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OCRWM	DESIGN CALCULATION OR ANALYSIS COVER SHEET	1. QA: QA 2. Page 1

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Transportation Cask Receipt/Return Facility Criticality Safety Evaluations

6. Group
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8. Notes/Comments
An LP-2.14Q-BSC review is not required because this is an editorial correction only. The results and conclusions are not impacted.

NOTICE OF OPEN CHANGE DOCUMENTS - THIS DOCUMENT IS IMPACTED BY THE LISTED CHANGE DOCUMENTS AND CANNOT BE USED WITHOUT THEM.

1) ECN-001, DATED 07/27/2005
2) ECN-002, DATED 07/29/2005

Attachments	Total Number of Pages
Attachment I: List of Computer Files	3
Attachment II: One Compact Disc	N/A
Attachment III: Sketches: Transportation Cask Receipt/Return & Waste Package Receipt Facilities General Arrangement	4

RECORD OF REVISIONS

9. No.	10. Reason For Revision	11. Total # of Pgs.	12. Last Pg. #	13. Originator (Print/Sign/Date)	14. Checker (Print/Sign/Date)	15. QER (Print/Sign/Date)	16. Approved/Accepted (Print/Sign)	17. Date
00A	Initial Issue	48	III-4	Charlotta E. Sanders	Jason E. Huffer	Daniel J. Tunney	William E. Hutchins	02/04/2005
00B	In response to Condition Report 5108, revised to remove an extra, unused reference listed in Section 7. The only affected pages are 1 and 37. Attachment II was copied over from previous revision (00A) but had no modifications.	48	III-4	Charlotta E. Sanders 04/25/05	Jason E. Huffer 4/25/05	Daniel J. Tunney 4/25/2005	William E. Hutchins	4/26/05

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1. PURPOSE

The purpose of this design calculation is to demonstrate that the handling operations of transportation casks performed in the Transportation Cask Receipt and Return Facility (TCRRF) and Buffer Area meet the nuclear criticality safety design criteria specified in the *Project Design Criteria (PDC) Document* (BSC [Bechtel SAIC Company] 2004 [DIRS 171599], Section 4.9.2.2), and the functional nuclear criticality safety requirement described in the *Transportation Cask Receipt/Return Facility Description Document* (BSC 2004 [DIRS 170217], Section 3.2.3). Specific scope of work contained in this activity consists of the following items:

- Evaluate criticality effects for both dry and fully flooded conditions pertaining to TCRRF and Buffer Area operations for defense in depth.

- Evaluate Category 1 and 2 event sequences for the TCRRF as identified in the *Categorization of Event Sequences for License Application* (BSC 2004 [DIRS 167268], Section 7). This evaluation includes credible fuel reconfiguration conditions.

In addition to the scope of work listed above, an evaluation was also performed of modeling assumptions for commercial spent nuclear fuel (CSNF) regarding inclusion of plenum and end regions of the active fuel.

This calculation is limited to CSNF and U.S. Department of Energy (DOE) SNF. It should be mentioned that the latter waste form is evaluated more in depth in the *Canister Handling Facility Criticality Safety Calculations* (BSC 2004 [DIRS 167614]). Further, the design and safety analyses of the naval SNF canisters are the responsibility of the U.S. Department of the Navy (Naval Nuclear Propulsion Program) and will not be included in this document. In addition, this calculation is valid for the current design of the TCRRF and Buffer Area and may not reflect the ongoing design evolution of the facility. However, it is anticipated that design changes to the facility layout will have little or no impact on the criticality results and/or conclusions presented in this document

This calculation is subject to the *Quality Assurance Requirements and Description* (DOE 2004 [DIRS 171539]) because the TCRRF is included in the *Q-List* (BSC 2004 [DIRS 168361], p. A-3) as an item important to safety. This calculation is prepared in accordance with AP-3.12Q, *Design Calculations and Analyses* [DIRS 168413].

2. METHOD

2.1 CRITICALITY SAFETY ANALYSIS

The criticality safety calculations presented in this document evaluate the transportation casks, certified under 10 CFR 71 [DIRS 171308], in the TCRRF to ensure they meet the criticality safety requirements under normal conditions as well as for Category 1 and 2 event sequences, in accordance with 10 CFR 63 [DIRS 158535]. The HI-STAR transportation cask is used as a representative cask for the calculations (Assumption 3.3), since it is considered bounding for operations of CSNF in the TCRRF (BSC 2004 [DIRS 170217], Section 3.1.1.3.1). The criticality safety evaluations will demonstrate that the multiplication factor (k_{eff}) of the HI-STAR 100 System, including all biases and uncertainties at a 95 % confidence level, will not exceed 0.95 under all normal, off-normal, and accident conditions (NRC 2000 [DIRS 149756], Section 8.4.1.1). The off-normal and accident conditions are inclusive of Category 1 and 2 event sequences as defined in 10 CFR 63.2 (10 CFR 63. 2002 [DIRS 158535]). Moderator and reflector conditions are varied to find the most reactive configuration. Criticality safety of the HI-STAR 100 System does not rely on credit for (Holtec International 2003 [DIRS 172633], p. 6.1-2):

- burnup of fuel
- fuel-related burnable absorbers
- more than 75 % of the manufacturer's minimum B-10 content for Boral neutron absorber.

Conservative modeling assumptions will also include a fuel stack density of 96 % theoretical (Holtec International 2003 [DIRS 172633], p. 6.1-4), no credit for ^{234}U and ^{236}U in fuel (BSC 2004 [DIRS 172058], p. 14), and worst case combination of manufacturing and fabrication tolerances (Holtec International 2003 [DIRS 172633], p. 6.1-3).

Note that the terms "model(s)" and "modeling" as used in this calculation document refer to the geometric configurations of the criticality cases analyzed and not scientific models per AP-SIII.10Q, *Models* [DIRS 171760].

These calculations use the qualified software MCNP (Briesmeister 1997 [DIRS 103897] and CRWMS M&O 1998 [DIRS154060]). MCNP is a three-dimensional Monte Carlo particle transportation code with the capability to calculate eigenvalues for critical systems. The Nuclear Regulatory Commission (NRC) accepts MCNP in NUREG-1567 (NRC 2000 [DIRS 149756], p. 8-10) for criticality calculations.

2.2 ELECTRONIC MANAGEMENT OF INFORMATION

Electronic management of information generated from these calculations is controlled in accordance with Section 5.1.2 of AP-3.13Q, *Design Control* [DIRS 167460]. The computer input and output files generated from this calculation are stored on a Compact Disc (CD), and submitted as an attachment to this document (Attachment II).

3. ASSUMPTIONS

3.1 DOE SNF FUEL (NORMAL OPERATIONS)

Assumption: It is assumed that the DOE SNF canisters will remain subcritical during normal handling operations in the TCRRF.

Rationale: The DOE SNF canisters will arrive subcritical to the TCRRF. Since the canisters will not be opened in the TCRRF, moderator cannot intrude into the canister to increase the reactivity of the system.

Confirmation Status: This assumption requires no further confirmation based on the stated rationale.

Use in the Calculation: Section 5.1.2.

3.2 DOE SNF FUEL (DROP SCENARIOS)

Assumption: It is assumed that a transportation cask containing DOE SNF canisters will remain subcritical following a drop in the TCRRF.

Rationale: The transportation casks containing the DOE SNF canisters will be lifted onto the site rail transfer cart (SRTC) in the TCRRF (see Category 2 event in Section 5.2.3). This could potentially lead to a criticality if the drop caused a DOE SNF canister to breach and moderator was present in the facility. Based on preliminary design, the height of the SRTC is 4'8" above the floor (BSC 2004 [DIRS 170217], Figure B-4). DOE SNF standardized canisters can withstand, without breaching, a drop in any orientation from a height of 23 ft (7 m) onto an essentially unyielding flat surface per the *U.S. Department of Energy Spent Nuclear Fuel Canister Survivability* document (BSC 2004 [DIRS 168792], Section 6). Multicanister overpack (MCO) canisters can withstand, without breaching, a flat-bottom drop (3 degrees or less off vertical) from a height of 23 ft (7 m) and a drop in any orientation from a height of 2 ft (0.6 m) (individually–not both in sequence) onto an essentially unyielding flat surface (BSC 2004 [DIRS 168792], Section 6). It is therefore reasonable to assume that the lift heights required for moving the transportation casks containing the DOE SNF canisters onto the SRCT will be below 23 ft in the TCRRF. In addition, design requirements can be implemented to limit lift heights and ensure usage of crush pads. Note that these drop height limits (e.g., 2 ft MCO drop height in any orientation) can be exceeded when utilizing crush pads (BSC 2004 [DIRS 167268], Section 5.1.1.19). Further, criticality safety for DOE canisters given a drop is also assumed for the *Categorization of Event Sequences for License Application* document (BSC 2004 [DIRS 167268], Section 5.1.1.3).

Confirmation Status: This assumption requires no further confirmation based on the stated rationale.

Use in the Calculation: Section 5.2.3.

3.3 SELECTION OF REPRESENTATIVE TRANSPORTATION CASK

Assumption: It is assumed that the HI-STAR transportation cask is a representative and bounding cask for operations in the TCRRF.

Rationale: Performance requirement 3.1.1.3.1 of the *Transportation Cask Receipt/Return Facility Description Document* (BSC 2004 [DIRS 170217]) states that no decision has been made as to which transportation casks will be used. However, the following casks should be bounding for operations of CSNF: (1) GA-4; (2) HI-STAR; (3) NAC-UMS; (4) TS-125; (5) NAC-STC; (6) NUHOMS-MP-187; (7) TN-68; and (8) NUHOMS-MP-197. Tables 3.3-1 and 3.3-2 compare k_{eff} values along with enrichment of the various transportation casks. It can be seen that the HI-STAR cask has the highest k_{eff} values for both PWR and BWR fuel and a quite high enrichment. Therefore, HI-STAR is an acceptable choice for a representative cask for this calculation.

