 905 -906
3007   7 -2.35     -305 906 -907
3008   7 -2.35     -305 907 -908
3009   7 -2.35     -305 908 -909
c
3010   8 -7.82  305 -307 903 -904
3011   8 -7.82  305 -307 904 -905
3012   8 -7.82  305 -307 905 -906
3013   8 -7.82  305 -307 906 -907
3014   8 -7.82  305 -307 907 -908
3015   8 -7.82  305 -307 908 -909
c
3021   8 -7.82     -307 909 -910
3022   8 -7.82     -307 910 -911
3023   8 -7.82     -307 911 -912
3024   8 -7.82     -307 912 -913
c
3030   0           -303 913 -914
3031   0           -303 914 -915
3032   0           -303 915 -916
3033   0           -303 916 -917
3034   0           -303 917 -918
c
3035   8 -7.82 303 -304 913 -914
3036   8 -7.82 303 -304 914 -915
3037   8 -7.82 303 -304 915 -916
3038   8 -7.82 303 -304 916 -917
3039   0       303 -304 917 -918
c
3040   7 -2.35 304 -307 913 -914
3041   7 -2.35 304 -307 914 -915
3042   7 -2.35 304 -307 915 -916
3043   7 -2.35 304 -307 916 -917
3044   0       304 -307 917 -918
c
c
c      steel,concrete and air in gap between mpc and overpack
```

```
c
4000   7 -2.35    302 -700 817 -816
4001   8 -7.82    302 -700 816 -815
4002   8 -7.82    302 -700 815 -814
4003   9 -1.17e-3 302 -700 814 -813
4004   9 -1.17e-3 302 -700 813 -812
4005   9 -1.17e-3 302 -700 812 -811
4006   9 -1.17e-3 302 -700 811 -810
4007   9 -1.17e-3 302 -700 810 -809
4008   9 -1.17e-3 302 -700 809 -808
4009   9 -1.17e-3 302 -700 808 -807
4010   9 -1.17e-3 302 -700 807 -806
4011   9 -1.17e-3 302 -700 806 -805
4012   9 -1.17e-3 302 -700 805 -804
4013   9 -1.17e-3 302 -700 804 -803
4014   9 -1.17e-3 302 -700 803 -802
4015   9 -1.17e-3 302 -700 802 -801
4016   9 -1.17e-3 302 -700 801 -610
4017   9 -1.17e-3 302 -700 610 -615
4018   9 -1.17e-3 302 -700 615 -620
4019   9 -1.17e-3 302 -700 620 -420
4020   9 -1.17e-3 302 -700 420 -430
4021   9 -1.17e-3 302 -700 430 -445
4022   9 -1.17e-3 302 -700 445 -460
4023   9 -1.17e-3 302 -700 460 -675
4024   9 -1.17e-3 302 -700 675 -651
4025   9 -1.17e-3 302 -700 651 -652
4026   9 -1.17e-3 302 -700 652 -653
4027   9 -1.17e-3 302 -700 653 -654
4028   9 -1.17e-3 302 -700 654 -655
4029   9 -1.17e-3 302 -700 655 -656
4030   9 -1.17e-3 302 -700 656 -657
4031   9 -1.17e-3 302 -700 657 -658
4032   9 -1.17e-3 302 -700 658 -659
4033   9 -1.17e-3 302 -700 659 -680
4034   9 -1.17e-3 302 -700 680 -901
4035   9 -1.17e-3 307 -700 901 -902
4036   9 -1.17e-3 307 -700 902 -903
4037   9 -1.17e-3 307 -700 903 -904
4038   9 -1.17e-3 307 -700 904 -905
4039   9 -1.17e-3 307 -700 905 -906
4040   9 -1.17e-3 307 -700 906 -907
4041   9 -1.17e-3 307 -700 907 -908
4042   9 -1.17e-3 307 -700 908 -909
4043   8 -7.82    307 -700 909 -910
4044   8 -7.82    307 -700 910 -911
4045   8 -7.82    307 -700 911 -912
4046   8 -7.82    307 -700 912 -913
4047   7 -2.35    307 -700 913 -914
4048   7 -2.35    307 -700 914 -915
4049   7 -2.35    307 -700 915 -916
4050   7 -2.35    307 -700 916 -917
4051   0     307 -700 917 -918
c
c      importance splitting regions in overpack
c
5000   7 -2.35   700 -701 817 -816
5001   0     700 -701 816 -815  fill=10
5002   0     700 -701 815 -814  fill=10
5003   0     700 -701 814 -813  fill=11
5004   0     700 -701 813 -812  fill=11
5005   0     700 -701 812 -811  fill=11
5006   0     700 -701 811 -810  fill=11
5007   0     700 -701 810 -809  fill=11
5008   0     700 -701 809 -808  fill=11
```

```
5009   0     700 -701 808 -807  fill=11
5010   8 -7.82     700 -701 807 -806
5011   8 -7.82     700 -701 806 -805
5012   8 -7.82     700 -701 805 -804
5013   8 -7.82     700 -701 804 -803
5014   8 -7.82     700 -701 803 -802
5015   8 -7.82     700 -701 802 -801
5016   8 -7.82     700 -701 801 -610
5017   8 -7.82     700 -701 610 -615
5018   8 -7.82     700 -701 615 -620
5019   8 -7.82     700 -701 620 -420
5020   8 -7.82     700 -701 420 -430
5021   8 -7.82     700 -701 430 -445
5022   8 -7.82     700 -701 445 -460
5023   8 -7.82     700 -701 460 -675
5024   8 -7.82     700 -701 675 -651
5025   8 -7.82     700 -701 651 -652
5026   8 -7.82     700 -701 652 -653
5027   8 -7.82     700 -701 653 -654
5028   8 -7.82     700 -701 654 -655
5029   8 -7.82     700 -701 655 -656
5030   8 -7.82     700 -701 656 -657
5031   8 -7.82     700 -701 657 -658
5032   8 -7.82     700 -701 658 -659
5033   8 -7.82     700 -701 659 -680
5034   8 -7.82     700 -701 680 -901
5035   8 -7.82     700 -701 901 -902
5036   8 -7.82     700 -701 902 -903
5037   8 -7.82     700 -701 903 -904
5038   0     700 -701 904 -905  fill=13
5039   0     700 -701 905 -906  fill=13
5040   0     700 -701 906 -907  fill=13
5041   0     700 -701 907 -908  fill=13
5042   0     700 -701 908 -909  fill=13
5043   8 -7.82     700 -701 909 -910
5044   8 -7.82     700 -701 910 -911
5045   8 -7.82     700 -701 911 -912
5046   8 -7.82     700 -701 912 -913
5047   7 -2.35     700 -701 913 -914
5048   7 -2.35     700 -701 914 -915
5049   7 -2.35     700 -701 915 -916
5050   7 -2.35     700 -701 916 -917
5051   0     700 -701 917 -918
c
5100   7 -2.35    701 -702 817 -816
5101   0     701 -702 816 -815  fill=10
5102   0     701 -702 815 -814  fill=10
5103   0     701 -702 814 -813  fill=11
5104   0     701 -702 813 -812  fill=11
5105   0     701 -702 812 -811  fill=11
5106   0     701 -702 811 -810  fill=11
5107   0     701 -702 810 -809  fill=11
5108   0     701 -702 809 -808  fill=11
5109   0     701 -702 808 -807  fill=11
5110   8 -7.82     701 -311 807 -806
5111   8 -7.82     701 -311 806 -805
5112   8 -7.82     701 -311 805 -804
5113   8 -7.82     701 -311 804 -803
5114   8 -7.82     701 -311 803 -802
5115   8 -7.82     701 -311 802 -801
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5117   8 -7.82     701 -311 610 -615
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5120   8 -7.82     701 -311 420 -430
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5150   7 -2.35    701 -702 916 -917
5151   0      701 -702 917 -918
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5250   7 -2.35    702 -703 916 -917
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```

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c       5645    8 -7.82     706 -707 911 -912
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c       5848    0      708 -709 914 -915
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c       5850    0      708 -709 916 -917
c       5851    0      708 -709 917 -918
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5940    0     709 -711 906 -907  fill=13
5941    0     709 -711 907 -908  fill=13
5942    0     709 -711 908 -909  fill=13
5943    8 -7.82     709 -711 909 -910
5944    8 -7.82     709 -711 910 -911
5945    8 -7.82     709 -711 911 -912
5946    8 -7.82     709 -711 912 -913
c       5947    0      709 -711 913 -914
c       5948    0      709 -711 914 -915
c       5949    0      709 -711 915 -916
c       5950    0      709 -711 916 -917
c       5951    0      709 -711 917 -918
c
c       6001    0      710 -711 816 -815   fill=10
c       6002    0      710 -711 815 -814   fill=10
```

```
c      6003   0     710 -711 814 -813  fill=11
c      6004   0     710 -711 813 -812  fill=11
c      6005   0     710 -711 812 -811  fill=11
c      6006   0     710 -711 811 -810  fill=11
c      6007   0     710 -711 810 -809  fill=11
c      6008   0     710 -711 809 -808  fill=11
c      6009   0     710 -711 808 -807  fill=11
c      6010   0     710 -711 807 -806  fill=112
c      6011   0     710 -711 806 -805  fill=112
c      6012   0     710 -711 805 -804  fill=112
c      6013   0     710 -711 804 -803  fill=112
c      6014   0     710 -711 803 -802  fill=112
c      6015   0     710 -711 802 -801  fill=112
c      6016   0     710 -711 801 -610  fill=112
c      6017   0     710 -711 610 -615  fill=112
c      6018   0     710 -711 615 -620  fill=112
c      6019   0     710 -711 620 -420  fill=112
c      6020   0     710 -711 420 -430  fill=112
c      6021   0     710 -711 430 -445  fill=112
c      6022   0     710 -711 445 -460  fill=112
c      6023   0     710 -711 460 -675  fill=112
c      6024   0     710 -711 675 -651  fill=112
c      6025   0     710 -711 651 -652  fill=112
c      6026   0     710 -711 652 -653  fill=112
c      6027   0     710 -711 653 -654  fill=112
c      6028   0     710 -711 654 -655  fill=112
c      6029   0     710 -711 655 -656  fill=112
c      6030   0     710 -711 656 -657  fill=112
c      6031   0     710 -711 657 -658  fill=112
c      6032   0     710 -711 658 -659  fill=112
c      6033   0     710 -711 659 -680  fill=112
c      6034   0     710 -711 680 -901  fill=112
c      6035   0     710 -711 901 -902  fill=112
c      6036   0     710 -711 902 -903  fill=112
c      6037   0     710 -711 903 -904  fill=112
c      6038   0     710 -711 904 -905  fill=13
c      6039   0     710 -711 905 -906  fill=13
c      6040   0     710 -711 906 -907  fill=13
c      6041   0     710 -711 907 -908  fill=13
c      6042   0     710 -711 908 -909  fill=13
c      6043   8 -7.82     710 -711 909 -910
c      6044   8 -7.82     710 -711 910 -911
c      6045   8 -7.82     710 -711 911 -912
c      6046   8 -7.82     710 -711 912 -913
c      6047   0     710 -711 913 -914
c      6048   0     710 -711 914 -915
c      6049   0     710 -711 915 -916
c      6050   0     710 -711 916 -917
c      6051   0     710 -711 917 -918
c
6100   7 -2.35   711 -713 817 -816
6101   0     711 -713 816 -815  fill=10
6102   0     711 -713 815 -814  fill=10
6103   0     711 -713 814 -813  fill=11
6104   0     711 -713 813 -812  fill=11
6105   0     711 -713 812 -811  fill=11
6106   0     711 -713 811 -810  fill=11
6107   0     711 -713 810 -809  fill=11
6108   0     711 -713 809 -808  fill=11
6109   0     711 -713 808 -807  fill=11
6110   0     711 -713 807 -806  fill=112
6111   0     711 -713 806 -805  fill=112
6112   0     711 -713 805 -804  fill=112
6113   0     711 -713 804 -803  fill=112
6114   0     711 -713 803 -802  fill=112
```