Confirmation Status: This assumption requires no further confirmation based on the stated rationale.

Use in the Calculation: Sections 2.1 and 5.1.3.

Table 3.3-1 Comparison of Most Reactive PWR Fuel in Various Transportation Casks

Cask Type	PWR Fuel				
	Fuel Type	Enrichment (wt% ^{235}U)	k_{eff}	St. Dev.	Reference
GA-4	W 15x15 OFA	3.15	0.9300	0.0011	General Atomics 1998 [DIRS 103042], Table 6.4-2
HI-STAR	B&W 15x15	4.1	0.9478[a]	N/A	Holtec International 2003 [DIRS 172633], p. 6.2-2
NAC-UMS	W 17x17 OFA	4.2	0.9247	0.0009	NAC International 2002 [DIRS 164612], Section 6.1 & Table 6.1-1
TS-125	W 17x17 OFA	4.6	0.94025	0.00093	Sisley, S.E. 2002 [DIRS 171545], Table 6.4-6
NAC-STC	Framatome-Cogema 17x17	4.5	0.92541	0.00086	Thompson, T.C. 2003 [DIRS 169362], Section 6.1.1
NUHOMS-MP-187	B&W 15x15	3.43	0.9374[a]	N/A	Transnuclear West 2002 [DIRS 161510], Table 6.1-1
TN-68	N/A				
NUHOMS-MP-197	N/A				

[a] k_{eff} includes 2 standard deviations uncertainty.

Table 3.3-2 Comparison of Most Reactive BWR Fuel in Various Transportation Casks

Cask Type	BWR Fuel				
	Fuel Type	Enrichment (wt% ^{235}U)	k_{eff}	St. Dev.	Reference
GA-4	N/A				
HI-STAR	GE 8x8	4.2	0.9384	0.0007	Holtec International 2003 [DIRS 172633], p. 6.2-36
NAC-UMS	Exxon/ANF 9x9	4.0	0.9055	0.0008	NAC International 2002 [DIRS 164612], Section 6.1 & Table 6.1-1
TS-125	Siemens 11x11	4.1	0.93422	0.00089	Sisley, S.E. 2002 [DIRS 170407], Table 6.4-10
NAC-STC	N/A				
NUHOMS-MP-187	N/A				
TN-68	GE 10x10	3.7	0.9250	0.0008	Transnuclear 2001 [DIRS 167988], Section 6.1
NUHOMS-MP-197	GE 10x10	4.4	0.9349	0.0011	Transnuclear 2002 [DIRS 160736], Section 6.4.4

3.4 HYDRAULIC FLUID COMPOSITION

Assumption: It is assumed that the hydraulic fluid used as an alternative moderator material was a conventional silicone fluid (polysiloxane fluid) with a degree of polymerization of four (Gelest 2004 [DIRS 169915], p. 11).

Rationale: The basis for this assumption is that this material is a common hydraulic fluid (Gelest 2004 [DIRS 169915], p. 7).

Confirmation Status: This assumption requires no further confirmation based on the stated rationale.

Use in the Calculation: Section 5.1.6.2.

4. USE OF COMPUTER SOFTWARE

4.1 BASELINED SOFTWARE

4.1.1 MCNP

The MCNP code (CRWMS M&O 1998 [DIRS 154060]) was used to calculate the multiplication factor, k_{eff}, for all systems presented in this report. The software specifications are as follows:

- Program Name: MCNP (CRWMS M&O 1998 [DIRS 154060])
- Version/Revision Number: Version 4B2LV
- Status/Operating System: Qualified/HP-UX B.10.20
- Software Tracking Number: 30033 V4B2LV
- Computer Type: HP 9000 Series Workstations
- CPU Number: 700887

The input and output files for the various MCNP calculations are contained on a CD (Attachment II) and the files are listed in Attachment I.

The MCNP software used was: (1) appropriate for the criticality (k_{eff}) calculations, (2) used only within the range of validation as documented through Briesmeister (1997 [DIRS 103897]) and CRWMS M&O (1998 [DIRS 102836], Section 3.1), and (3) obtained from Software Configuration Management in accordance with appropriate procedures.

4.2 COMMERCIAL OFF-THE-SHELF SOFTWARE

4.2.1 MICROSOFT EXCEL 97 SR-2

- Title: Excel
- Version/Revision Number: Microsoft® Excel 97 SR-2
- This version is installed on a PC running Microsoft Windows 2000 with CPU number 503009

The file for the Excel calculation is contained on a CD (Attachment II) and the file is listed in Attachment I.

Excel was used to calculate weight fractions and weight percent. The calculations can be reproduced and checked by hand. Excel is exempt from qualification per Section 2.1.6 of LP-SI.11Q, *Software Management* [DIRS 171923].

5. CALCULATION

All technical product inputs and sources of the inputs used in the development of this calculation are documented in this section. Attachment III features sketches of the TCRRF and Buffer Area as of the date of this calculation, and may not reflect the ongoing design evolution. The purpose of these sketches is to show the functional areas where the transportation casks will be handled and staged.

5.1 CALCULATIONAL INPUTS

5.1.1 Design Requirements and Criteria

The design criteria for criticality safety analysis provided in Section 4.9.2.2 of the *Project Design Criteria Document* (BSC 2004 [DIRS 171599]) are used in these calculations. The pertinent criteria for TCRRF criticality include the following (BSC 2004 [DIRS 171599], Section 4.9.2.2):

- The multiplication factor, k_{eff}, including all biases and uncertainty at a 95 percent confidence level, shall not exceed 0.95 under all normal conditions, and Category 1 and Category 2 event sequences.
- For fixed-neutron absorbers used for criticality control such as grid plates or inserts, no more than 75 percent credit of the neutron absorber content is used for preclosure criticality analyses, unless standard acceptance tests verify that the presence and uniformity of the neutron absorber are more effective.

Section 3.2.3 of the *Transportation Cask Receipt/Return Facility Description Document* (BSC 2004 [DIRS 170217]) states that the "facility shall be designed and operated to prevent any credible criticality event from occurring". Further, criticality shall be prevented in the facility "by maintaining the neutron multiplication factor (k_{eff}) below 0.95, including bias, and all uncertainties at 95 % confidence levels for all normal operations, Category 1 and 2 event sequences". The basis for these requirements is to prevent nuclear criticality events, in accordance with DOE nuclear facility safety programs.

5.1.2 DOE SNF

Per Assumption 3.1, it is assumed that the DOE SNF canisters will remain subcritical during handling operations in the TCRRF. Therefore, DOE fuel will not be evaluated in this document.

5.1.3 CSNF Transportation Cask

Per Assumption 3.3, the HI-STAR transportation cask is used as a representative cask in this calculation. The fuel basket designs used for this criticality evaluation were a 24 PWR assembly basket and a 68 BWR assembly basket as specified in Holtec International 2003 [DIRS 172633].

5.1.4 Fuel Assembly Selection

The Babcock & Wilcox (B&W) 15x15 fuel assembly (4.1 wt% enriched) was chosen as a representative fuel assembly inside the multi-purpose canister (MPC) for PWR fuel. Studies have shown that the B&W 15x15 and the Westinghouse 17x17 OFA (optimized fuel assembly) are the most reactive fuel assemblies inside the MPC-24 (Holtec International 2003 [DIRS 172633], p. 6.2-2). The B&W 15x15 fuel assembly is used in other criticality calculations on the Yucca Mountain project (BSC 2004 [DIRS 172553]).

The GE 8x8 fuel assembly (4.2 wt% enriched) was selected as a representative BWR fuel inside the MPC-68. Studies for the MPC-68 have shown that an 8x8 fuel array is the most reactive assembly configuration in the design inventory (Holtec International 2003 [DIRS 172633], Tables 6.2.20 – 6.2.36). Note that a hypothetical optimized for high reactivity 10x10 assembly produces a slightly higher k_{eff} than the 8x8 fuel assembly does (Holtec International 2003 [DIRS 172633], p. 6.2-3). However, since the hypothetical 10x10 is not an actual assembly design, the 8x8 fuel assembly was selected for this evaluation.

5.1.5 Upper Subcritical Limit

The upper subcritical limit (USL) for CSNF (both PWR and BWR fuel) is 0.9472 as a limit in order to meet the design criteria that k_{eff} can not exceed 0.95 including bias and uncertainties at 95% confidence level (BSC 2004 [DIRS 171599], Section 4.9.2.2). In other words, the USL provides a margin of 0.0028 (0.95 - 0.9472) to account for code bias and uncertainties at 95% confidence level. Bias and uncertainties that need to be considered in this analysis pertain to statistical uncertainties, dimensional uncertainties, code bias, and tolerance uncertainties. Applicable code bias for similar fuel type and enrichment range of this analysis has been estimated to be 0.0021 (value increased by truncation) with a standard deviation of ± 0.0007 (Holtec International 2003 [DIRS 172633], Appendix 6.A-2). Note that the uncertainties associated with the MCNP calculated k_{eff} values are not included in the USL (see discussion below).

All evaluations utilizing the HI-STAR 100 cask system are performed for the worst case combination of manufacturing tolerances with respect to criticality (Holtec International 2003 [DIRS 172633], p. 6.3-2). The values presented in Sections 5.1.6.1 and 5.1.6.3 of this document include the tolerances that maximize criticality potential. Evaluations have been performed to determine the effects of tolerances (Holtec International 2003 [DIRS 172633], Tables 6.3-1 & 6.3-2). It was determined that design parameters important to criticality safety are fuel enrichment, the inherent geometry of the fuel basket structure and the fixed neutron absorbing panels (Boral) (Holtec International 2003 [DIRS 172633], p. 6.3-3).