```
6115   0     711 -713 802 -801  fill=112
6116   0     711 -713 801 -610  fill=112
6117   0     711 -713 610 -615  fill=112
6118   0     711 -713 615 -620  fill=112
6119   0     711 -713 620 -420  fill=112
6120   0     711 -713 420 -430  fill=112
6121   0     711 -713 430 -445  fill=112
6122   0     711 -713 445 -460  fill=112
6123   0     711 -713 460 -675  fill=112
6124   0     711 -713 675 -651  fill=112
6125   0     711 -713 651 -652  fill=112
6126   0     711 -713 652 -653  fill=112
6127   0     711 -713 653 -654  fill=112
6128   0     711 -713 654 -655  fill=112
6129   0     711 -713 655 -656  fill=112
6130   0     711 -713 656 -657  fill=112
6131   0     711 -713 657 -658  fill=112
6132   0     711 -713 658 -659  fill=112
6133   0     711 -713 659 -680  fill=112
6134   0     711 -713 680 -901  fill=112
6135   0     711 -713 901 -902  fill=112
6136   0     711 -713 902 -903  fill=112
6137   0     711 -713 903 -904  fill=112
6138   0     711 -713 904 -905  fill=13
6139   0     711 -713 905 -906  fill=13
6140   0     711 -713 906 -907  fill=13
6141   0     711 -713 907 -908  fill=13
6142   0     711 -713 908 -909  fill=13
6143   8 -7.82    711 -713 909 -910
6144   8 -7.82    711 -713 910 -911
6145   8 -7.82    711 -713 911 -912
6146   8 -7.82    711 -713 912 -913
c      6147   0     711 -713 913 -914
c      6148   0     711 -713 914 -915
c      6149   0     711 -713 915 -916
c      6150   0     711 -713 916 -917
c      6151   0     711 -713 917 -918
c
c      6201   0     712 -713 816 -815  fill=10
c      6202   0     712 -713 815 -814  fill=10
c      6203   0     712 -713 814 -813  fill=11
c      6204   0     712 -713 813 -812  fill=11
c      6205   0     712 -713 812 -811  fill=11
c      6206   0     712 -713 811 -810  fill=11
c      6207   0     712 -713 810 -809  fill=11
c      6208   0     712 -713 809 -808  fill=11
c      6209   0     712 -713 808 -807  fill=11
c      6210   0     712 -713 807 -806  fill=112
c      6211   0     712 -713 806 -805  fill=112
c      6212   0     712 -713 805 -804  fill=112
c      6213   0     712 -713 804 -803  fill=112
c      6214   0     712 -713 803 -802  fill=112
c      6215   0     712 -713 802 -801  fill=112
c      6216   0     712 -713 801 -610  fill=112
c      6217   0     712 -713 610 -615  fill=112
c      6218   0     712 -713 615 -620  fill=112
c      6219   0     712 -713 620 -420  fill=112
c      6220   0     712 -713 420 -430  fill=112
c      6221   0     712 -713 430 -445  fill=112
c      6222   0     712 -713 445 -460  fill=112
c      6223   0     712 -713 460 -675  fill=112
c      6224   0     712 -713 675 -651  fill=112
c      6225   0     712 -713 651 -652  fill=112
c      6226   0     712 -713 652 -653  fill=112
c      6227   0     712 -713 653 -654  fill=112
```

```
c       6228    0     712 -713 654 -655   fill=112
c       6229    0     712 -713 655 -656   fill=112
c       6230    0     712 -713 656 -657   fill=112
c       6231    0     712 -713 657 -658   fill=112
c       6232    0     712 -713 658 -659   fill=112
c       6233    0     712 -713 659 -680   fill=112
c       6234    0     712 -713 680 -901   fill=112
c       6235    0     712 -713 901 -902   fill=112
c       6236    0     712 -713 902 -903   fill=112
c       6237    0     712 -713 903 -904   fill=112
c       6238    0     712 -713 904 -905   fill=13
c       6239    0     712 -713 905 -906   fill=13
c       6240    0     712 -713 906 -907   fill=13
c       6241    0     712 -713 907 -908   fill=13
c       6242    0     712 -713 908 -909   fill=13
c       6243    8 -7.82     712 -713 909 -910
c       6244    8 -7.82     712 -713 910 -911
c       6245    8 -7.82     712 -713 911 -912
c       6246    8 -7.82     712 -713 912 -913
c       6247    0     712 -713 913 -914
c       6248    0     712 -713 914 -915
c       6249    0     712 -713 915 -916
c       6250    0     712 -713 916 -917
c       6251    0     712 -713 917 -918
c
6300    7 -2.35    713 -714 817 -816
6301    0     713 -714 816 -815   fill=10
6302    0     713 -714 815 -814   fill=10
6303    0     713 -714 814 -813   fill=11
6304    0     713 -714 813 -812   fill=11
6305    0     713 -714 812 -811   fill=11
6306    0     713 -714 811 -810   fill=11
6307    0     713 -714 810 -809   fill=11
6308    0     713 -714 809 -808   fill=11
6309    0     713 -714 808 -807   fill=11
6310    0     713 -714 807 -806   fill=112
6311    0     713 -714 806 -805   fill=112
6312    0     713 -714 805 -804   fill=112
6313    0     713 -714 804 -803   fill=112
6314    0     713 -714 803 -802   fill=112
6315    0     713 -714 802 -801   fill=112
6316    0     713 -714 801 -610   fill=112
6317    0     713 -714 610 -615   fill=112
6318    0     713 -714 615 -620   fill=112
6319    0     713 -714 620 -420   fill=112
6320    0     713 -714 420 -430   fill=112
6321    0     713 -714 430 -445   fill=112
6322    0     713 -714 445 -460   fill=112
6323    0     713 -714 460 -675   fill=112
6324    0     713 -714 675 -651   fill=112
6325    0     713 -714 651 -652   fill=112
6326    0     713 -714 652 -653   fill=112
6327    0     713 -714 653 -654   fill=112
6328    0     713 -714 654 -655   fill=112
6329    0     713 -714 655 -656   fill=112
6330    0     713 -714 656 -657   fill=112
6331    0     713 -714 657 -658   fill=112
6332    0     713 -714 658 -659   fill=112
6333    0     713 -714 659 -680   fill=112
6334    0     713 -714 680 -901   fill=112
6335    0     713 -714 901 -902   fill=112
6336    0     713 -714 902 -903   fill=112
6337    0     713 -714 903 -904   fill=112
6338    0     713 -714 904 -905   fill=13
6339    0     713 -714 905 -906   fill=13
```

```
6340    0      713 -714 906 -907  fill=13
6341    0      713 -714 907 -908  fill=13
6342    0      713 -714 908 -909  fill=13
6343    8 -7.82     713 -714 909 -910
6344    8 -7.82     713 -714 910 -911
6345    8 -7.82     713 -714 911 -912
6346    8 -7.82     713 -714 912 -913
c       6347   0     713 -714 913 -914
c       6348   0     713 -714 914 -915
c       6349   0     713 -714 915 -916
c       6350   0     713 -714 916 -917
c       6351   0     713 -714 917 -918
c
6400    7 -2.35    714 -715 817 -816
6401    0      714 -715 816 -815  fill=10
6402    0      714 -715 815 -814  fill=10
6403    0      714 -715 814 -813  fill=11
6404    0      714 -715 813 -812  fill=11
6405    0      714 -715 812 -811  fill=11
6406    0      714 -715 811 -810  fill=11
6407    0      714 -715 810 -809  fill=11
6408    0      714 -715 809 -808  fill=11
6409    0      714 -715 808 -807  fill=11
6410    0      714 -715 807 -806  fill=112
6411    0      714 -715 806 -805  fill=112
6412    0      714 -715 805 -804  fill=112
6413    0      714 -715 804 -803  fill=112
6414    0      714 -715 803 -802  fill=112
6415    0      714 -715 802 -801  fill=112
6416    0      714 -715 801 -610  fill=112
6417    0      714 -715 610 -615  fill=112
6418    0      714 -715 615 -620  fill=112
6419    0      714 -715 620 -420  fill=112
6420    0      714 -715 420 -430  fill=112
6421    0      714 -715 430 -445  fill=112
6422    0      714 -715 445 -460  fill=112
6423    0      714 -715 460 -675  fill=112
6424    0      714 -715 675 -651  fill=112
6425    0      714 -715 651 -652  fill=112
6426    0      714 -715 652 -653  fill=112
6427    0      714 -715 653 -654  fill=112
6428    0      714 -715 654 -655  fill=112
6429    0      714 -715 655 -656  fill=112
6430    0      714 -715 656 -657  fill=112
6431    0      714 -715 657 -658  fill=112
6432    0      714 -715 658 -659  fill=112
6433    0      714 -715 659 -680  fill=112
6434    0      714 -715 680 -901  fill=112
6435    0      714 -715 901 -902  fill=112
6436    0      714 -715 902 -903  fill=112
6437    0      714 -715 903 -904  fill=112
6438    0      714 -715 904 -905  fill=13
6439    0      714 -715 905 -906  fill=13
6440    0      714 -715 906 -907  fill=13
6441    0      714 -715 907 -908  fill=13
6442    0      714 -715 908 -909  fill=13
6443    0      714 -715 909 -910  fill=15
6444    0      714 -715 910 -911  fill=15
6445    0      714 -715 911 -912  fill=15
6446    0      714 -715 912 -913  fill=15
c       6447   0     714 -715 913 -914
c       6448   0     714 -715 914 -915
c       6449   0     714 -715 915 -916
c       6450   0     714 -715 916 -917
c       6451   0     714 -715 917 -918
```

```
c
6500    7 -2.35    715 -716 817 -816
6501    0      715 -716 816 -815   fill=10
6502    0      715 -716 815 -814   fill=10
6503    0      715 -716 814 -813   fill=11
6504    0      715 -716 813 -812   fill=11
6505    0      715 -716 812 -811   fill=11
6506    0      715 -716 811 -810   fill=11
6507    0      715 -716 810 -809   fill=11
6508    0      715 -716 809 -808   fill=11
6509    0      715 -716 808 -807   fill=11
6510    0      715 -716 807 -806   fill=12
6511    0      715 -716 806 -805   fill=12
6512    0      715 -716 805 -804   fill=12
6513    0      715 -716 804 -803   fill=12
6514    0      715 -716 803 -802   fill=12
6515    0      715 -716 802 -801   fill=12
6516    0      715 -716 801 -610   fill=12
6517    0      715 -716 610 -615   fill=12
6518    0      715 -716 615 -620   fill=12
6519    0      715 -716 620 -420   fill=12
6520    0      715 -716 420 -430   fill=12
6521    0      715 -716 430 -445   fill=12
6522    0      715 -716 445 -460   fill=12
6523    0      715 -716 460 -675   fill=12
6524    0      715 -716 675 -651   fill=12
6525    0      715 -716 651 -652   fill=12
6526    0      715 -716 652 -653   fill=12
6527    0      715 -716 653 -654   fill=12
6528    0      715 -716 654 -655   fill=12
6529    0      715 -716 655 -656   fill=12
6530    0      715 -716 656 -657   fill=12
6531    0      715 -716 657 -658   fill=12
6532    0      715 -716 658 -659   fill=12
6533    0      715 -716 659 -680   fill=12
6534    0      715 -716 680 -901   fill=12
6535    0      715 -716 901 -902   fill=12
6536    0      715 -716 902 -903   fill=12
6537    0      715 -716 903 -904   fill=12
6538    0      715 -716 904 -905   fill=13
6539    0      715 -716 905 -906   fill=13
6540    0      715 -716 906 -907   fill=13
6541    0      715 -716 907 -908   fill=13
6542    0      715 -716 908 -909   fill=13
6543    0      715 -716 909 -910
6544    0      715 -716 910 -911
6545    0      715 -716 911 -912
6546    0      715 -716 912 -913
c       6547    0     715 -716 913 -914
c       6548    0     715 -716 914 -915
c       6549    0     715 -716 915 -916
c       6550    0     715 -716 916 -917
c       6551    0     715 -716 917 -918
c
6601    0      716 -717 816 -815
6602    0      716 -717 815 -814
6603    0      716 -717 814 -813
6604    0      716 -717 813 -812
6605    0      716 -717 812 -811
6606    0      716 -717 811 -810
6607    0      716 -717 810 -809
6608    0      716 -717 809 -808
6609    0      716 -717 808 -807
6610    0      716 -717 807 -806
6611    0      716 -717 806 -805
```

```
6612    0     716 -717 805 -804
6613    0     716 -717 804 -803
6614    0     716 -717 803 -802
6615    0     716 -717 802 -801
6616    0     716 -717 801 -610
6617    0     716 -717 610 -615
6618    0     716 -717 615 -620
6619    0     716 -717 620 -420
6620    0     716 -717 420 -430
6621    0     716 -717 430 -445
6622    0     716 -717 445 -460
6623    0     716 -717 460 -675
6624    0     716 -717 675 -651
6625    0     716 -717 651 -652
6626    0     716 -717 652 -653
6627    0     716 -717 653 -654
6628    0     716 -717 654 -655
6629    0     716 -717 655 -656
6630    0     716 -717 656 -657
6631    0     716 -717 657 -658
6632    0     716 -717 658 -659
6633    0     716 -717 659 -680
6634    0     716 -717 680 -901
6635    0     716 -717 901 -902
6636    0     716 -717 902 -903
6637    0     716 -717 903 -904
6638    0     716 -717 904 -905
6639    0     716 -717 905 -906
6640    0     716 -717 906 -907
6641    0     716 -717 907 -908
6642    0     716 -717 908 -909
6643    0     716 -717 909 -910
6644    0     716 -717 910 -911
6645    0     716 -717 911 -912
6646    0     716 -717 912 -913
6647    0     716 -717 913 -914
6648    0     716 -717 914 -915
6649    0     716 -717 915 -916
6650    0     716 -717 916 -917
6651    0     716 -717 917 -918
c
c       overpack universes
c       overpack baseplate
10001  8 -7.82     371 -372 373 -374   u=10
10002  8 -7.82     374 -362            u=10
10003  8 -7.82     374  363            u=10
10004  9 -1.17e-3 374 362 -363         u=10
10005  8 -7.82    -371  367 -374       u=10
10006  8 -7.82    -371  373 -366       u=10
10007  9 -1.17e-3 -371  366 -367       u=10
10008  8 -7.82    -373 -362            u=10
10009  8 -7.82    -373 363             u=10
10010  9 -1.17e-3 -373 362 -363        u=10
10011  8 -7.82      372 373 -366       u=10
10012  8 -7.82      372 367 -374       u=10
10013  9 -1.17e-3  372 366 -367        u=10
c
c       walls and top of bottom duct
10101  8 -7.82      361 -362 -932        u=11
10102  8 -7.82      363 -364 -932        u=11
10103  8 -7.82      362 -363  931 -932 u=11
c
10104  8 -7.82      365 -366 -932        u=11
10105  8 -7.82      367 -368 -932        u=11
10106  8 -7.82      366 -367  931 -932 u=11
```

```
c      inner and outer shell between bottom ducts
10107  8 -7.82     368 364 -932 315   u=11
10108  8 -7.82     368 -361 -932 315  u=11
10109  8 -7.82    -365 364 -932 315   u=11
10110  8 -7.82    -365 -361 -932 315  u=11
c
10111  8 -7.82     368 364 -932 -310  u=11
10112  8 -7.82     368 -361 -932 -310 u=11
10113  8 -7.82    -365 364 -932 -310  u=11
10114  8 -7.82    -365 -361 -932 -310 u=11
c      concrete and radial plates between bottom ducts
10121  8 -7.82     310 -315 391 -392  -932 u=11
10122  8 -7.82     310 -315 393 -394  -932 u=11
c
10131  7 -2.35     310 -315 394 -365  -932 u=11
10132  7 -2.35     310 -315 368 -391  -932 u=11
10133  7 -2.35     310 -315 392  364  -932 u=11
10134  7 -2.35     310 -315 -361 394  -932 u=11
10135  7 -2.35     310 -315 368 -393  -932 u=11
10136  7 -2.35     310 -315 392 -365  -932 u=11
10137  7 -2.35     310 -315 -391 -361 -932 u=11
10138  7 -2.35     310 -315 364 -393  -932 u=11
c      air and grid spacers in bottom ducts
10141  9 -1.17e-3  362 -363 -931 263 -264 u=11
10142  9 -1.17e-3  366 -367 -931 261 -262 u=11
c
10143  9 -1.17e-3  362 -201 -931 (-263:264) u=11
10144  9 -1.17e-3  206 -363 -931 (-263:264) u=11
10145  9 -1.17e-3  201 -202 -221 (-263:264) u=11
10146  5 -7.92     202 -203 -221 (-273:274) u=11
11146  9 -1.17e-3  202 -203 -221 273 -274 (-263:264) u=11
10147  9 -1.17e-3  203 -204 -221 (-263:264) u=11
10148  5 -7.92     204 -205 -221 (-273:274) u=11
11148  9 -1.17e-3  204 -205 -221 273 -274 (-263:264) u=11
10149  9 -1.17e-3  205 -206 -221 (-263:264) u=11
10150  5 -7.92     201 -202 221 -222 (-263:264) u=11
10151  5 -7.92     202 -203 221 -222 (-263:264) u=11
10152  5 -7.92     203 -204 221 -222 (-263:264) u=11
10153  5 -7.92     204 -205 221 -222 (-263:264) u=11
10154  5 -7.92     205 -206 221 -222 (-263:264) u=11
10155  9 -1.17e-3  201 -202 222 -223 (-263:264) u=11
10156  5 -7.92     202 -203 222 -223 (-263:264) u=11
10157  9 -1.17e-3  203 -204 222 -223 (-263:264) u=11
10158  5 -7.92     204 -205 222 -223 (-263:264) u=11
10159  9 -1.17e-3  205 -206 222 -223 (-263:264) u=11
10160  5 -7.92     201 -202 223 -224 (-263:264) u=11
10161  5 -7.92     202 -203 223 -224 (-263:264) u=11
10162  5 -7.92     203 -204 223 -224 (-263:264) u=11
10163  5 -7.92     204 -205 223 -224 (-263:264) u=11
10164  5 -7.92     205 -206 223 -224 (-263:264) u=11
10165  9 -1.17e-3  201 -202 224 -225 (-263:264) u=11
10166  5 -7.92     202 -203 224 -225 (-263:264) u=11
10167  9 -1.17e-3  203 -204 224 -225 (-263:264) u=11
10168  5 -7.92     204 -205 224 -225 (-263:264) u=11
10169  9 -1.17e-3  205 -206 224 -225 (-263:264) u=11
10170  9 -1.17e-3  201 -206 225 -931 (-263:264) u=11
c
10243  9 -1.17e-3  366 -211 -931 (-261:262) u=11
10244  9 -1.17e-3  216 -367 -931 (-261:262) u=11
10245  9 -1.17e-3  211 -212 -221 (-261:262) u=11
10246  5 -7.92     212 -213 -221 (-261:262) u=11
10247  9 -1.17e-3  213 -214 -221 (-261:262) u=11
10248  5 -7.92     214 -215 -221 (-261:262) u=11
10249  9 -1.17e-3  215 -216 -221 (-261:262) u=11
10250  5 -7.92     211 -212 221 -222 (-261:262) u=11
```

```
10251  5 -7.92      212 -213 221 -222 (-261:262) u=11
10252  5 -7.92      213 -214 221 -222 (-261:262) u=11
10253  5 -7.92      214 -215 221 -222 (-261:262) u=11
10254  5 -7.92      215 -216 221 -222 (-261:262) u=11
10255  9 -1.17e-3  211 -212 222 -223 (-261:262) u=11
10256  5 -7.92      212 -213 222 -223 (-261:262) u=11
10257  9 -1.17e-3  213 -214 222 -223 (-261:262) u=11
10258  5 -7.92      214 -215 222 -223 (-261:262) u=11
10259  9 -1.17e-3  215 -216 222 -223 (-261:262) u=11
10260  5 -7.92      211 -212 223 -224 (-261:262) u=11
10261  5 -7.92      212 -213 223 -224 (-261:262) u=11
10262  5 -7.92      213 -214 223 -224 (-261:262) u=11
10263  5 -7.92      214 -215 223 -224 (-261:262) u=11
10264  5 -7.92      215 -216 223 -224 (-261:262) u=11
10265  9 -1.17e-3  211 -212 224 -225 (-261:262) u=11
10266  5 -7.92      212 -213 224 -225 (-261:262) u=11
10267  9 -1.17e-3  213 -214 224 -225 (-261:262) u=11
10268  5 -7.92      214 -215 224 -225 (-261:262) u=11
10269  9 -1.17e-3  215 -216 224 -225 (-261:262) u=11
10270  9 -1.17e-3  211 -216 225 -931 (-261:262) u=11
c
c      inner, outer shells and concrete between top and bot ducts
c
10301  8 -7.82      932       -311 u=11
10302  8 -7.82      932        315 u=11
10303  8 -7.82  932       311 -315 391 -392  u=11
10304  8 -7.82  932       311 -315 393 -394  u=11
10305  7 -2.35  932       311 -315 394 -391  u=11
10306  7 -2.35  932       311 -315 392  394  u=11
10307  7 -2.35  932       311 -315 392 -393  u=11
10308  7 -2.35  932      311 -315 -391 -393  u=11
c
11302  8 -7.82                315 u=12
11303  8 -7.82              -315 391 -392  u=12
11304  8 -7.82              -315 393 -394  u=12
11305  7 -2.35              -315 394 -391  u=12
11306  7 -2.35              -315 392  394  u=12
11307  7 -2.35              -315 392 -393  u=12
11308  7 -2.35             -315 -391 -393  u=12
c
13303  8 -7.82              391 -392  u=112
13304  8 -7.82              393 -394  u=112
13305  7 -2.35              394 -391  u=112
13306  7 -2.35              392  394  u=112
13307  7 -2.35              392 -393  u=112
13308  7 -2.35             -391 -393  u=112
c
12301  8 -7.82          -933 -311 u=13
12302  8 -7.82          -933  315 u=13
12303  8 -7.82      -933  311 -315 391 -392  u=13
12304  8 -7.82      -933  311 -315 393 -394  u=13
12305  7 -2.35      -933  311 -315 394 -391  u=13
12306  7 -2.35      -933  311 -315 392  394  u=13
12307  7 -2.35      -933  311 -315 392 -393  u=13
12308  7 -2.35      -933 311 -315 -391 -393  u=13
c      top duct bottom plates
10309  8 -7.82  933 -934 351 -354  u=13
10310  8 -7.82  933 -934 355 -358  u=13
c      top duct walls
10311  8 -7.82  934      351 -352  u=13
10312  8 -7.82  934      353 -354  u=13
10313  8 -7.82  934      355 -356  u=13
10314  8 -7.82  934      357 -358  u=13
c      inner and outer shell between top ducts
10407  8 -7.82     358 354  933 315   u=13
```

```
10408  8 -7.82     358 -351  933 315  u=13
10409  8 -7.82    -355 354  933 315   u=13
10410  8 -7.82    -355 -351  933 315  u=13
c
10411  8 -7.82     358 354  933 -310  u=13
10412  8 -7.82     358 -351  933 -310 u=13
10413  8 -7.82    -355 354  933 -310  u=13
10414  8 -7.82    -355 -351  933 -310 u=13
c      concrete and radial plates next to top ducts
10421  8 -7.82     310 -315 391 -392  933 -935 u=13
10422  8 -7.82     310 -315 393 -394  933 -935 u=13
c
10431  7 -2.35     310 -315 394 -355  933 -935 u=13
10432  7 -2.35     310 -315 358 -391  933 -935 u=13
10433  7 -2.35     310 -315 392  354  933 -935 u=13
10434  7 -2.35     310 -315 -351 394  933 -935 u=13
10435  7 -2.35     310 -315 358 -393  933 -935 u=13
10436  7 -2.35     310 -315 392 -355  933 -935 u=13
10437  7 -2.35     310 -315 -391 -351 933 -935 u=13
10438  7 -2.35     310 -315 354 -393  933 -935 u=13
c
c      air and grid spacers in top ducts
10441  9 -1.17e-3  352 -353  934 263 -264 u=13
10442  9 -1.17e-3  356 -357  934 261 -262 u=13
c
10443  9 -1.17e-3  352 -231  934 (-263:264) u=13
10444  9 -1.17e-3  236 -353  934 (-263:264) u=13
c
10445  9 -1.17e-3  231 -232 934 -251 (-263:264) u=13
10446  5 -7.92     232 -233 934 -251 (-263:264) u=13
10447  9 -1.17e-3  233 -234 934 -251 (-263:264) u=13
10448  5 -7.92     234 -235 934 -251 (-263:264) u=13
10449  9 -1.17e-3  235 -236 934 -251 (-263:264) u=13
10450  5 -7.92     231 -232 251 -252 (-263:264) u=13
10451  5 -7.92     232 -233 251 -252 (-263:264) u=13
10452  5 -7.92     233 -234 251 -252 (-263:264) u=13
10453  5 -7.92     234 -235 251 -252 (-263:264) u=13
10454  5 -7.92     235 -236 251 -252 (-263:264) u=13
10455  9 -1.17e-3  231 -232 252 -253 (-263:264) u=13
10456  5 -7.92     232 -233 252 -253 (-263:264) u=13
10457  9 -1.17e-3  233 -234 252 -253 (-263:264) u=13
10458  5 -7.92     234 -235 252 -253 (-263:264) u=13
10459  9 -1.17e-3  235 -236 252 -253 (-263:264) u=13
10470  9 -1.17e-3  231 -236 253       (-263:264) u=13
c
10543  9 -1.17e-3  356 -241  934 (-261:262) u=13
10544  9 -1.17e-3  246 -357  934 (-261:262) u=13
c
10545  9 -1.17e-3  241 -242 934 -251 (-261:262) u=13
10546  5 -7.92     242 -243 934 -251 (-261:262) u=13
10547  9 -1.17e-3  243 -244 934 -251 (-261:262) u=13
10548  5 -7.92     244 -245 934 -251 (-261:262) u=13
10549  9 -1.17e-3  245 -246 934 -251 (-261:262) u=13
10550  5 -7.92     241 -242 251 -252 (-261:262) u=13
10551  5 -7.92     242 -243 251 -252 (-261:262) u=13
10552  5 -7.92     243 -244 251 -252 (-261:262) u=13
10553  5 -7.92     244 -245 251 -252 (-261:262) u=13
10554  5 -7.92     245 -246 251 -252 (-261:262) u=13
10555  9 -1.17e-3  241 -242 252 -253 (-261:262) u=13
10556  5 -7.92     242 -243 252 -253 (-261:262) u=13
10557  9 -1.17e-3  243 -244 252 -253 (-261:262) u=13
10558  5 -7.92     244 -245 252 -253 (-261:262) u=13
10559  9 -1.17e-3  245 -246 252 -253 (-261:262) u=13
10570  9 -1.17e-3  241 -246 253       (-261:262) u=13
c      top plate
```

```
10641  8 -7.82     358 354  935 310 -315   u=13
10642  8 -7.82     358 -351  935 310 -315  u=13
10643  8 -7.82    -355 354  935 310 -315   u=13
10644  8 -7.82    -355 -351  935 310 -315  u=13
c
10701  8 -7.82    -314 u=15
10702  0           314 u=15
c
10711  7 -2.35     -312      u=14
10712  8 -7.82      312 -313 u=14
10713  0            313      u=14
c
99999   0 -817:918:717:(716 -816)
c
c      BLANK LINE

c      BLANK LINE
c
c      MPC surfaces\/ \/ \/ \/ \/
c
10     px        -12.169775
11     px        -12.017375
12     px        -11.826875
13     px        -11.1125
14     px         11.1125
15     px         11.826875
16     px         12.017375
17     px         12.169775
18     py        -12.169775
19     py        -12.017375
20     py        -11.826875
21     py        -11.1125
22     py         11.1125
23     py         11.826875
24     py         12.017375
25     py         12.169775
c
26     py  -9.525
27     py   9.525
28     px  -9.525
29     px   9.525
30     py  -6.35
31     py   6.35
32     px  -6.35
33     px   6.35
c
35     px  -11.46969
36     px   11.46969
37     py  -11.46969
38     py   11.46969
c
40     px  -10.8204
41     px   10.8204
42     py  -10.8204
43     py   10.8204
c
101    py  82.12074
102    py  54.74716
103    py  27.37358
104    py  0.0
105    py -27.37358
106    py -54.74716
107    py -82.12074
c
116    px  82.12074
```