As stated in the first paragraph of this section, a system is considered acceptably subcritical if the calculated k_{eff} value plus calculation uncertainties (i.e., 2 times the standard deviation associated with the MCNP calculated value) lies at or below 0.9472 for commercial spent nuclear fuel. The definition of upper subcritical limit (USL) is (BSC 2004 [DIRS 172058], Section 3.5):

$$k_S + \Delta k_S \leq USL \qquad (1)$$

where k_S is the MCNP calculated value for the system, Δk_S is an allowance for (a) statistical or convergence uncertainties, or both in the computation of k_s, (b) material and fabrication tolerances, and (c) uncertainties due to the geometric or material representations used in the computational method [Note: allowance for items (b) and (c) can be obviated by using bounding representations].

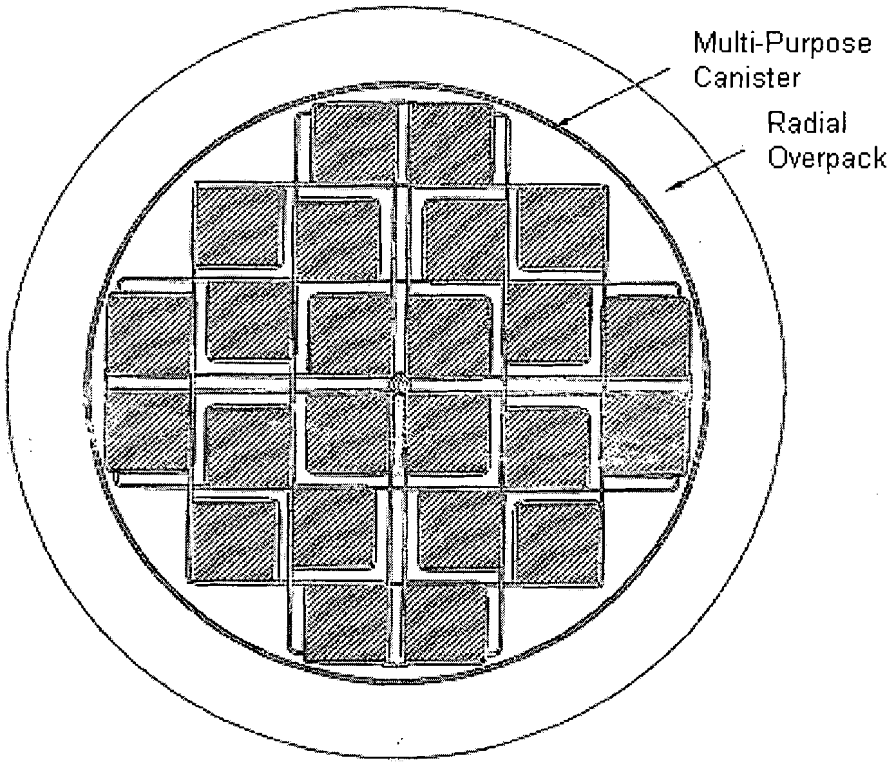
As an example, if the standard deviation associated with the MCNP calculated value for commerical spent nuclear fuel is 0.00028 (see Section 6), the MCNP calculated k_S value may not exceed 0.94664 (0.9472 – 2x0.00028), per expression 1, in order to meet the USL. For a more detailed description of USL determination and criterion, see BSC 2004 [DIRS 172058] (Sections 3.4.1, 3.4.2, and 3.5). For commercial spent nuclear fuel, the criticality evaluation was performed for the worst-case configuration (see second paragraph of Section 5.1.5), which already accounted for all uncertainites other than the MCNP statistical uncertainty (Holtec International 2003 [DIRS 172633], p.6.3-2). Based on this bounding representation, items (b) and (c) mentioned above were eliminated.

5.1.6 Transportation Cask Calculation Inputs

The HI-STAR transportation cask in the TCRRF was modeled in accordance with the *HI-STAR 100 Transport Cask Safety Analysis Report* (Holtec International 2003 [DIRS 172633], Section 6.3). The cask was modeled as a single cask with various moderator and reflector conditions. Since the transportation casks are placed 30 ft apart in the TCRRF (Attachment III), these conditions will accurately depict the TCRRF environment. An infinite array of transportation casks was also modeled to show neutronic isolation. Physical inputs for the transportation casks are described in the following subsections.

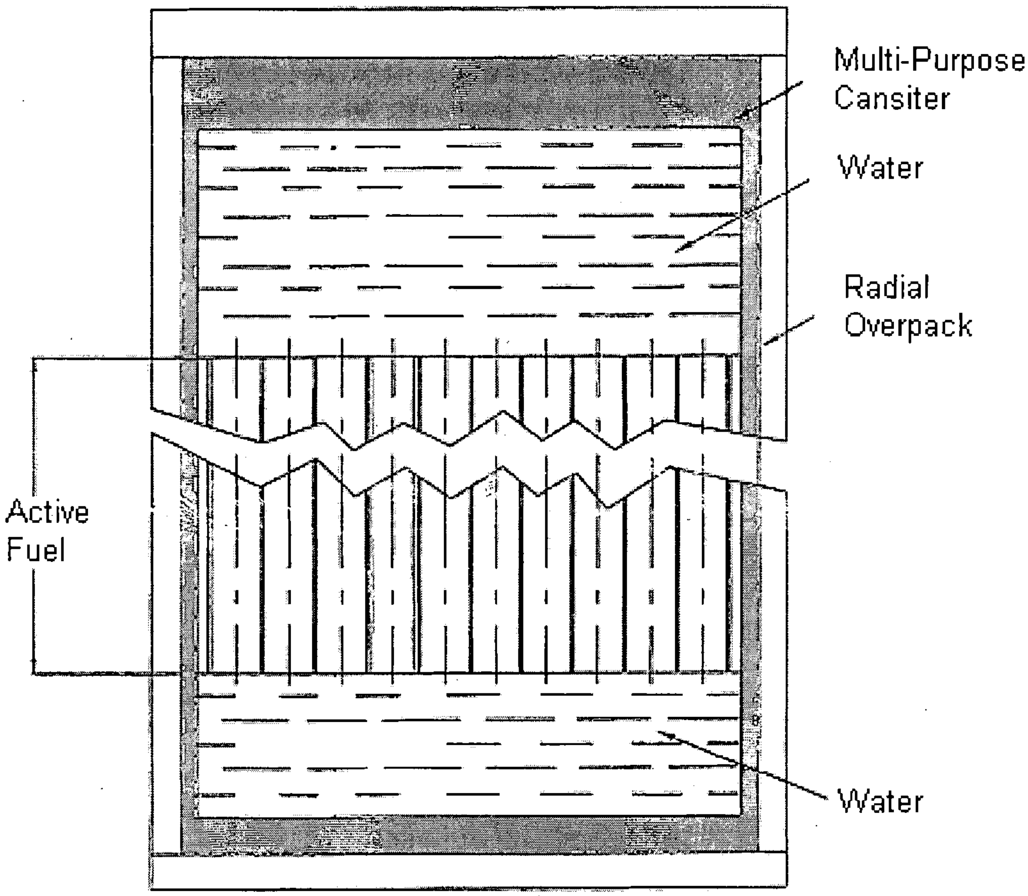
5.1.6.1 PWR MPC-24 Configuration and Physical Dimensions

The MPC-24 for pressurized water reactor (PWR) fuel consists of a stainless steel (SS) cask/overpack and an interior 24 PWR assembly basket. Figure 5.1-1 displays the planar cross-section of the MPC-24 calculational model inside the overpack and Figure 5.1-2 presents the axial view. Note that some of the MCNP models also include a reflector region surrounding the transportation cask (i.e., in the radial and axial directions) modeled to a width/height of 30 cm. Various reflector materials were modeled including void, water, iron and concrete.



NOTE: Figure not to scale.

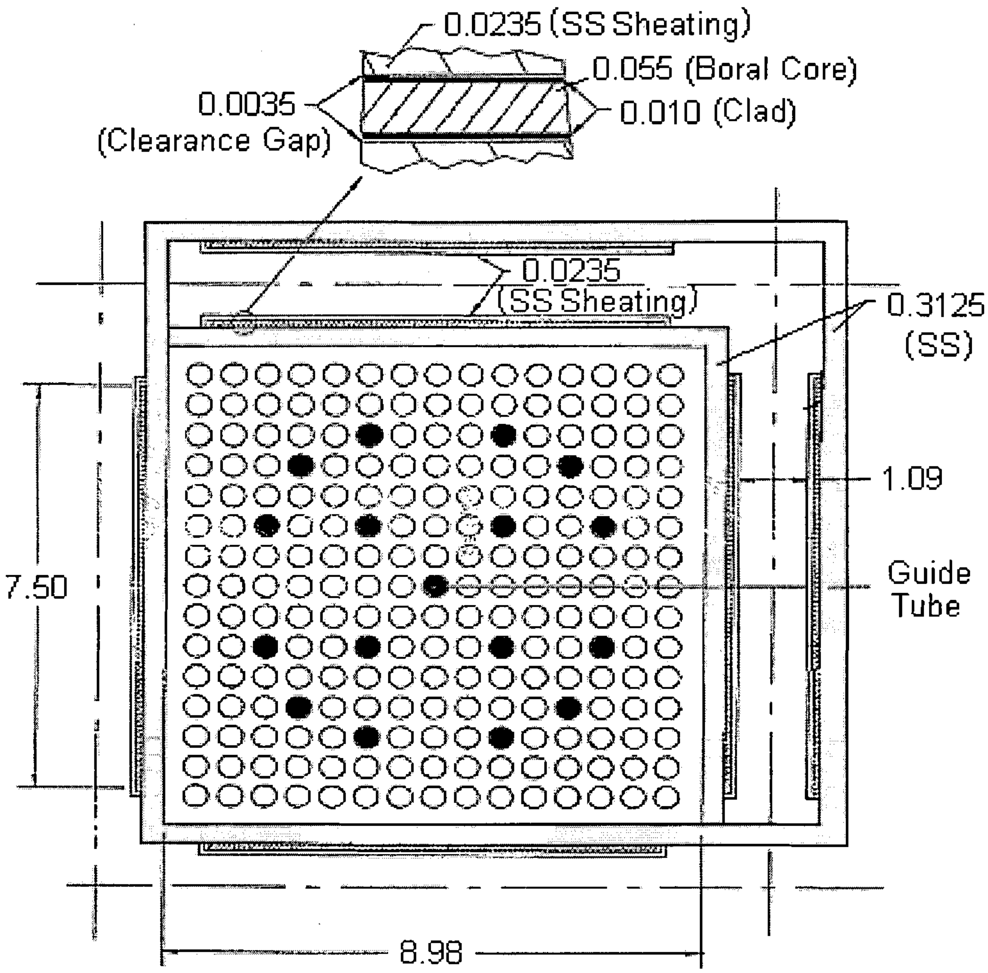
Figure 5.1-1 Radial View of the MPC-24 PWR Fuel Transportation Cask
(Source: Holtec International 2003 [DIRS 172633], Figure 6.3-4)



NOTE: Figure is not to scale.

Figure 5.1-2 Axial View of the MPC-24 PWR Fuel Transportation Cask
(Source: Holtec International 2003 [DIRS 172633], Figure 6.3-7)

The basket cells contain B&W 15x15 fuel assemblies, as mentioned in Section 5.1.4. Figure 5.1-3 displays a single basket cell with the B&W 15x15 fuel assembly. Table 5.1-1 provides the radial dimensions of the MPC-24 and cell geometry while Table 5.1-2 shows the axial dimensions. Table 5.1-3 displays the specifications of the PWR fuel assembly.



SS = Stainless Steel

NOTE: Dimensions are in inches. Figure is not to scale.

Figure 5.1-3 PWR Fuel Basket Cell Containing B&W 15 x 15 Assembly
(Source: Holtec International 2003 [DIRS 172633], Figure 6.3-1)

Table 5.1-1 Radial Dimensions of the MPC-24, Overpack, and Cell Geometry

Component	Dimension (cm)	Reference
Stainless steel (SS) overpack thickness	22.86 (9.00 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.4
SS overpack, i.d.	171.1325 (67.375 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.4
Center column	6.985 (2.75 in.)	Holtec International 2003 [DIRS 172633], Drawing 3926 (Sheet 2)
Cell box inside dimension	22.8092 (8.98 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.1 & Table 6.3.3
Cell pitch	27.7012 (10.906 in.)	Holtec International 2003 [DIRS 172633], Table 6.3.3 & Drawing 3926 (Sheet 3)
Flux trap	2.7686 (1.09 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.1 & Table 6.3.3
Cell wall thickness (SS)	0.79375 (0.3125 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.1
SS sheathing	0.05969 (0.0235 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.1
Boral thickness	0.1397 (0.055 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.1
Al thickness (Clad)	0.0254 (0.010 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.1
Boral width - wide	19.05 (7.50 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.1
Boral width – narrow [a]	15.875 (6.25 in.)	Holtec International 2003 [DIRS 172633], Drawing 3926 (Sheet 2)
Boral clearance gap	0.00889 (0.0035 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.1

[a] The periphery Boral panels have reduced width.

Table 5.1-2 Axial Dimensions of the MPC-24, Overpack, and Cell Geometry

Component	Dimension (cm)	Reference
Lower water thickness (below active fuel region)	10.16 (4.0 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.7
Upper water thickness (above active fuel region)	15.24 (6.0 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.7
Bottom overpack SS plate thickness	21.59 (8.5 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.7
Top overpack SS plate thickness	39.37 (15.5 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.7

Table 5.1-3 Specifications of the PWR B&W 15 x15 Assembly

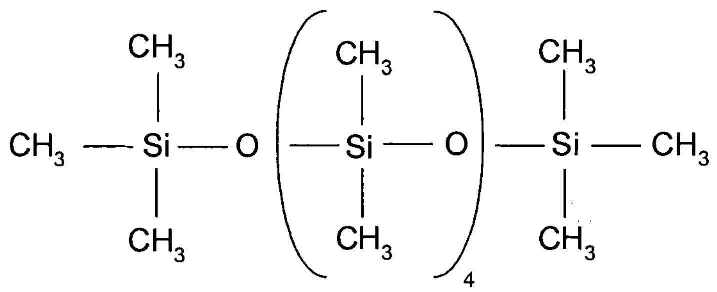
Parameter	Dimension (cm) [a]	Reference
Rod pitch	1.4428 (0.568 in.)	Holtec International 2003 [DIRS 172633], Table 6.2.2
Active fuel length	381.0 (150 in.)	Holtec International 2003 [DIRS 172633], Table 6.2.2
Cladding outside diameter	1.0872 (0.428 in.)	Holtec International 2003 [DIRS 172633], Table 6.2.2
Cladding thickness	0.05842 (0.023 in.)	Holtec International 2003 [DIRS 172633], Table 6.2.2
Pellet outside diameter	0.9504 (0.3742 in.)	Holtec International 2003 [DIRS 172633], Table 6.2.2
Guide/instrument tube outside diameter	1.3412 (0.528 in.)	Holtec International 2003 [DIRS 172633], Table 6.2.2
Guide/instrument tube inside diameter	1.27 (0.50 in.)	Holtec International 2003 [DIRS 172633], Table 6.2.2
Array size	15 x 15	Holtec International 2003 [DIRS 172633], Table 6.2.2
Number of fuel rods	208	Holtec International 2003 [DIRS 172633], Table 6.2.2
Number of guide/instrument tubes [b]	17	Holtec International 2003 [DIRS 172633], Table 6.2.2

[a] Some of the values are rounded up slightly.
[b] Locations of guide tubes are shown in Holtec International 2003 [DIRS 172633], Figure 6.3-2.

5.1.6.2 PWR Material Compositions

The calculations were performed with either the isotopic compositions given in weight fraction, weight percent (wt%), or atom densities (atoms/barn-cm) depending on the source of the input. Table 5.1-4 displays the relevant materials used for the transportation cask and the PWR fuel.

Per Assumption 3.4, Polysiloxane fluid was chosen as an alternate moderator material (in the event hydraulic fluid/oil leak from a handling crane). The chemical formula for this fluid is



Source: (Gelest 2004 [DIRS 169915], p. 11)

Polysiloxane fluid was modeled with a density of 0.9 g/cm^3 (Gelest 2004 [DIRS 169915], p. 11).

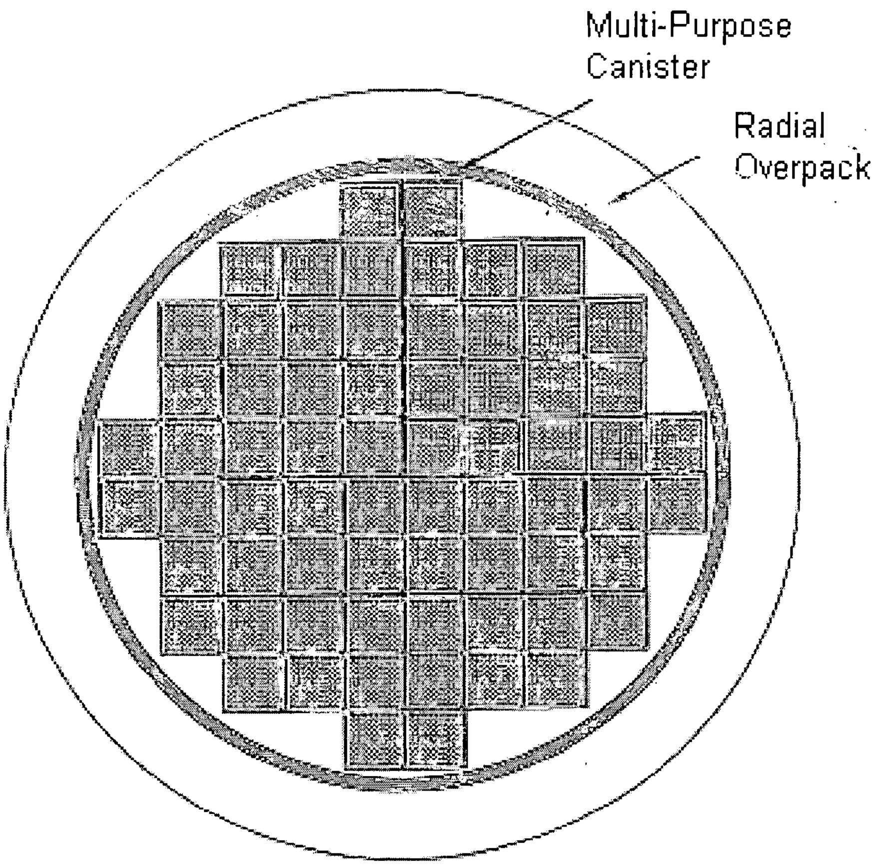
Table 5.1-4 Material Properties for the Transportation Cask and PWR Fuel