```
115    px  54.74716
114    px  27.37358
113    px  0.0
112    px -27.37358
111    px -54.74716
110    px -82.12074
c
301    cz   85.56625
302    cz   86.83625
c
c      620   pz    21.59     $ MPC baseplate        - 2.5 inches
400    pz   23.876   $ start of egg crate
410    pz   28.8925  $ start of boral
415    pz   32.004   $ begin fuel element
420    pz   50.7365  $ end of lower nozzle
425    pz   53.2765  $ end of space/ start of active fuel
430    pz   419.0365 $ end of active fuel
435    pz   425.1325 $ boral ends
440    pz   428.72025 $ space above fuel
445    pz   439.83275 $ plenum spacer ends
455    pz   452.6915  $ top of top nozzle
460    pz   467.614   $ top of basket
c
610    pz    15.24      $ overpack baseplate
615    pz    17.78
616    pz    20.32
620    pz    21.59      $ MPC baseplate        - 2.5 inches
675    pz    474.98     $ bottom of MPC in lid - 178.5 inches from 620
651    pz    476.25     $ 0.25 inch first segment
652    pz    478.79
653    pz    481.33
654    pz    483.87
655    pz    486.41
656    pz    488.95
657    pz    491.49
658    pz    494.03
659    pz    496.57
680    pz    499.11     $ top of MPC outer lid
c
c      MPC surfaces/\ /\ /\ /\ /\
c
c      overpack surfaces
c
303    cz    80.01      $ ID of item 27
304    cz    81.28      $ OD of item 27
305    cz    85.09      $ ID of item 7
306    cz    86.20125   $ ID of item 5
307    cz    87.63      $ OD of item 7
c
310    cz    96.52      $ outer rad of item 3 overpack inner shell
311    cz    98.425     $ outer rad of item 28
312    cz    107.95    $ ID of item 26
313    cz    109.22    $ OD of item 26
314    cz    160.02    $ OD of item 10
315    cz    166.37    $ ID of item 2
c      top duct planes
351    px    -33.02  $ start of item 12
352    px    -31.75  $ end of item 12
353    px     31.75  $ start of item 12
354    px     33.02  $ end of item 12
c
355    py    -33.02  $ start of item 12
356    py    -31.75  $ end of item 12
357    py     31.75  $ start of item 12
358    py     33.02  $ end of item 12
```

```
c     bottom duct planes
361   px    -20.955  $ start of item 13
362   px    -19.05  $ end of item 13
363   px     19.05  $ start of item 13
364   px     20.955  $ end of item 13
c
365   py    -20.955  $ start of item 13
366   py    -19.05  $ end of item 13
367   py     19.05  $ start of item 13
368   py     20.955  $ end of item 13
c     cutouts in item 1
371   px    -123.19
372   px     123.19
373   py    -123.19
374   py     123.19
c       item 14
391   1 py    -0.9525    $ steel plate in concrete at 45/225 degrees
392   1 py     0.9525    $ steel plate in concrete at 45/225 degrees
393   1 px    -0.9525    $ steel plate in concrete at 135/315 degrees
394   1 px     0.9525    $ steel plate in concrete at 135/315 degrees
c
c     bottom shielding cross plates
c
201   px   -18.57375
202   px   -6.35
203   px   -5.715
204   px    5.715
205   px    6.35
206   px    18.57375
c
211   py   -18.57375
212   py   -6.35
213   py   -5.715
214   py    5.715
215   py    6.35
216   py    18.57375
c
221   pz   -32.8168
222   pz   -32.1818
223   pz   -24.3586
224   pz   -23.7236
225   pz   -15.9004
c
c     top shielding cross plates
c
231   px   -31.27375
232   px   -10.795
233   px   -10.16
234   px    10.16
235   px    10.795
236   px    31.27375
c
241   py   -31.27375
242   py   -10.795
243   py   -10.16
244   py    10.16
245   py    10.795
246   py    31.27375
c
251   pz    523.24
252   pz    523.875
253   pz    530.86
c     end of cross plates in openings
261   px   -107.315
262   px    107.315
```

```
263     py    -107.315
264     py     107.315
c       end of part of bottom cross plates
271     px    -124.46
272     px     124.46
273     py    -124.46
274     py     124.46
c
c       radial planes in overpack
700     cz     93.345  $ ID of overpack
701     cz     95.885
702     cz     98.5  $ slightly diff from  311
703     cz     103.505
704     cz     108.585
705     cz     113.665
706     cz     118.745
707     cz     123.825
708     cz     128.905
709     cz     133.985
710     cz     139.065
711     cz     144.145
712     cz     149.225
713     cz     154.305
714     cz     159.385
715     cz     164.465
716     cz     168.275
717     cz     169.275
c
c       planes in pedestal
c
801     pz     12.7
802     pz     10.16
803     pz     7.62
804     pz     5.08
805     pz     2.54  $ bottom of item 24
806     pz    -2.54
807     pz    -7.62
808     pz    -12.7
809     pz    -17.78
810     pz    -22.86
811     pz    -27.94
812     pz    -33.02
813     pz    -38.1
814     pz    -40.64 $ start of item 1
815     pz    -43.18 $
816     pz    -45.72 $ ground
817     pz    -76.20
c
c       planes in lid
c
901     pz     501.65 $ start of item 6
902     pz     502.285 $ 0.25 inch segement from start
903     pz     504.825 $ end of item 6
904     pz     509.905
905     pz     513.715
906     pz     516.3 $ end of item 8 plus a little
907     pz     521.335
908     pz     526.415
909     pz     531.495 $ end of concrete start of item 10
910     pz     534.035
911     pz     536.575
912     pz     539.115
913     pz     541.655 $ end of item 10
914     pz     546.735
915     pz     551.815
```

```
916     pz     556.895
917     pz     561.975
918     pz     562.975
c
c       planes in overpack
c
931     pz    -15.24    $ bottom of item 11
932     pz    -10.16    $ top of item 11
933     pz     513.08   $ bottom of item 8 and top of item 28
934     pz     516.255  $ top of item 8
935     pz     529.59   $ start of item 9
c
c       for tallying
c
501     pz    -45.72
502     pz    -30.48
503     pz    -15.24
504     pz    0.00
505     pz    15.24
506     pz    30.48
507     pz    45.72
508     pz    60.96
509     pz    76.20
510     pz    91.44
511     pz    106.68
512     pz    121.92
513     pz    137.16
514     pz    152.40
515     pz    167.64
516     pz    182.88
517     pz    198.12
518     pz    213.36
519     pz    228.60
520     pz    243.84
521     pz    259.08
522     pz    274.32
523     pz    289.56
524     pz    304.80
525     pz    320.04
526     pz    335.28
527     pz    350.52
528     pz    365.76
529     pz    381.00
530     pz    396.24
531     pz    411.48
532     pz    426.72
533     pz    441.96
534     pz    457.20
535     pz    472.44
536     pz    487.68
537     pz    502.92
538     pz    518.16
539     pz    533.40
c
550     cz    15.24
551     cz    30.48
552     cz    45.72
553     cz    60.96
554     cz    76.20
555     cz    91.44
556     cz    106.68
557     cz    121.92
558     cz    137.16
559     cz    152.40
560     cz    167.64
```

```
c
c     BLANK LINE

c     BLANK LINE
c
*tr1    0 0 0 45   315   90  135   45   90   90 90 0
c
c         PHOTON MATERIALS
c
c     fuel 3.4 w/o U235  10.412 gm/cc
m1           92235.01p   -0.029971
             92238.01p   -0.851529
             8016.01p    -0.1185
c     homogenized fuel  density 3.8699 gm/cc
m2           92235.01p   -0.027652
             92238.01p   -0.719715
              8016.01p   -0.100469
             40000.01p   -0.149015
             50000.01p   -0.002587
             26000.01p   -0.000365
             24000.01p   -0.000198
c     zirconium 6.55 gm/cc
m3           40000.01p   1.          $ Zr Clad
c     stainless steel 7.92 gm/cc
m5           24000.01p   -0.19
             25055.01p   -0.02
             26000.01p   -0.695
             28000.01p   -0.095
c     boral  2.644 gm/cc
m6           5010.01p    -0.044226
             5011.01p    -0.201474
             13027.01p   -0.6861
             6000.01p    -0.0682
c             Concrete (NBS Ordinary) @ 2.35 g/cc (Ref: LA-12827-M)
m7           14000.01p  -0.315
             13027.01p  -0.048
             8016.01p   -0.500
             1001.01p   -0.006
             11023.01p  -0.017
             20000.01p  -0.083
             26000.01p  -0.012
             19000.01p  -0.019
c     carbon steel 7.82 gm/cc
m8      6000.01p -0.005 26000.01p -0.995
c     air density 1.17e-3 gm/cc
m9      7014.01p 0.78 8016.01p 0.22
c     c
c     c          NEUTRON MATERIALS
c
c     fuel 3.4 w/o U235  10.412 gm/cc
c     m1             92235.50c   -0.029971
c                    92238.50c   -0.851529
c                    8016.50c    -0.1185
c     c     homogenized fuel  density 3.8699 gm/cc
c     m2             92235.50c   -0.027652
c                    92238.50c   -0.719715
c                     8016.50c   -0.100469
c                    40000.35c   -0.149015
c                    50000.35c   -0.002587
c                    26000.55c   -0.000365
c                    24000.50c   -0.000198
c     c     helium  1e-4 gm/cc
c     m3     2004.50c 1.0
c     c     stainless steel 7.92 gm/cc
c     m5             24000.50c   -0.19
```

```
c                    25055.50c   -0.02
c                    26000.55c   -0.695
c                    28000.50c   -0.095
c      c     boral  2.644 gm/cc
c      m6            5010.50c    -0.044226
c                    5011.56c    -0.201474
c                    13027.50c   -0.6861
c                    6000.50c    -0.0682
c      c              Concrete (NBS Ordinary) @ 2.35 g/cc (Ref: LA-12827-M)
c      m7            14000.50c  -0.315
c                    13027.50c  -0.048
c                    8016.50c   -0.500
c                    1001.50c   -0.006
c                    11023.50c  -0.017
c                    20000.50c  -0.083
c                    26000.55c  -0.012
c                    19000.50c  -0.019
c      mt7          lwtr.01t
c      c     carbon steel 7.82 gm/cc
c      m8      6000.50c -0.005 26000.55c -0.995
c      c     air density 1.17e-3 gm/cc
c      m9      7014.50c 0.78 8016.50c 0.22
c
phys:n   20 0.0
phys:p   100 0
c      imp:n   1 228r 0
c      imp:p   1 228r 0
nps     13500000
prdmp    j   -60   1   2
c      print   10 110 160 161 20 170
print
mode p
ssw   716 917
c
sdef  par=2  erg=d1 axs=0 0 1 x=d4 y=fx d5 z=d3
c
c     energy dist for gammas in the fuel
c
c     si1  h  0.7 1.0 1.5 2.0 2.5 3.0
c     sp1     0  0.43 0.27 0.22 0.04 0.04
c
c     energy dist for neutrons in the fuel
c
c     si1  h  0.1 0.4 0.9 1.4 1.85 3.0 6.43 20.0
c     sp1     0   0.03787 0.1935 0.1773 0.1310 0.2320 0.2098 0.01853
c
c     energy dist for Co60 gammas
c
si1  l 1.3325 1.1732
sp1    0.5    0.5
c
c     axial dist for phot in fuel
c
c     si3  h 53.2765 68.5165 83.7565 114.2365 175.1965 236.1565
c            297.1165 358.0765 388.5565 403.7965 419.0365
c     sp3  0 0.022854 0.035321 0.08975 0.184167 0.183 0.179833
c            0.175017 0.080033 0.030575 0.019458
c     sb3  0 1 1 1 1 1 1 1 1 1 1
c
c     axial dist for Co60 - a zero prob is in the fuel
c
si3  h 32.004 50.7365 419.0365 428.72025 439.83275 452.6915
sp3    0      0.44    0.0       0.05      0.05       0.46
sb3    0      0.50    0.0       0.05      0.10       0.35
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
#    imp:p
314      2
315      2
316      2
317      2
318      2
319      2
320      2
321      2
346      2
353      2
360      2
361      2
362      2
363      2
364      2
365      2
366      2
367      2
414      2
415      2
416      2
417      2
```

| | |
|---|---|
| 418 | 2 |
| 419 | 2 |
| 420 | 2 |
| 421 | 2 |
| 446 | 2 |
| 453 | 2 |
| 460 | 2 |
| 461 | 2 |
| 462 | 2 |
| 463 | 2 |
| 464 | 2 |
| 465 | 2 |
| 466 | 2 |
| 467 | 2 |
| 514 | 2 |
| 515 | 2 |
| 516 | 2 |
| 517 | 2 |
| 518 | 2 |
| 519 | 2 |
| 520 | 2 |
| 521 | 2 |
| 546 | 2 |
| 553 | 2 |
| 560 | 2 |
| 561 | 2 |
| 562 | 2 |
| 563 | 2 |
| 564 | 2 |
| 565 | 2 |
| 566 | 2 |
| 567 | 2 |
| 614 | 2 |
| 615 | 2 |
| 616 | 2 |
| 617 | 2 |
| 618 | 2 |
| 619 | 2 |
| 620 | 2 |
| 621 | 2 |
| 646 | 2 |
| 653 | 2 |
| 660 | 2 |
| 661 | 2 |
| 662 | 2 |
| 663 | 2 |
| 664 | 2 |
| 665 | 2 |
| 666 | 2 |
| 667 | 2 |
| 714 | 2 |
| 715 | 2 |
| 716 | 2 |
| 717 | 2 |
| 718 | 2 |
| 719 | 2 |
| 720 | 2 |
| 721 | 2 |
| 746 | 2 |
| 753 | 2 |
| 760 | 2 |
| 761 | 2 |
| 762 | 2 |
| 763 | 2 |
| 764 | 2 |