Material	Density (g/cm^3)	Element	Weight Fraction or Weight Percent (wt %)	Atom Fraction or Atom Density (atoms/barn-cm)	Reference/ Remark
H_2O (throughout model)	1.0	H O	N/A	fraction - 0.6667 fraction - 0.3333	Holtec International 2003 [DIRS 172633], Table 6.3-4
Air	0.001204	N O C Ar	75.52 23.18 0.01 1.29	N/A	Weast 1985 [DIRS 111561], p. F-10. Weight percentages calculated in spreadsheet *at_dens.xls*
SS304 (vessel & cell wall)	7.84	Cr Mn Fe Ni	N/A	1.761E-02 1.761E-03 5.977E-02 8.239E-03	Holtec International 2003 [DIRS 172633], Table 6.3-4
Al (Boral panel)	2.7	Al	N/A	0.06026	Holtec International 2003 [DIRS 172633], Table 6.3-4
Boral (0.02 g $^{10}B/cm^2$) [a]	2.66	B-10 B-11 C Al	5.443E-02 2.414E-01 8.210E-02 6.222E-01	N/A	Holtec International 2003 [DIRS 172633], Table 6.3-4
UO_2 – (fuel) 3.00 % enriched	10.522	U-235 U-238 O-16	2.6440 85.500 11.850	N/A	Holtec International 2003 [DIRS 172633], Table 6.3-4
UO_2 – (fuel) 3.50 % enriched	10.522	U-235 U-238 O-16	3.0850 85.060 11.850	N/A	Average value taken from Holtec International 2003 [DIRS 172633], Table 6.3-4 of 4.0 % and 3.0 % enrichment
UO_2 – (fuel) 4.00 % enriched	10.522	U-235 U-238 O-16	3.5260 84.620 11.850	N/A	Holtec International 2003 [DIRS 172633], Table 6.3-4
UO_2 – (fuel) 4.10 % enriched (design enrichment)	10.522	U-235 U-238 O-16	3.6140 84.536 11.850	N/A	Average value taken from Holtec International 2003 [DIRS 172633], Table 6.3-4 of 4.0 % and 4.2 % enrichment
Zr (Cladding)	6.55	Zr	100	N/A	Holtec International 2003 [DIRS 172633], Table 6.3-4
Fe (reflector material)	7.85	Fe	100	N/A	ASME 2001 [DIRS 158115], Section II-A, SA-20, Section 14.1
Concrete (reflector material)	2.147	Fe, H, C, Na, O, Mg, Al, Si, S, Cl, K, Ca, Ti, Mn	0.5595, 0.3319, 10.5321, 0.1411, 49.9430, 9.4200, 0.7859, 4.2101, 0.2483, 0.0523, 0.9445, 22.6318, 0.1488, 0.0512	N/A	Petrie, L. M. et. al. 2000 [DIRS 170550], p. M8.2.28

[a] The ^{10}B loading of 0.020 g/cm^2 is 75 % of the minimum loading 0.0267 g/cm^2 (Holtec International 2003 [DIRS 172633], p. 6.2-2)

5.1.6.3 BWR MPC-68 Configuration and Physical Dimensions

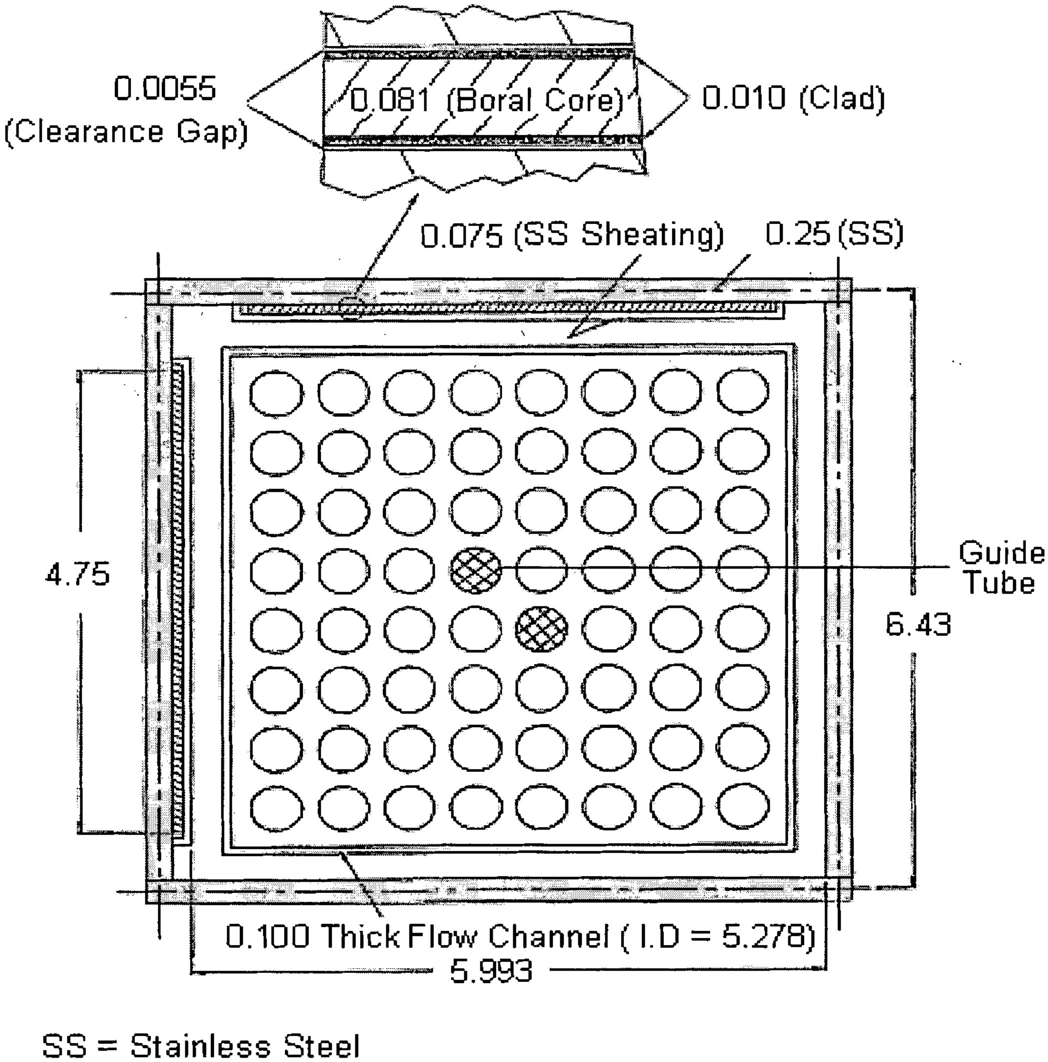
The MPC-68 for boiling water reactor (BWR) fuel consists of a SS cask/overpack and an interior 68 BWR assembly basket. Figure 5.1-4 displays the planar cross-section of the MPC-68 cask calculational model and Figure 5.1-2 presents the axial view (it is the same as for the MPC-24). Note that some of the MCNP models also include a reflector region surrounding the transportation cask (i.e., in the radial and axial directions) modeled to a width/height of 30 cm. The same reflector materials used for PWR fuel (i.e., void, water, iron and concrete) was also evaluated for BWR fuel.



NOTE: Figure is not to scale.

Figure 5.1-4 Radial View of the MPC-68 BWR Fuel Transportation Cask
(Source: Holtec International 2003 [DIRS 172633], Figure 6.3-6)

Figure 5.1-5 displays the basket cell with the GE 8x8 assembly. Table 5.1-5 provides the radial dimensions of the MPC-68 and cell geometry while Table 5.1-6 shows the axial dimensions. Table 5.1-7 displays the specifications of the BWR fuel assembly.



NOTE: Dimensions are in inches. Figure not to scale.

Figure 5.1-5 BWR Fuel Basket Cell Containing GE 8x8 Assembly
(Source: Holtec International 2003 [DIRS 172633], Figure 6.3-3)

Table 5.1-5 Radial Dimensions of the MPC-68, Overpack, and Cell Geometry

Component	Dimension (cm)	Reference
SS overpack thickness	22.86 (9.00 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.6
SS overpack, i.d.	171.1325 (67.375 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.6
Cell box inside dimension	15.2222 (5.993 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.3 & Table 6.3.3
Cell pitch	16.3322 (6.43 in.)	Holtec International 2003 [DIRS 172633], Table 6.3.3 & Figure 6.3.3
Cell wall thickness (SS)	0.635 (0.25 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.3 & Table 6.3.3
SS sheathing	0.1905 (0.075 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.3
Boral thickness	0.2057 (0.081 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.3
Al thickness (Clad)	0.0254 (0.010 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.3
Boral width	12.065 (4.75 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.3
Boral clearance gap	0.01397 (0.0055 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.3

Table 5.1-6 Axial Dimensions of the MPC-68, Overpack, and Cell Geometry

Component	Dimension (cm)	Reference
Lower water thickness (below active fuel region)	18.542 (7.30 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.7
Upper water thickness (above active fuel region)	21.4884 (8.46 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.7
Bottom overpack SS plate thickness	21.59 (8.5 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.7
Top overpack SS plate thickness	39.37 (15.5 in.)	Holtec International 2003 [DIRS 172633], Figure 6.3.7

Table 5.1-7 Specifications of the BWR GE 8 x 8 Standard Assembly

Parameter	Dimension (cm)	Reference
Rod pitch	1.6256 (0.640 in.)	Holtec International 2003 [DIRS 172633], Table 6.2.22
Active fuel length	381.0 (150 in.)	Holtec International 2003 [DIRS 172633], Table 6.2.22
Cladding outside diameter	1.2268 (0.483 in.)	Holtec International 2003 [DIRS 172633], Table 6.2.22
Cladding inside diameter	1.0796 (0.425 in.)	Holtec International 2003 [DIRS 172633], Table 6.2.22
Pellet outside diameter	1.0566 (0.416 in.)	Holtec International 2003 [DIRS 172633], Table 6.2.22
Guide tube (Thimble) outside diameter	1.3488 (0.531 in.)	Holtec International 2003 [DIRS 172633], p. 6.D-15
Guide tube (Thimble) thickness	1.5012 (0.59 in.)	Holtec International 2003 [DIRS 172633], p. 6.D-15
Array size	8 x 8	Holtec International 2003 [DIRS 172633], Table 6.2.22
Number of fuel rods	62	Holtec International 2003 [DIRS 172633], Table 6.2.22
Number of guide/instrument tubes [a]	2	Holtec International 2003 [DIRS 172633], Table 6.2.22

[a] Locations of guide tubes are shown in Holtec International 2003 [DIRS 172633], Figure 6.3-3.

5.1.6.4 BWR Material Compositions

The BWR material compositions are identical to those of the PWR material specifications (see Table 5.1-4), except for those listed in Table 5.1-8.

Table 5.1-8 Material Properties for the Transportation Cask and BWR Fuel

Material	Density (g/cm^3)	Element	Weight Percent (wt %)	Atom Fraction or Atom Density (atoms/barn-cm)	Reference/ Remark
Boral [a] (0.0279 g $^{10}B/cm^2$)	2.66	Al B-10 B-11 C	N/A	3.805E-02 8.071E-03 3.255E-02 1.015E-02	Holtec International 2003 [DIRS 172633] , Table 6.3.4
UO_2 – (fuel) 4.20 % enriched	10.522	U-235 U-238 O-16	3.702 84.45 11.85	N/A	Holtec International 2003 [DIRS 172633], Table 6.3.4

[a] The ^{10}B loading of 0.0279 g/cm^2 is 75 % of the minimum loading 0.0372 g/cm^2 (Holtec International 2003 [DIRS 172633], p. 6.2-3)

5.1.7 Fuel Region Modeling Study Compositions

The B&W 15x15 fuel assembly was modeled with and without end-regions (i.e., plenum and end-fittings) to study the impact on k_{eff}. For the purpose of this study, the Mark-B4 version of the B&W 15x15 fuel assembly was utilized. Table 5.1-9 presents the fuel assembly dimensions.

Table 5.1-9 B&W 15x15 Fuel Assembly Dimensions

Assembly Component	Dimension (cm)	Reference
Fuel Pellet Outer Diameter	0.93980	Punatar 2001[DIRS 155635] , p. 2-5
Fuel Rod Cladding Inner Diameter	0.95758	Punatar 2001[DIRS 155635] , p. 2-5
Fuel Rod Cladding Outer Diameter	1.09220	Punatar 2001[DIRS 155635] , p. 2-5
Guide Tube Inner Diameter	1.26492	Punatar 2001[DIRS 155635] , p. 2-5
Guide Tube Outer Diameter	1.34620	Punatar 2001[DIRS 155635] , p. 2-5
Instrument Tube Inner Diameter	1.12014	Punatar 2001[DIRS 155635] , p. 2-5
Instrument Tube Outer Diameter	1.38193	Punatar 2001[DIRS 155635] , p. 2-5
Upper Plenum	18.447	Punatar 2001[DIRS 155635] , p. 2-15
Lower Plenum	10.319	Punatar 2001[DIRS 155635] , p. 2-15
Upper End-fitting	0.714	Punatar 2001[DIRS 155635] , p. 2-15
Lower End-fitting	0.714	Punatar 2001[DIRS 155635] , p. 2-15

Table 5.1-10 presents the upper and lower fuel rod plenum material volume fractions and Table 5.1-11 presents the upper and lower fuel rod plenum homogenized material compositions, which are calculated in *material_comp.xls*. Table 5.1-12 presents the component material volume fractions for the upper and lower end-fitting regions and Table 5.1-13 presents the upper and lower end-fitting homogenized material compositions, which are calculated in *material_comp.xls*.

Table 5.1-10 Fuel Rod Plenum Material Volume Fractions

Plenum Location	Type 304 Stainless Steel	Gas (modeled as void)	Zircaloy-4
Upper	0.0811	0.7793	0.1396
Lower	0.1569	0.5973	0.2458

Source: Punatar 2001 [DIRS 155635], Table 2-9 and Figures 2-3 and 2-7

NOTE: Volume fractions are renormalized to exclude the cladding, which is modeled explicitly in the input.

Table 5.1-11 Plenum Homogenized Material Compositions

Element/Isotope	Wt% of Element/Isotope in Material Composition [a]	
	Upper Fuel Rod Plenum	Lower Fuel Rod Plenum
C-nat	0.0330	0.0349
N-14	0.0413	0.0436
Si-nat	0.3095	0.3270
P-31	0.0186	0.0196
S-32	0.0124	0.0131
Mn-55	0.8254	0.8720
Fe-54	1.6100	1.7002
Fe-56	26.1845	27.6517
Fe-57	0.6158	0.6504
Fe-58	0.0828	0.0874
Ni-58	2.5653	2.7101
Ni-60	1.0220	1.0797
Ni-61	0.0452	0.0477
Ni-62	0.1462	0.1545
Ni-64	0.0387	0.0408
Cr-50	0.3301	0.3485
Cr-52	6.6121	6.9806
Cr-53	0.7641	0.8067
Cr-54	0.1934	0.2042
O-16	0.0734	0.0705
Zr-nat	57.6247	55.3392
Sn-nat	0.8516	0.8178
Density (g/cm^3)	1.5597	2.8583

NOTE: Values calculated in *material_comp.xls*.

Table 5.1-12 End-Fitting Component Material Volume Fractions

Assembly Design	Stainless Steel Type 304	Inconel	Zircaloy-4	Moderator
Upper End-Fitting	0.2756	0.0441	0.0081	0.6722
Lower End-Fitting	0.1656	0.0306	0.0125	0.7913

Source: Punatar 2001 [DIRS 155635], Table 2-3

Table 5.1-13 End-Fitting Homogenized Material Compositions

Element/ Isotope	Upper End-Fitting (wt%)	Lower End-Fitting (wt%)
C-nat	0.0579	0.0472
N-14	0.0668	0.0539
Si-nat	0.5210	0.4229
P-31	0.0301	0.0243
S-32	0.0209	0.0170
Mn-55	1.3563	1.0968
Fe-54	2.7111	2.2021
Fe-56	44.0929	35.8143
Fe-57	1.0370	0.8423
Fe-58	0.1394	0.1132
Ni-58	8.0448	6.9769
Ni-60	3.2050	2.7796
Ni-61	0.1417	0.1229
Ni-62	0.4585	0.3976
Ni-64	0.1213	0.1052
Cr-50	0.6181	0.5098
Cr-52	12.3820	10.2112
Cr-53	1.4309	1.1800
Cr-54	0.3622	0.2987
H-1	2.2966	3.6303
O-16	18.2320	28.8205
Nb-93	0.5658	0.5272
Mo-nat	0.3364	0.3134
Ti-nat	0.0993	0.0925
Al-27	0.0551	0.0514
Zr-nat	1.5920	3.2990
Sn-nat	0.0235	0.0488
Density (g/cm^3)	3.2748	2.4388

NOTE: Values calculated in *material_comp.xls*.

5.1.8 Category 1 and 2 Event Sequences

This design calculation considered Category 1 and Category 2 event sequences as identified in the *Categorization of Event Sequences for License Application* (BSC 2004 [DIRS 167268], Section 7). The evaluation of the event sequences applicable to the TCRRF is presented in Section 5.2.3.

5.2 CRITICALITY CALCULATIONS

5.2.1 Fuel Region Modeling Study

A study was performed with MCNP, as mentioned in Section 5.1.7, to investigate the impact on k_{eff} when the end-regions (i.e., the plenum and end-fittings) are included in the model versus not included. A few scenarios were considered, and they are as follows:

1. The fuel rod includes, in addition to the active fuel region, the upper and lower plenum regions as well as the upper and lower end-fitting regions (see Section 5.1.7 for dimensions and material compositions).

2. The fuel rod only includes the active fuel region. The upper and lower plenum and end-fitting regions are replaced with water.

3. The active fuel region has been extended to cover the entire fuel rod (i.e., the upper and lower plenum and end-fitting regions are replaced with fuel).

Table 5.2-1 presents the results of the cases described above. It can be seen that the results are within 2-sigma of each other and, consequently, the fuel rod can be modeled either with or without end-regions included for criticality calculations. The calculations presented in Section 6 are all modeled per scenario 3 (i.e., the upper and lower plenum and end-fitting regions are replaced with fuel).

Table 5.2-1 Comparison of Various Fuel Modeling Scenarios

Case	Case Description	k_{eff}	Standard Deviation	MCNP Files
1	Plenum and end-fittings included in fuel region	0.93012	0.00028	sta15com, sta15com.out
2	Fuel region only modeled (regular active fuel length)	0.93057	0.00027	sta15h2o, sta15h2o.out
3	Fuel region only modeled (active fuel length extended)	0.93068	0.00029	sta15ori, sta15ori.out

5.2.2 Moderator Density and Material Variations

Water moderator density, which could vary from dry to fully moderated conditions under accident conditions, was varied on the inside and outside of the transportation cask for PWR and BWR fuel assemblies. Density variations other than dry (0 % density water) and fully moderated (100 % density water) were not considered. The Certificate of Compliance (no. 9261) for the HI-STAR transportation cask states that evaluations of casks (both single and arrays) show that optimum internal moderation occurs when the cask is fully flooded with 100% density water (Holtec International 2003 [DIRS 172633], p. 6-5). The results are presented in Sections 6.1 and 6.2.

Another moderator material, hydraulic fluid/oil, was also evaluated because it may leak from a handling crane. The results are presented in Section 6.3.

5.2.3 Reflector Evaluation

In order to find the most reactive configuration in the TCRRF and Buffer Area, various potential reflector materials were evaluated. The reflector materials considered are void/air, water, iron, and concrete. The reflector is modeled with a 30 cm width/height in the radial and axial directions. An infinite array of casks was also evaluated to ensure neutronic isolation. The results are presented in Sections 6.1 and 6.2.

5.2.4 Category 1 and 2 Event Sequences

The Category 1 and Category 2 event sequences applicable to the TCRRF have been identified in the *Categorization of Event Sequences for License Application* document (BSC 2004 [DIRS 167268], Section 7). Only a Category 2 event has been identified for the TCRRF and is presented in Table 5.2-2. The supporting calculations for the event sequence are provided in Section 6.3.

Table 5.2-2 Category 2 Event Sequence for TCRRF

Event Sequence identifier	Criticality Event Description	Reference
2-01	Drop of a transportation cask without impact limiters in the TCRRF	BSC 2004 [DIRS 167268], Section 7

6. RESULTS AND CONCLUSIONS

This section presents the results of the criticality calculations and makes recommendations for additional criticality safety design features as appropriate. The outputs presented in this document are all reasonable compared to the inputs and the results are suitable for the intended use. The uncertainties are taken into account by consistently using a conservative approach, which is the result of the methods and assumptions described in Sections 2 and 3, respectively.