```
765     2
766     2
767     2
322     1
323     1
324     1
325     1
326     1
327     1
328     1
329     1
347     1
355     1
368     1
369     1
370     1
371     1
372     1
373     1
374     1
375     1
422     1
423     1
424     1
425     1
426     1
427     1
428     1
429     1
447     1
455     1
468     1
469     1
470     1
471     1
472     1
473     1
474     1
475     1
522     1
523     1
524     1
525     1
526     1
527     1
528     1
529     1
547     1
555     1
568     1
569     1
570     1
571     1
572     1
573     1
574     1
575     1
622     1
623     1
624     1
625     1
626     1
627     1
628     1
629     1
```

| | |
|---|---|
| 647 | 1 |
| 655 | 1 |
| 668 | 1 |
| 669 | 1 |
| 670 | 1 |
| 671 | 1 |
| 672 | 1 |
| 673 | 1 |
| 674 | 1 |
| 675 | 1 |
| 722 | 1 |
| 723 | 1 |
| 724 | 1 |
| 725 | 1 |
| 726 | 1 |
| 727 | 1 |
| 728 | 1 |
| 729 | 1 |
| 747 | 1 |
| 755 | 1 |
| 768 | 1 |
| 769 | 1 |
| 770 | 1 |
| 771 | 1 |
| 772 | 1 |
| 773 | 1 |
| 774 | 1 |
| 775 | 1 |
| 330 | 2 |
| 331 | 2 |
| 332 | 2 |
| 333 | 2 |
| 334 | 2 |
| 335 | 2 |
| 336 | 2 |
| 337 | 2 |
| 348 | 2 |
| 356 | 2 |
| 357 | 2 |
| 376 | 2 |
| 377 | 2 |
| 378 | 2 |
| 379 | 2 |
| 380 | 2 |
| 381 | 2 |
| 382 | 2 |
| 383 | 2 |
| 430 | 2 |
| 431 | 2 |
| 432 | 2 |
| 433 | 2 |
| 434 | 2 |
| 435 | 2 |
| 436 | 2 |
| 437 | 2 |
| 448 | 2 |
| 456 | 2 |
| 457 | 2 |
| 476 | 2 |
| 477 | 2 |
| 478 | 2 |
| 479 | 2 |
| 480 | 2 |
| 481 | 2 |
| 482 | 2 |

| | |
|---|---|
| 483 | 2 |
| 530 | 2 |
| 531 | 2 |
| 532 | 2 |
| 533 | 2 |
| 534 | 2 |
| 535 | 2 |
| 536 | 2 |
| 537 | 2 |
| 548 | 2 |
| 556 | 2 |
| 557 | 2 |
| 576 | 2 |
| 577 | 2 |
| 578 | 2 |
| 579 | 2 |
| 580 | 2 |
| 581 | 2 |
| 582 | 2 |
| 583 | 2 |
| 630 | 2 |
| 631 | 2 |
| 632 | 2 |
| 633 | 2 |
| 634 | 2 |
| 635 | 2 |
| 636 | 2 |
| 637 | 2 |
| 648 | 2 |
| 656 | 2 |
| 657 | 2 |
| 676 | 2 |
| 677 | 2 |
| 678 | 2 |
| 679 | 2 |
| 680 | 2 |
| 681 | 2 |
| 682 | 2 |
| 683 | 2 |
| 730 | 2 |
| 731 | 2 |
| 732 | 2 |
| 733 | 2 |
| 734 | 2 |
| 735 | 2 |
| 736 | 2 |
| 737 | 2 |
| 748 | 2 |
| 756 | 2 |
| 757 | 2 |
| 776 | 2 |
| 777 | 2 |
| 778 | 2 |
| 779 | 2 |
| 780 | 2 |
| 781 | 2 |
| 782 | 2 |
| 783 | 2 |
| 349 | 4 |
| 358 | 4 |
| 384 | 4 |
| 385 | 4 |
| 386 | 4 |
| 387 | 4 |
| 388 | 4 |

```
389      4
390      4
391      4
449      4
458      4
484      4
485      4
486      4
487      4
488      4
489      4
490      4
491      4
549      4
558      4
584      4
585      4
586      4
587      4
588      4
589      4
590      4
591      4
649      4
658      4
684      4
685      4
686      4
687      4
688      4
689      4
690      4
691      4
749      4
758      4
784      4
785      4
786      4
787      4
788      4
789      4
790      4
791      4
351      8
451      8
551      8
651      8
751      8
1051      16
1052      8
1053      4
1060      24
1061      24
1062      72
1063      72
1064      216
1065      216
1066      648
1067      648
1068      1944
1069      1944
1001      16
1003      8
1005      8
1007      4
```

```
1009      2
1011      4
1013      8
1014      16
1015      48
1017      24
1019      72
1021      72
1023      216
1025      216
1027      648
1028      648
1029      1944
1031      1944
c
2001      32
2002      64
2003      128
2004      256
2005      512
2006      1024
2007      1024
2008      2048
2009      2048
2010      4096
2011      4096
2012      8192
2013      8192
2014      16384
c
2016      1024
2017      1024
2028      2048
2019      2048
2020      4096
2021      4096
2022      8192
2023      8192
2024      16384
c
2031      16384
2032      16384
2033      16384
c
3001      3888
3002      3888
3003      3888
c
3004      7776
3005      7776
3006      7776
3007      7776
3008      15552
3009      15552
c
3010      7776
3011      7776
3012      7776
3013      7776
3014      15552
3015      15552
c
3021      46656
3022      46656
3023      139968
```

```
3024      139968
c
3030      1
3031      1
3032      1
3033      1
3034      1
c
3035      279936
3036      279936
3037      559872
3038      559872
3039      1
c
3040      279936
3041      279936
3042      559872
3043      559872
3044      1
c
4000      32768
4001      32768
4002      32768
4003      32768
4004      16384
4005      16384
4006      8192
4007      8192
4008      4096
4009      4096
4010      2048
4011      2048
4012      1024
4013      512
4014      256
4015      128
4016      64
4017      32
4018      16
4019      8
4020      4
4021      8
4022      16
4023      32
4024      96
4025      48
4026      144
4027      144
4028      432
4029      432
4030      1296
4031      1296
4032      3888
4033      3888
4034      7776
4035      7776
4036      7776
4037      15552
4038      15552
4039      15552
4040      15552
4041      31104
4042      31104
4043      93312
4044      93312
```

```
4045        279936
4046        279936
4047        559872
4048        559872
4049        1119744
4050        1119744
4051        1
c
5000        32768
5001        32768
5002        32768
5003        32768
5004        16384
5005        16384
5006        8192
5007        8192
5008        4096
5009        4096
5010        2048
5011        2048
5012        1024
5013        512
5014        256
5015        128
5016        64
5017        32
5018        16
5019        8
5020        4
5021        8
5022        16
5023        32
5024        96
5025        48
5026        144
5027        144
5028        432
5029        432
5030        1296
5031        1296
5032        3888
5033        3888
5034        7776
5035        7776
5036        7776
5037        15552
5038        15552
5039        15552
5040        15552
5041        31104
5042        31104
5043        93312
5044        93312
5045        279936
5046        279936
5047        559872
5048        559872
5049        1119744
5050        1119744
5051        1
c
5100        65536
5101        65536
5102        65536
5103        65536
```

```
5104     32768
5105     32768
5106     16384
5107     16384
5108     8192
5109     8192
5110     4096
5111     4096
5112     2048
5113     1024
5114     512
5115     256
5116     128
5117     64
5118     32
5119     16
5120     8
5121     16
5122     32
5123     64
5124     192
5125     96
5126     288
5127     288
5128     864
5129     864
5130     2592
5131     2592
5132     7776
5133     7776
5134     15552
5135     15552
5136     15552
5137     31104
5138     31104
5139     31104
5140     31104
5141     62208
5142     62208
5143     186624
5144     186624
5145     559872
5146     559872
5147     1119744
5148     1119744
5149     2239488
5150     2239488
5151     1
c
5200     131072
5201     131072
5202     131072
5203     131072
5204     65536
5205     65536
5206     32768
5207     32768
5208     16384
5209     16384
5210     8192
5211     8192
5212     4096
5213     2048
5214     1024
5215     512
```

```
5216        256
5217        128
5218        64
5219        32
5220        16
5221        32
5222        64
5223        128
5224        384
5225        192
5226        576
5227        576
5228        1728
5229        1728
5230        5184
5231        5184
5232        15552
5233        15552
5234        31104
5235        31104
5236        31104
5237        62208
5238        62208
5239        62208
5240        62208
5241        124416
5242        124416
5243        373248
5244        373248
5245        1119744
5246        1119744
5247        2239488
5248        2239488
5249        4478976
5250        4478976
5251        1
c
5300        262144
5301        262144
5302        262144
5303        262144
5304        131072
5305        131072
5306        65536
5307        65536
5308        32768
5309        32768
5310        16384
5311        16384
5312        8192
5313        4096
5314        2048
5315        1024
5316        512
5317        256
5318        128
5319        64
5320        32
5321        64
5322        128
5323        256
5324        768
5325        384
5326        1152
5327        1152
```

```
5328      3456
5329      3456
5330      10368
5331      10368
5332      31104
5333      31104
5334      62208
5335      62208
5336      62208
5337      124416
5338      124416
5339      124416
5340      124416
5341      248832
5342      248832
5343      746496
5344      746496
5345      2239488
5346      2239488
5347      4478976
5348      4478976
5349      8957952
5350      8957952
5351      1
c
5500      524288
5501      524288
5502      524288
5503      524288
5504      262144
5505      262144
5506      131072
5507      131072
5508      65536
5509      65536
5510      32768
5511      32768
5512      16384
5513      8192
5514      4096
5515      2048
5516      1024
5517      512
5518      256
5519      128
5520      64
5521      128
5522      256
5523      512
5524      1536
5525      768
5526      2304
5527      2304
5528      6912
5529      6912
5530      20736
5531      20736
5532      62208
5533      62208
5534      124416
5535      124416
5536      124416
5537      248832
5538      248832
5539      248832
```

```
5540      248832
5541      497664
5542      497664
5543      1492992
5544      1492992
5545      4478976
5546      4478976
5547      1
5548      1
5549      1
5550      1
5551      1
c
5700      1048576
5701      1048576
5702      1048576
5703      1048576
5704      524288
5705      524288
5706      262144
5707      262144
5708      131072
5709      131072
5710      65536
5711      65536
5712      32768
5713      16384
5714      8192
5715      4096
5716      2048
5717      1024
5718      512
5719      256
5720      128
5721      256
5722      512
5723      1024
5724      3072
5725      1536
5726      4608
5727      4608
5728      13824
5729      13824
5730      41472
5731      41472
5732      124416
5733      124416
5734      248832
5735      248832
5736      248832
5737      497664
5738      497664
5739      497664
5740      497664
5741      995328
5742      995328
5743      2985984
5744      2985984
5745      8957952
5746      8957952
c
5900      2097152
5901      2097152
5902      2097152
5903      2097152
```

```
5904      1048576
5905      1048576
5906      524288
5907      524288
5908      262144
5909      262144
5910      131072
5911      131072
5912      65536
5913      32768
5914      16384
5915      8192
5916      4096
5917      2048
5918      1024
5919      512
5920      256
5921      512
5922      1024
5923      2048
5924      6144
5925      3072
5926      9216
5927      9216
5928      27648
5929      27648
5930      82944
5931      82944
5932      248832
5933      248832
5934      497664
5935      497664
5936      497664
5937      995328
5938      995328
5939      995328
5940      995328
5941      1990656
5942      1990656
5943      5971968
5944      5971968
5945      17915904
5946      17915904
c
6100      4194304
6101      4194304
6102      4194304
6103      4194304
6104      2097152
6105      2097152
6106      1048576
6107      1048576
6108      524288
6109      524288
6110      262144
6111      262144
6112      131072
6113      65536
6114      32768
6115      16384
6116      8192
6117      4096
6118      2048
6119      1024
6120      512
```

```
6121        1024
6122        2048
6123        4096
6124        12288
6125        6144
6126        18432
6127        18432
6128        55296
6129        55296
6130        165888
6131        165888
6132        497664
6133        497664
6134        995328
6135        995328
6136        995328
6137        1990656
6138        1990656
6139        1990656
6140        1990656
6141        3981312
6142        3981312
6143        11943936
6144        11943936
6145        35831808
6146        35831808
c
6300        8388608
6301        8388608
6302        8388608
6303        8388608
6304        4194304
6305        4194304
6306        2097152
6307        2097152
6308        1048576
6309        1048576
6310        524288
6311        524288
6312        262144
6313        131072
6314        65536
6315        32768
6316        16384
6317        8192
6318        4096
6319        2048
6320        1024
6321        2048
6322        4096
6323        8192
6324        24576
6325        12288
6326        36864
6327        36864
6328        110592
6329        110592
6330        331776
6331        331776
6332        995328
6333        995328
6334        1990656
6335        1990656
6336        1990656
6337        3981312
```

```
6338        3981312
6339        3981312
6340        3981312
6341        7962624
6342        7962624
6343        23887872
6344        23887872
6345        71663616
6346        71663616
c
6400        8388608
6401        8388608
6402        8388608
6403        8388608
6404        4194304
6405        4194304
6406        2097152
6407        2097152
6408        1048576
6409        1048576
6410        524288
6411        524288
6412        262144
6413        131072
6414        65536
6415        32768
6416        16384
6417        8192
6418        4096
6419        2048
6420        1024
6421        2048
6422        4096
6423        8192
6424        24576
6425        12288
6426        36864
6427        36864
6428        110592
6429        110592
6430        331776
6431        331776
6432        995328
6433        995328
6434        1990656
6435        1990656
6436        1990656
6437        3981312
6438        3981312
6439        3981312
6440        3981312
6441        7962624
6442        7962624
6443        23887872
6444        23887872
6445        71663616
6446        71663616
c
6500        16777216
6501        16777216
6502        16777216
6503        16777216
6504        8388608
6505        8388608
6506        4194304
```

```
6507      4194304
6508      2097152
6509      2097152
6510      1048576
6511      1048576
6512      524288
6513      262144
6514      131072
6515      65536
6516      32768
6517      16384
6518      8192
6519      4096
6520      2048
6521      4096
6522      8192
6523      16384
6524      49152
6525      24576
6526      73728
6527      73728
6528      221184
6529      221184
6530      663552
6531      663552
6532      1990656
6533      1990656
6534      3981312
6535      3981312
6536      3981312
6537      7962624
6538      7962624
6539      7962624
6540      7962624
6541      15925248
6542      15925248
6543      47775744
6544      47775744
6545      143327232
6546      143327232
c
6601      1
6602      1
6603      1
6604      1
6605      1
6606      1
6607      1
6608      1
6609      1
6610      1
6611      1
6612      1
6613      1
6614      1
6615      1
6616      1
6617      1
6618      1
6619      1
6620      1
6621      1
6622      1
6623      1
6624      1
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6625       1
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6627       1
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6630       1
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6651       1
c
c
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312      1
313      1
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394      1
395      1
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402      1
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404      1
405      1
406      1
407      1
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| | |
|---|---|
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| 493 | 1 |
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| 501 | 1 |
| 502 | 1 |
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| 507 | 1 |
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| 554 | 1 |
| 559 | 1 |
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| 594 | 1 |
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| 602 | 1 |
| 603 | 1 |
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| 605 | 1 |
| 606 | 1 |
| 607 | 1 |
| 608 | 1 |
| 609 | 1 |
| 610 | 1 |
| 611 | 1 |
| 612 | 1 |
| 613 | 1 |
| 638 | 1 |

| | |
|---|---|
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| 642 | 1 |
| 643 | 1 |
| 644 | 1 |
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| 738 | 1 |
| 739 | 1 |
| 740 | 1 |
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| 742 | 1 |
| 743 | 1 |
| 744 | 1 |
| 745 | 1 |
| 750 | 1 |
| 752 | 1 |
| 754 | 1 |
| 759 | 1 |
| 792 | 1 |
| 793 | 1 |
| 794 | 1 |
| 795 | 1 |
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| 203 | 1 |
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| 206 | 1 |
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| 208 | 1 |
| 210 | 1 |
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| 104 | 1 |
| 105 | 1 |
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| 108 | 1 |
| 109 | 1 |
| 110 | 1 |
| 111 | 1 |
| 112 | 1 |

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10305  1
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10308  1
11302  1
11303  1
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| | |
|---|---|
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| 13305 | 1 |
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| 10459 | 1 |
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| 10543 | 1 |
| 10544 | 1 |