6.1 MPC-24 (PWR FUEL)

The internal moderator and external moderator/reflector conditions of the MPC-24 were altered in order to find the most reactive configuration for the TCRRF and the Buffer Area. The scenarios considered include dry and water flooded inside of the cask (i.e., inside the MPC) with a dry and water flooded outside cask environment, respectively. The water region surrounding the transportation cask (i.e., in the radial and axial directions), for the flooded scenarios outside the transportation cask, was modeled with a width/height of 30 cm. The results from the calculations are presented in Table 6.1-1. It can be seen from the results that the highest k_{eff} value is for fully-flooded inside cask conditions. This observation is further supported by the HI-STAR Safety Analysis Report (SAR) where studies of reactivity effects of partial cask flooding also proved that fully-flooded condition corresponds to the highest k_{eff} (Holtec International 2003 [DIRS 172633], Table 6.4.6).

Table 6.1-1 MPC-24 with Varied Moderator (Water) Conditions

Moderation conditions	k_{eff}	St. Dev.	MCNP files
dry inside cask, dry outside cask	0.36610	0.00010	star15d, star15d.out
dry inside cask, flooded outside cask	0.36650	0.00011	star15wd, star15wd.out
flooded inside cask, dry outside cask	0.93522	0.00028	star15, star15.out
flooded inside cask, flooded outside cask	0.93666	0.00026	star15w, star15w.out

Table 6.1-2 shows the k_{eff} for a fully flooded (water) cask on the inside with various reflector materials surrounding the cask. The reflector materials are modeled with a width/height of 30 cm in the radial and axial directions.

Table 6.1-2 MPC-24 with Varied Reflector Conditions

Reflector Material	k_{eff}	St. Dev.	MCNP files
Iron	0.93617	0.00031	star15fe, star15fe.out
Concrete	0.93592	0.00027	star15co, star15co.out

To ensure neutronic decoupling of the HI-STAR cask in the TCRRF and Buffer Area, an infinite array of casks were modeled with 0.01 cm and 30 cm water separation, respectively. Table 6.1-3 presents the results and it can be seen that the transportation casks are sufficiently neutronically isolated.

Table 6.1-3 Array of MPC-24 with Water Reflection

Distance between Casks	k_{eff}	St. Dev.	MCNP files
0.01 cm	0.93600	0.00027	star15wl, star15wl.out
30 cm	0.93624	0.00028	star15wR, star15wR.out

6.2 MPC-68 (BWR FUEL)

The same conditions were evaluated for the MPC-68 containing BWR fuel as presented in Section 6.1 for PWR fuel. Again, the inside moderator and outside moderator/reflector were altered in order to find the most reactive configuration for the cask. The scenarios considered include flooded inside of the cask (i.e., inside the MPC) with a dry and flooded outside cask environment, respectively. The water region surrounding the transportation cask (i.e., in the radial and axial directions), for the flooded scenarios outside the transportation cask, was modeled with a width/height of 30 cm. The results from the calculations are presented in Table 6.2-1, which shows that the most reactive configuration is for a fully-flooded cask. As with the PWR case, partial flooding was evaluated in the HI-STAR SAR for BWR fuel and it was demonstrated that the fully-flooded condition is the most reactive (Holtec International 2003 [DIRS 172633], Table 6.4.6).

Table 6.2-1 MPC-68 with Varied Moderator Condition

Moderation conditions	k_{eff}	St. Dev.	MCNP files
dry inside cask, dry outside cask	0.37647	0.00009	star8d, star8d.out
dry inside cask, flooded outside cask	0.37696	0.00009	star8wd, star8wd.out
flooded inside cask, dry outside cask	0.93490	0.00027	star8, star8.out
flooded inside cask, flooded outside cask	0.93422	0.00029	star8w, star8w.out

Table 6.2-2 shows the k_{eff} for a fully flooded (water) cask on the inside with various reflector materials surrounding the cask. The reflector materials are modeled with a width/height of 30 cm in the radial and axial directions.

Table 6.2-2 MPC-68 with Varied Reflector Conditions

Reflector Material	k_{eff}	St. Dev.	MCNP files
Iron	0.93424	0.00028	star8fe, star8fe.out
Concrete	0.93475	0.00028	star8co, star8co.out

To ensure neutronic decoupling of the HI-STAR cask containing BWR fuel, an infinite array of casks were modeled with 0.01 cm and 30 cm water separation, respectively. Table 6.2-3 presents the results and it can be seen that the transportation casks are sufficiently neutronically isolated.

Table 6.2-3 Array of MPC-68 with Water Reflection

Distance between Casks	k_{eff}	St. Dev.	MCNP files
0.01 cm	0.93473	0.00028	star8wl, star8wl.out
30 cm	0.93422	0.00029	star8wR, star8wR.out

6.3 CATEGORY 1 AND 2 EVENT SEQUENCES

Table 6.3-1 presents the evaluation of the Category 1 and 2 event sequences for the TCRRF. As mentioned in Section 5.2.4, only a Category 2 event has been identified for the TCRRF.

Table 6.3-1 Evaluation of Category 2 Event Sequence for TCRRF

Event Sequence identifier [a]	Criticality Event Description	Criticality Safety Evaluation
2-01	Drop of a transportation cask without impact limiters in the TCRRF	Per Assumption 3.2, design requirements will ensure that a drop of a transportation cask containing DOE canister will not lead to a criticality. For transportation casks containing CSNF, see drop scenario evaluated below.

[a] BSC 2004 [DIRS 167268], Section 7

Fuel reconfiguration was studied for both PWR and BWR fuel in the HI-STAR transportation cask to ensure criticality safety in the event this would occur due to a drop. Both dry and flooded cask inside conditions was evaluated. Since the transportation casks will remain unopened, the dry conditions will represent undamaged transportation cask containment. For defense-in-depth, the flooded conditions are considered in the event the drop will puncture the transportation cask containment. Table 6.3-2 presents the k_{eff} for PWR and BWR fuel as a function of pin pitch. The pin pitches have been varied from closest possible rearrangement to largest possible pin separation within the fuel basket structure. It can be seen that fuel rearrangement does not impact k_{eff}

significantly during dry conditions, but an increase in pin pitch during flooded conditions causes k_{eff} to exceed the USL.

Table 6.3-2 Comparison of Various Pin Pitch Scenarios

Pin Pitch (cm)	k_{eff}	Standard Deviation	MCNP Files	k_{eff}	Standard Deviation	MCNP Files
	PWR fuel (MPC-24) –Dry inside			**PWR fuel (MPC-24) –Flooded inside**		
smallest (1.40)	0.36653	0.00011	star15cd star15cd.out	0.91562	0.00028	star15c star15c.out
regular (1.44)	0.36610	0.00010	star15d star15d.out	0.93522	0.00028	star15 star15.out
increased (1.45)	0.36604	0.00011	star15ad star15ad.out	0.93989	0.00029	star15a star15a.out
largest (1.50)	0.36537	0.00010	star15bd star15bd.out	0.95935	0.00029	star15b star15b.out
	BWR fuel (MPC-68) –Dry inside			**BWR fuel (MPC-68) –Flooded inside**		
smallest (1.52)	0.37720	0.00010	star8cd star8cd.out	0.87693	0.00027	star8c star8c.out
regular (1.63)	0.37647	0.00009	star8d star8d.out	0.93490	0.00027	star8 star8.out
increased (1.65)	0.37620	0.00009	star8ad star8ad.out	0.94562	0.00028	star8a star8a.out
largest (1.70)	0.37598	0.00009	star8bd star8bd.out	0.96987	0.00026	star8b star8b.out

In order for k_{eff} to exceed the USL, significant amounts of water must be present in the facility and the drop will need to puncture the transportation cask, in addition to rearranging the fuel in a worst-case scenario. A study was performed with the transportation cask containing rearranged fuel (largest pin pitch) and the transportation cask partially filled with water to assess the amount of water that can be present in the transportation cask without exceeding the USL. Table 6.3-3 shows the k_{eff} values for PWR and BWR fuel at various water heights in the horizontally orientated transportation cask. It can be seen that the transportation casks can be filled up to 50 % with water (54.215 cm above the floor) with rearranged fuel and not be in violation of the USL. It is recommended that the water height is limited/controlled to approximately 50 cm above the floor.

In the event that hydraulic fluid/oil is present in the facility, due to a leak form the handling crane, evaluations were also performed for a cask containing rearranged fuel (from a drop) partially filled with oil to assess the amount of oil that can be present in the transportation cask without exceeding the USL. Table 6.3-4 shows the k_{eff} values for PWR and BWR fuel at various oil heights in the horizontally orientated transportation cask. It can be seen that the transportation casks can be filled up to 100 % with oil with rearranged fuel and not be in violation of the USL.

Table 6.3-3 Comparison of Various Partial Water Flooding Scenarios

Case	k_{eff}	Standard Deviation	MCNP Files
	Reconfigured PWR fuel (MPC-24)		
0 % flooding	0.36537	0.00010	star15bd, star15bd.out
25 % flooding	0.91843	0.00028	sta15bp1, sta15bp1.out
50 % flooding	0.94495	0.00027	star15bp, star15bp.out
75 % flooding	0.95753	0.00027	sta15bp2, sta15bp2.out
100 % flooding	0.95935	0.00029	star15b, star15b.out
	Reconfigured BWR fuel (MPC-68)		
0 % flooding	0.37598	0.00009	star8bd, star8bd.out
25 % flooding	0.87510	0.00027	star8bp1, star8bp1.out
50 % flooding	0.94565	0.00026	star8bp, star8bp.out
75 % flooding	0.96541	0.00027	star8bp2, star8bp2.out
100 % flooding	0.97141	0.00028	star8b, star8b.out

Table 6.3-4 Comparison of Various Partial Oil Flooding Scenarios

Case	k_{eff}	Standard Deviation	MCNP Files
	Reconfigured PWR fuel (MPC-24)		
50 % flooding	0.85089	0.00027	sta15bpO, sta15bpO.out
100 % flooding	0.86951	0.00030	star15bO, star15bO.out
	Reconfigured BWR fuel (MPC-68)		
50 % flooding	0.85678	0.00027	star8bpO, star8bpO.out
100 % flooding	0.88392	0.00026	star8bO, star8bO.out

Various fuel enrichments were also studied for reconfigured, fully water flooded fuel assemblies to investigate the reduction needed to achieve a k_{eff} below the USL. The design/highest allowed enrichment for the B&W 15x15 PWR fuel assembly is 4.1 wt% (see Table 5.1-4) while it is 4.2 wt% (see Table 5.1-8) for the GE 8x8 BWR fuel assembly. Table 6.3-5 shows the keff values for the MPC-24 and MPC-68 as a function of enrichment. It can see that a 3.5 wt% enrichment for fully flooded, reconfigured fuel reduces the k_{eff} below the USL.