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10642  1
10643  1
10644  1
10701  1
10702  1
10711  1
10712  1
10713  1
99999    0
c
c
c       neutron dose factors
c
c    2.5e-8   1.0e-7   1.0e-6   1.0e-5   1.0e-4   1.0e-3   1.0e-2     0.1
c        0.5      1.0      2.5       5.0       7.0      10.0      14.0      20.0
c    3.67e-6  3.67e-6  4.46e-6  4.54e-6  4.18e-6  3.76e-6  3.56e-6 2.17e-5
c        9.26e-5  1.32e-4  1.25e-4  1.56e-4  1.47e-4  1.47e-4  2.08e-4 2.27e-4
c
c       photon dose factors
c
c    0.01  0.03  0.05  0.07  0.1  0.15  0.2  0.25  0.3  0.35  0.4  0.45
c         0.5  0.55  0.6  0.65  0.7  0.8  1.0  1.4  1.8  2.2  2.6  2.8  3.25
c         3.75  4.25  4.75  5.0  5.25  5.75  6.25  6.75  7.5  9.0  11.0
c         13.0  15.0
c   3.96e-06  5.82e-07  2.90e-07  2.58e-07  2.83e-07  3.79e-07  5.01e-07
c        6.31e-07  7.59e-07  8.78e-07  9.85e-07  1.08e-06  1.17e-06  1.27e-06
c        1.36e-06  1.44e-06  1.52e-06  1.68e-06  1.98e-06  2.51e-06  2.99e-06
c        3.42e-06  3.82e-06  4.01e-06  4.41e-06  4.83e-06  5.23e-06  5.60e-06
c        5.80e-06  6.01e-06  6.37e-06  6.74e-06  7.11e-06  7.66e-06  8.77e-06
c        1.03e-05  1.18e-05  1.33e-05
c
c
c      PHOTON TALLIES
c
f102:p  716 917
ft102    scx 3
de102    0.01  0.03  0.05  0.07  0.1  0.15  0.2  0.25  0.3  0.35  0.4  0.45
         0.5  0.55  0.6  0.65  0.7  0.8  1.0  1.4  1.8  2.2  2.6  2.8  3.25
         3.75  4.25  4.75  5.0  5.25  5.75  6.25  6.75  7.5  9.0  11.0
         13.0  15.0
df102   3.96e-06  5.82e-07  2.90e-07  2.58e-07  2.83e-07  3.79e-07  5.01e-07
        6.31e-07  7.59e-07  8.78e-07  9.85e-07  1.08e-06  1.17e-06  1.27e-06
        1.36e-06  1.44e-06  1.52e-06  1.68e-06  1.98e-06  2.51e-06  2.99e-06
        3.42e-06  3.82e-06  4.01e-06  4.41e-06  4.83e-06  5.23e-06  5.60e-06
        5.80e-06  6.01e-06  6.37e-06  6.74e-06  7.11e-06  7.66e-06  8.77e-06
        1.03e-05  1.18e-05  1.33e-05
fq102   u s
c
```

# APPENDIX 5.D

# DOSE RATE COMPARISON FOR DIFFERENT COBALT IMPURITY LEVELS

The dose rate adjacent to and one meter from the 100-ton HI-TRAC and the HI-STORM overpack are presented on Tables 5.D.1 through 5.D.4 for the MPC-24 with different burnup and cooling times and different assumed Cobalt-59 impurity levels for inconel. The HI-TRAC results were calculated for an earlier design which utilized 30 steel fins 0.375 inches thick compared to 10 steel fins 1.25 inches thick. The change in rib design only affects the magnitude of the dose rates presented for the radial surface but does not affect the conclusions discussed below. The following burnup and cooling time combinations are presented.

<u>100-ton HI-TRAC</u>

- 35,000 MWD/MTU and 5 year cooling
  1000 ppm (1.0 gm/kg) Cobalt-59 impurity in inconel
- 45,000 MWD/MTU and 9 year cooling
  4700 ppm (4.7 gm/kg) Cobalt-59 impurity in inconel

<u>HI-STORM</u>

- 45,000 MWD/MTU and 5 year cooling
  1000 ppm (1.0 gm/kg) Cobalt-59 impurity in inconel
- 45,000 MWD/MTU and 9 year cooling
  4700 ppm (4.7 gm/kg) Cobalt-59 impurity in inconel

On Tables 5.D.1 through 5.D.4, the contribution to the dose rate from activation in incore grid spacers is explicitly shown.

These results demonstrate that the dose rates at the longer cooling time are essentially equivalent to (within 11%) or bounded by the dose rates at the shorter cooling times even though a very conservative Cobalt-59 impurity level of 4700 ppm was assumed for the longer cooling times.

Table 5.2.1 shows the masses of inconel and steel that are used in the modeling of the PWR fuel assembly. When 4700 ppm was used for the impurity level in the inconel, an effective Cobalt-59 impurity level was used for the regions containing both steel and inconel. The following table summarizes the impurity levels that were used.

| Region | Regional Co-59 impurity when 1000 ppm in inconel assumed | Regional Co-59 impurity when 4700 ppm in inconel assumed |
|---|---|---|
| Lower end fitting | 1000 ppm | 1340 ppm |
| Incore grid spacers | 1000 ppm | 4700 ppm |
| Gas plenum springs | 1000 ppm | 3417 ppm |
| Gas plenum spacer | 1000 ppm | 3417 ppm |
| Upper end fitting | 1000 ppm | 1000 ppm |

Table 5.D.1

DOSE RATES ADJACENT TO 100-TON HI-TRAC FOR NORMAL CONDITIONS
MPC-24 DESIGN BASIS ZIRCALOY CLAD FUEL

| Dose Point † Location | Incore Grid Spacer $^{60}$Co Gammas (mrem/hr) | Fuel Gammas (mrem/hr) | (n,γ) Gammas (mrem/hr) | $^{60}$Co Gammas (mrem/hr) | Neutrons (mrem/hr) | Totals (mrem/hr) |
|---|---|---|---|---|---|---|
| **4700 ppm Co-59 in inconel** | | | | | | |
| **45,000 MWD/MTU AND 9-YEAR COOLING** | | | | | | |
| 1 | 12.20 | 11.89 | 12.65 | 507.16 | 171.98 | 715.87 |
| 2 | 345.15 | 332.90 | 52.81 | 0.75 | 88.26 | 819.87 |
| 3 | 4.72 | 5.19 | 1.98 | 369.24 | 214.70 | 595.83 |
| 4 | 7.13 | 8.11 | 0.97 | 197.76 | 180.55 | 394.52 |
| 5 (pool lid) | 48.63 | 54.68 | 17.52 | 2557.68 | 1194.17 | 3872.68 |
| 5(transfer lid) | 137.52 | 155.17 | 0.97 | 3811.45 | 674.42 | 4779.53 |
| **1000 ppm Co-59 in inconel** | | | | | | |
| **35,000 MWD/MTU AND 5-YEAR COOLING** | | | | | | |
| 1 | 3.73 | 27.05 | 6.51 | 543.06 | 88.57 | 668.92 |
| 2 | 105.37 | 696.56 | 27.19 | 0.80 | 45.46 | 875.38 |
| 3 | 1.44 | 11.44 | 1.02 | 473.51 | 110.57 | 597.98 |
| 4 | 2.18 | 17.87 | 0.50 | 241.22 | 92.97 | 354.74 |
| 5 (pool lid) | 28.09 | 186.49 | 8.27 | 2751.19 | 554.51 | 3528.55 |
| 5(transfer lid) | 41.98 | 293.57 | 0.50 | 4081.28 | 347.33 | 4764.66 |

† Refer to Figure 5.1.4.

Table 5.D.2

DOSE RATES AT 1 METER FROM 100-TON HI-TRAC FOR NORMAL CONDITIONS
MPC-24 DESIGN BASIS ZIRCALOY CLAD FUEL

| Dose Point † Location | Incore Grid Spacer $^{60}$Co Gammas (mrem/hr) | Fuel Gammas (mrem/hr) | (n,γ) Gammas (mrem/hr) | $^{60}$Co Gammas (mrem/hr) | Neutrons (mrem/hr) | Totals (mrem/hr) |
|---|---|---|---|---|---|---|
| **4700 ppm Co-59 in inconel** | | | | | | |
| **45,000 MWD/MTU AND 9-YEAR COOLING** | | | | | | |
| 1 | 44.32 | 43.03 | 7.14 | 73.99 | 27.98 | 196.46 |
| 2 | 148.49 | 143.94 | 16.40 | 6.18 | 32.38 | 347.39 |
| 3 | 18.76 | 18.25 | 3.88 | 72.75 | 13.83 | 127.47 |
| 4 | 2.19 | 2.80 | 0.17 | 61.70 | 44.87 | 111.73 |
| 5(transfer lid) | 55.57 | 64.25 | 0.18 | 1556.99 | 188.18 | 1865.16 |
| **1000 ppm Co-59 in inconel** | | | | | | |
| **35,000 MWD/MTU AND 5-YEAR COOLING** | | | | | | |
| 1 | 13.53 | 91.20 | 3.68 | 79.16 | 14.41 | 201.97 |
| 2 | 45.33 | 302.99 | 8.44 | 6.13 | 16.68 | 379.57 |
| 3 | 5.73 | 38.74 | 2.00 | 71.95 | 7.12 | 125.54 |
| 4 | 0.67 | 6.21 | 0.09 | 74.47 | 23.11 | 104.55 |
| 5(transfer lid) | 16.96 | 128.14 | 0.09 | 1667.22 | 96.91 | 1909.32 |

† Refer to Figure 5.1.4.

Table 5.D.3

DOSE RATES ADJACENT TO HI-STORM OVERPACK FOR NORMAL CONDITIONS
MPC-24 DESIGN BASIS ZIRCALOY CLAD FUEL

| Dose Point † Location | Incore Grid Spacer $^{60}$Co Gammas (mrem/hr) | Fuel Gammas†† (mrem/hr) | $^{60}$Co Gammas (mrem/hr) | Neutrons (mrem/hr) | Totals (mrem/hr) |
|---|---|---|---|---|---|
| **4700 ppm Co-59 in inconel** | | | | | |
| **45,000 MWD/MTU AND 9-YEAR COOLING** | | | | | |
| 1 | 0.54 | 2.95 | 3.86 | 2.37 | 9.72 |
| 2 | 7.73 | 10.40 | 0.03 | 1.48 | 19.63 |
| 3 | 0.36 | 1.97 | 2.59 | 1.18 | 6.11 |
| 4 | 0.10 | 0.53 | 0.33 | 3.10 | 4.06 |
| **1000 ppm Co-59 in inconel** | | | | | |
| **45,000 MWD/MTU AND 5-YEAR COOLING** | | | | | |
| 1 | 0.20 | 5.68 | 4.87 | 2.76 | 13.51 |
| 2 | 2.73 | 28.93 | 0.03 | 1.88 | 33.58 |
| 3 | 3.87 | 0.13 | 3.21 | 1.38 | 8.59 |
| 4 | 0.04 | 0.91 | 0.36 | 3.60 | 4.91 |

† Refer to Figures 5.1.1.

†† Gammas generated by neutron capture are included with fuel gammas.

Table 5.D.4

DOSE RATES ONE METER FROM HI-STORM OVERPACK FOR NORMAL CONDITIONS
MPC-24 DESIGN BASIS ZIRCALOY CLAD FUEL

| Dose Point † Location | Incore Grid Spacer $^{60}$Co Gammas (mrem/hr) | Fuel Gammas†† (mrem/hr) | $^{60}$Co Gammas (mrem/hr) | Neutrons (mrem/hr) | Totals (mrem/hr) |
|---|---|---|---|---|---|
| **4700 ppm Co-59 in inconel** | | | | | |
| **45,000 MWD/MTU AND 9-YEAR COOLING** | | | | | |
| 1 | 0.77 | 2.01 | 2.30 | 0.46 | 5.54 |
| 2 | 3.90 | 5.14 | 0.39 | 0.64 | 10.08 |
| 3 | 0.44 | 1.09 | 1.72 | 0.18 | 3.42 |
| 4 | 0.05 | 0.23 | 0.14 | 0.94 | 1.37 |
| **1000 ppm Co-59 in inconel** | | | | | |
| **45,000 MWD/MTU AND 5-YEAR COOLING** | | | | | |
| 1 | 0.28 | 4.49 | 2.90 | 0.54 | 8.21 |
| 2 | 1.41 | 14.98 | 0.25 | 0.78 | 17.42 |
| 3 | 0.16 | 2.57 | 2.09 | 0.21 | 5.03 |
| 4 | 0.02 | 0.42 | 0.16 | 1.10 | 1.70 |

† Refer to Figures 5.1.1.

†† Gammas generated by neutron capture are included with fuel gammas.

**APPENDIX 5.E**

**DELETED**

# APPENDIX 5.F

## Additional Information on the Burnup Versus Decay Heat and Enrichment Equation

The equation in Section 5.2.5.3 was determined to be the best equation capable of reproducing the burnup versus enrichment and decay heat data calculated with ORIGEN-S. As an example, Figure 5.F.1 graphically presents ORIGEN-S burnup versus decay heat data for various enrichments for the 9x9C/D fuel assembly array/classes with a 20- year cooling time. This data could also be represented graphically as a surface on a three dimensional plot. However, the 2D plot is easier to visualize. Additional enrichments were used in the ORIGEN-S calculations and have been omitted for clarity.

Figures 5.F.2 through 5.F.4 show ORIGEN-S burnup versus decay heat data for specific enrichments. In addition to the ORIGEN-S data, these figures present the results of the original curve fit and the adjusted curve fit. Table 5.F.1 below shows the equation coefficients used for both curve fits. As these figures indicate, the curve fit faithfully reproduces the ORIGEN-S data.

Figure 5.F.5 provides a different representation of the curve fit versus ORIGEN-S comparison. This figure was generated by taking the ORIGEN-S enrichment and decay heat data from Figure 5.F.1 for a constant burnup of 30,000 MWD/MTU and calculating the burnup using the fitted equation with coefficients from Table 5.F.1. The resulting burnup versus enrichment is plotted. Table 5.F.2 presents the ORIGEN-S and curve fit data in tabular form used to generate Figure 5.F.5. Since the ORIGEN-S calculations were performed for a specific burnup of 30,000 MWD/MTU, the ORIGEN-S data is represented as a straight line. Figures 5.F.6 and 5.F.7 provide the same representation for burnups of 45,000 and 65,000 MWD/MTU. These results also indicate that the non-adjusted curve fit provides a very good representation of the ORIGEN-S data. It is also clear that the adjusted curve fit always bounds the ORIGEN-S data by predicting a lower burnup which results in a more restrictive and conservative limit for the user.

Table 5.F.1

COEFFICIENTS FOR EQUATION IN SECTION 5.2.5.3 FOR THE 9X9C/D FUEL ASSEMBLY ARRAY/CLASSES WITH A COOLING TIME OF 20 YEARS

| **Coefficient** | **Original Curve Fit** | **Adjusted Curve Fit** |
|---|---|---|
| A | 249944 | 249944 |
| B | -382059 | -382059 |
| C | 308281 | 308281 |
| D | -205.495 | -205.495 |
| E | 9362.63 | 9362.63 |
| F | 1389.71 | 1389.71 |
| G | -1995.54 | -2350.49 |

Table 5.F.2

ORIGEN-S AND CURVE FIT DATA FOR THE 9X9C/D FUEL ASSEMBLY ARRAY/CLASSES WITH A COOLING TIME OF 20 YEARS

| Specified Enrichment | ORIGEN-S calculated decay heat per assembly (kw) | ORIGEN-S calculated burnup (MWD/MTU) | Burnup calculated with original curve fit (MWD/MTU) | Burnup calculated with adjusted curve fit (MWD/MTU) |
|---|---|---|---|---|
| 0.7 | 1.55E-01 | 30000 | 29700.69 | 29345.74 |
| 1 | 1.53E-01 | 30000 | 29715.24 | 29360.29 |
| 1.35 | 1.52E-01 | 30000 | 29759.8 | 29404.85 |
| 1.7 | 1.50E-01 | 30000 | 29849.09 | 29494.14 |
| 2 | 1.50E-01 | 30000 | 29997.43 | 29642.48 |
| 2.3 | 1.49E-01 | 30000 | 30050.56 | 29695.61 |
| 2.6 | 1.49E-01 | 30000 | 30120.16 | 29765.21 |
| 2.9 | 1.49E-01 | 30000 | 30228.56 | 29873.61 |
| 3.2 | 1.50E-01 | 30000 | 30340.01 | 29985.06 |
| 3.4 | 1.50E-01 | 30000 | 30354.95 | 30000 |
| 3.6 | 1.49E-01 | 30000 | 30172.21 | 29817.26 |
| 3.9 | 1.48E-01 | 30000 | 30095.41 | 29740.46 |
| 4.2 | 1.48E-01 | 30000 | 30001.17 | 29646.22 |
| 4.5 | 1.48E-01 | 30000 | 29890.42 | 29535.47 |
| 4.8 | 1.48E-01 | 30000 | 29764.09 | 29409.14 |
| 5 | 1.49E-01 | 30000 | 29731.66 | 29376.71 |

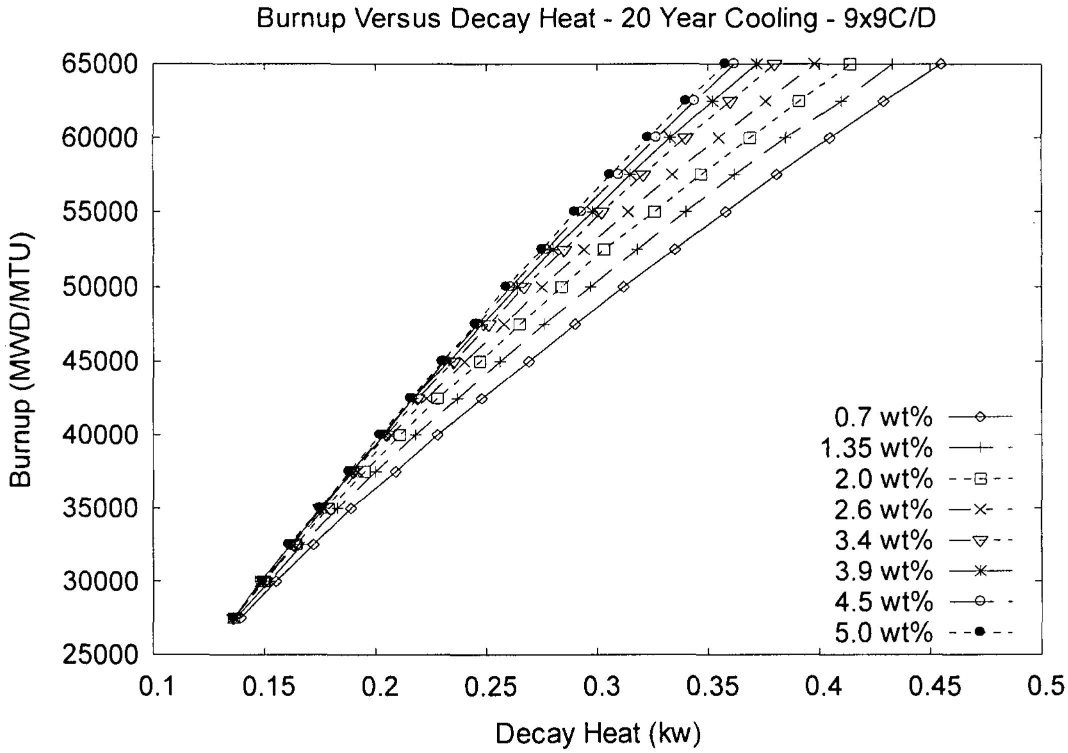


FIGURE 5.F.1; ORIGEN-S CALCULATED BURNUP VERSUS DECAY HEAT FOR VARIOUS ENRICHMENTS

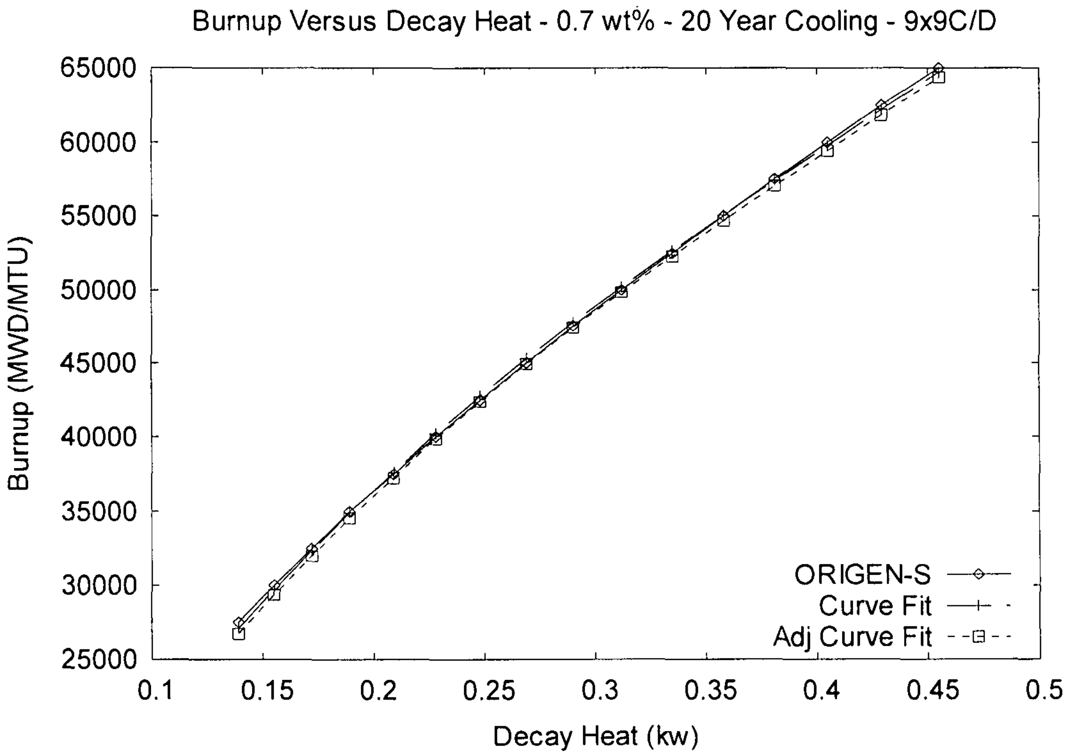


FIGURE 5.F.2; A COMPARISON OF THE BURNUP VERSUS DECAY HEAT CALCULATIONS FROM ORIGEN-S, THE ORIGINAL CURVE FIT, AND THE ADJUSTED CURVE FIT FOR AN ENRICHMENT OF 0.7 WT.% $^{235}U$.

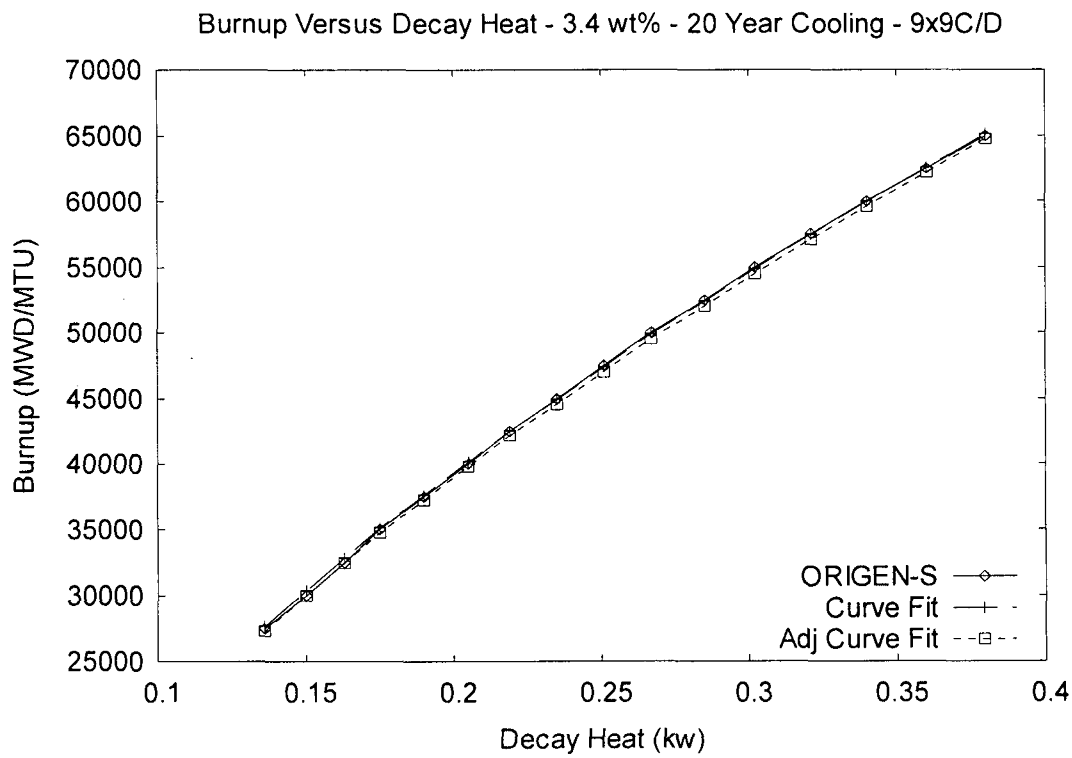


FIGURE 5.F.3; A COMPARISON OF THE BURNUP VERSUS DECAY HEAT CALCULATIONS FROM ORIGEN-S, THE ORIGINAL CURVE FIT, AND THE ADJUSTED CURVE FIT FOR AN ENRICHMENT OF 3.4 WT.% $^{235}U$.

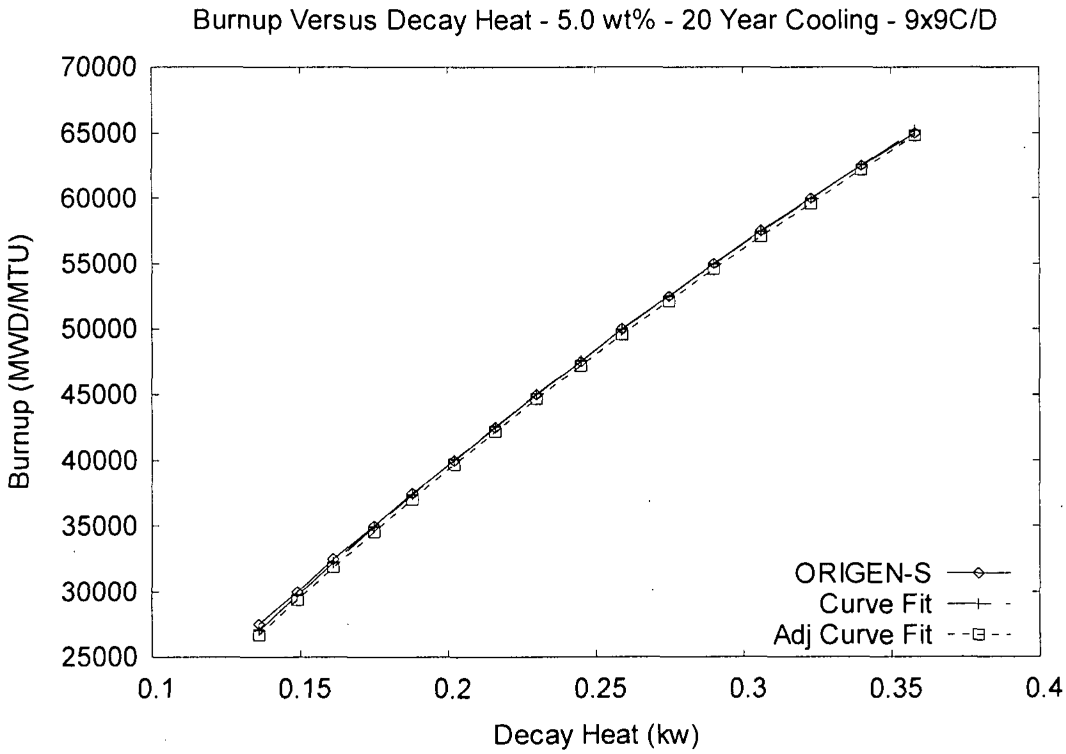


FIGURE 5.F.4; A COMPARISON OF THE BURNUP VERSUS DECAY HEAT CALCULATIONS FROM ORIGEN-S, THE ORIGINAL CURVE FIT, AND THE ADJUSTED CURVE FIT FOR AN ENRICHMENT OF 5.0 WT.% $^{235}U$.

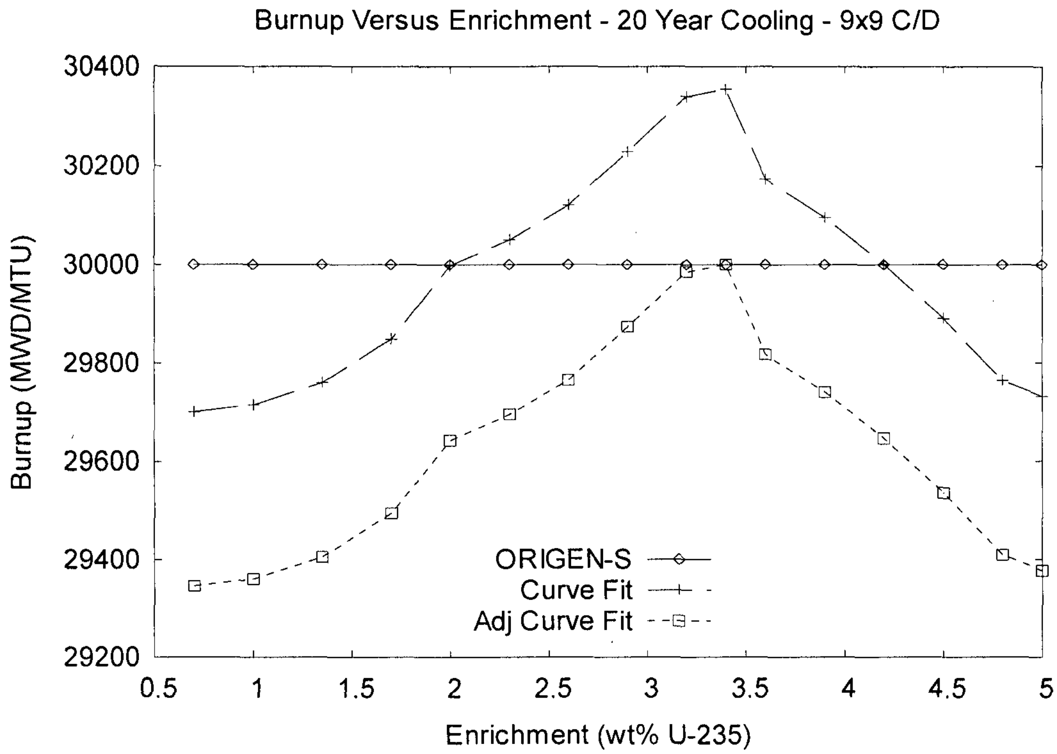


FIGURE 5.F.5; A COMPARISON OF THE CALCULATED BURNUPS USING THE CURVE FIT AND THE ADJUSTED CURVE FIT FOR VARIOUS ENRICHMENTS. ALL ORIGEN-S CALCULATIONS YIELDED A BURNUP OF 30,000 MWD/MTU.

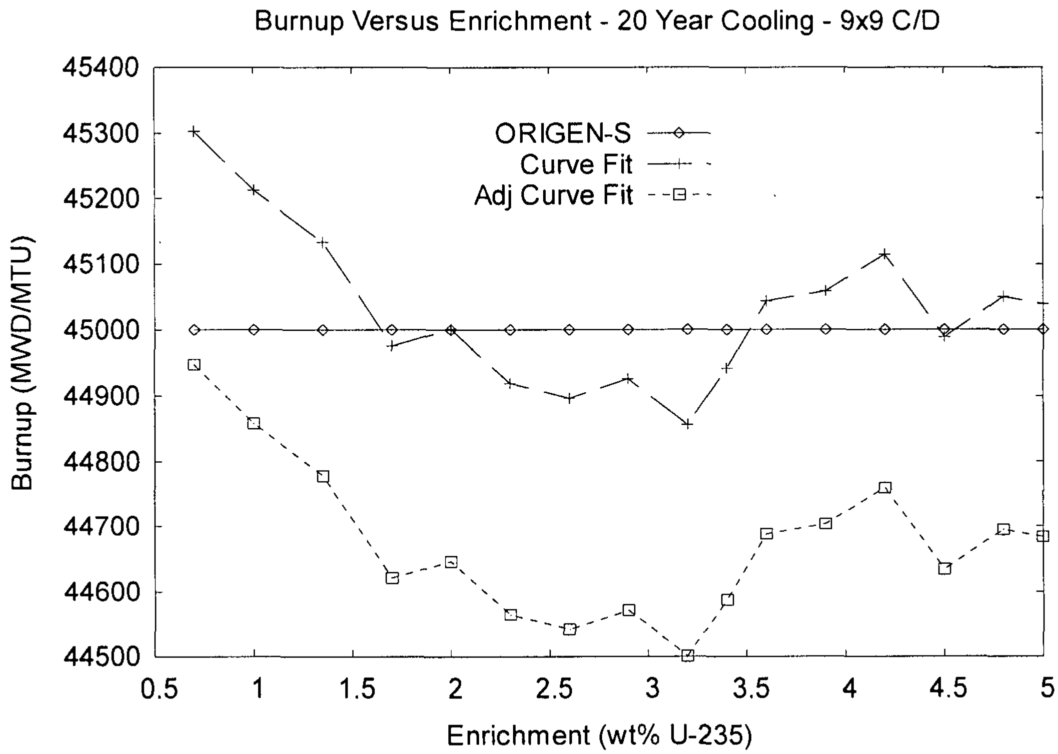


FIGURE 5.F.6; A COMPARISON OF THE CALCULATED BURNUPS USING THE CURVE FIT AND THE ADJUSTED CURVE FIT FOR VARIOUS ENRICHMENTS. ALL ORIGEN-S CALCULATIONS YIELDED A BURNUP OF 45,000 MWD/MTU.

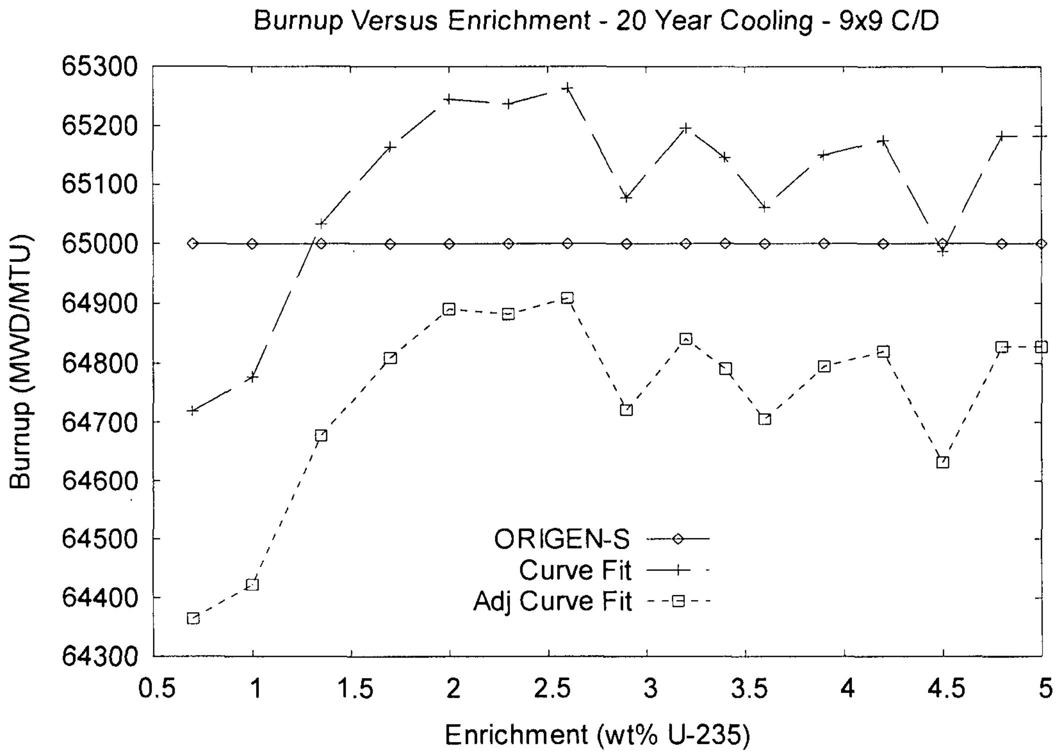


FIGURE 5.F.7; A COMPARISON OF THE CALCULATED BURNUPS USING THE CURVE FIT AND THE ADJUSTED CURVE FIT FOR VARIOUS ENRICHMENTS. ALL ORIGEN-S CALCULATIONS YIELDED A BURNUP OF 65,000 MWD/MTU.

## SUPPLEMENT 5.I

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## SUPPLEMENT 5.II

## [INTENTIONALLY DELETED]