Table 6.3-5 Variation in Fuel Enrichment for Reconfigured Fuel

Enrichment (wt%)	k_{eff}	Standard Deviation	MCNP Files
	Reconfigured, Fully Water Flooded PWR fuel (MPC-24)		
3.0	0.89552	0.00026	star15bE, star15bE.out
3.5	0.92771	0.00029	st15bE35, st15bE35.out
4.0	0.95402	0.00031	sta15bE4, sta15bE4.out
	Reconfigured, Fully Water Flooded BWR fuel (MPC-68)		
3.0	0.88796	0.00026	star8bE, star8bE.out
3.5	0.92622	0.00026	sta8bE35, sta8bE35.out
4.0	0.95785	0.00027	star8bE4, star8bE4.out

6.4 CONCLUSIONS AND RECOMMENDATIONS

The processes for the TCRRF and the Buffer Area have been evaluated for criticality safety for normal operations, Category 1 and 2 event sequences. The results presented in this document lead to the following conclusions and recommendations:

- A modeling study investigating the impact on k_{eff} when the end-regions are included versus not included in the MCNP model showed that either modeling scenario is acceptable (Section 5.2.1).
- The MPC-24, designed to hold 24 PWR assemblies, is subcritical and criticality safe in the TCRRF and Buffer Area under normal operation conditions. The same conclusion was found for the MPC-68, designed to hold 68 BWR assemblies.
- Reactivity of the loaded casks decreases with reduction in moderator density (Section 5.2.2).
- Maximum reactivity is reached when the transportation casks are fully flooded (as opposed to partial flooded) with water.
- The PWR and BWR fuel when placed inside the MPCs demonstrate that the conditions outside the transportation cask (e.g., moderation) have no significant impact on the reactivity of the cask.
- The identified evaluated Category 2 event for the TCRRF was found criticality safe under nominal conditions. For fully flooded defense-in-depth scenarios, the k_{eff} exceeded the USL but remained below 1.0 (see Section 6.3). The latter scenarios require a controlled moderator (i.e., water) height in the TCRRF of 50 cm above the floor in order for k_{eff} to remain below the USL. There are no restrictions for the presence of hydraulic fluid/oil in the TCRRF should it leak from a handling crane. In addition, reduced design enrichment for PWR and BWR fuel to 3.5 wt% brings the calculated k_{eff} below the USL for the fully flooded defense-in-depth scenarios (Section 6.3).

In summary, normal operations in TCRRF prove to be criticality safe for both CSNF and DOE SNF. During Category 2 conditions, a controlled moderator (i.e., water) height of 50 cm above the floor is required, for defense-in-depth, in order for k_{eff} to remain below the USL for CSNF. It should also be mentioned that usage of crush pads is required in the TCRRF to ensure no breaching of the MCOs during the Category 2 event (see Assumption 3.2). Design requirements should also be implemented to limit lift heights in the TCCRF to ensure no breaching of DOE SNF canisters (see Assumption 3.2).

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8. ATTACHMENTS

This calculation document includes three attachments:

ATTACHMENT I	List of Computer Files
ATTACHMENT II	One Compact Disc
ATTACHMENT III	Sketches: Transportation Cask Receipt/Return & Waste Package Receipt Facilities General Arrangement (Note that some secondary drawing references on the sketches are not relevant to this calculation. These drawings are not included)

ATTACHMENT I
LISTING OF COMPUTER FILES

All MCNP input and output files documented in this calculation were stored on an electronic medium (compact disc) as Attachment II. Also, the Microsoft® Excel spreadsheets used to calculate input values are included on the compact disc.

Date	Time	Size	File
12/15/2004	02:57p	24,064	at_dens.xls
01/05/2005	04:12p	228,864	material_comp.xls
12/13/2004	10:46a	18,403	PWR/star15
12/13/2004	10:46a	521,395	PWR/star15.out
12/13/2004	10:46a	18,400	PWR/star15a
12/13/2004	10:46a	520,127	PWR/star15a.out
12/13/2004	10:46a	18,396	PWR/star15b
12/13/2004	10:46a	521,411	PWR/star15b.out
12/13/2004	10:46a	18,397	PWR/star15c
12/13/2004	10:46a	521,411	PWR/star15c.out
01/28/2005	08:20a	18,358	PWR/star15bE
01/28/2005	08:20a	521,411	PWR/star15bE.out
01/31/2005	09:28a	18,360	PWR/st15bE35
01/31/2005	09:28a	521,411	PWR/st15bE35.out
01/31/2005	09:28a	18,360	PWR/sta15bE4
01/31/2005	09:28a	521,411	PWR/sta15bE4.out
12/13/2004	10:46a	34,042	PWR/PARTIAL/sta15bp1
12/13/2004	10:46a	604,436	PWR/PARTIAL/sta15bp1.out
12/13/2004	10:46a	34,023	PWR/PARTIAL/sta15bp2
12/13/2004	10:46a	604,642	PWR/PARTIAL/sta15bp2.out
12/13/2004	10:46a	34,005	PWR/PARTIAL/star15bp
12/13/2004	10:46a	604,246	PWR/PARTIAL/star15bp.out
12/13/2004	10:46a	18,726	PWR/DRY/star15ad
12/13/2004	10:46a	521,892	PWR/DRY/star15ad.out
12/13/2004	10:46a	18,727	PWR/DRY/star15bd
12/13/2004	10:46a	521,710	PWR/DRY/star15bd.out
12/13/2004	10:46a	18,728	PWR/DRY/star15cd
12/13/2004	10:46a	521,916	PWR/DRY/star15cd.out
12/13/2004	10:46a	18,733	PWR/DRY/star15d
12/13/2004	10:46a	521,916	PWR/DRY/star15d.out
12/13/2004	10:46a	18,493	PWR/SURR/star15w
12/13/2004	10:46a	522,128	PWR/SURR/star15w.out
12/13/2004	10:46a	18,818	PWR/SURR/star15wd
12/13/2004	10:46a	523,158	PWR/SURR/star15wd.out
01/28/2005	08:21a	522,112	PWR/SURR/star15wR.out
01/28/2005	08:21a	18,496	PWR/SURR/star15wR
01/28/2005	08:21a	522,128	PWR/SURR/star15wI.out
01/28/2005	08:21a	18,500	PWR/SURR/star15wI

Date	Time	Size	File
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01/28/2005	08:21a	523,661	PWR/SURR/star15co.out
01/28/2005	08:21a	18,785	PWR/SURR/star15co
12/13/2004	10:46a	20,876	PWR/COMP/sta15com
12/13/2004	10:46a	531,324	PWR/COMP/sta15com.out
12/13/2004	10:46a	20,900	PWR/COMP/sta15h2o
12/13/2004	10:46a	528,631	PWR/COMP/sta15h2o.out
12/13/2004	10:46a	20,900	PWR/COMP/sta15ori
12/13/2004	10:46a	528,631	PWR/COMP/sta15ori.out
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01/31/2005	09:29a	34,044	PWR/MOD/sta15bpO
01/31/2005	09:29a	521,188	PWR/MOD/star15bO.out
01/31/2005	09:30a	8,859	BWR/star8
01/31/2005	09:30a	460,067	BWR/star8.out
02/01/2005	10:31a	8,852	BWR/star8a
02/01/2005	10:31a	460,067	BWR/star8a.out
02/01/2005	10:32a	8,849	BWR/star8b
02/01/2005	10:32a	460,067	BWR/star8b.out
02/01/2005	10:32a	8,849	BWR/star8c
02/01/2005	10:32a	460,067	BWR/star8c.out
02/01/2005	10:31a	8,857	BWR/sta8bE35
02/01/2005	10:31a	460,067	BWR/sta8bE35.out
02/01/2005	10:32a	460,067	BWR/star8bE4.out
02/01/2005	10:32a	8,857	BWR/star8bE4
02/01/2005	10:32a	460,067	BWR/star8bE.out
02/01/2005	10:32a	8,855	BWR/star8bE
02/01/2005	10:33a	13,517	BWR/PARTIAL/star8bp
02/01/2005	10:33a	487,134	BWR/PARTIAL/star8bp.out
12/13/2004	10:45a	13,554	BWR/PARTIAL/star8bp1
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12/13/2004	10:45a	13,484	BWR/PARTIAL/star8bp2
12/13/2004	10:45a	486,922	BWR/PARTIAL/star8bp2.out
12/13/2004	10:45a	9,051	BWR/DRY/star8ad
12/13/2004	10:45a	460,366	BWR/DRY/star8ad.out
12/13/2004	10:45a	9,057	BWR/DRY/star8bd
12/13/2004	10:45a	460,572	BWR/DRY/star8bd.out
12/13/2004	10:45a	9,046	BWR/DRY/star8cd
12/13/2004	10:45a	460,366	BWR/DRY/star8cd.out
12/13/2004	10:45a	9,050	BWR/DRY/star8d
12/13/2004	10:45a	460,572	BWR/DRY/star8d.out
12/13/2004	10:45a	9,168	BWR/SURR/star8w
12/13/2004	10:45a	461,655	BWR/SURR/star8w.out
12/13/2004	10:45a	9,373	BWR/SURR/star8wd

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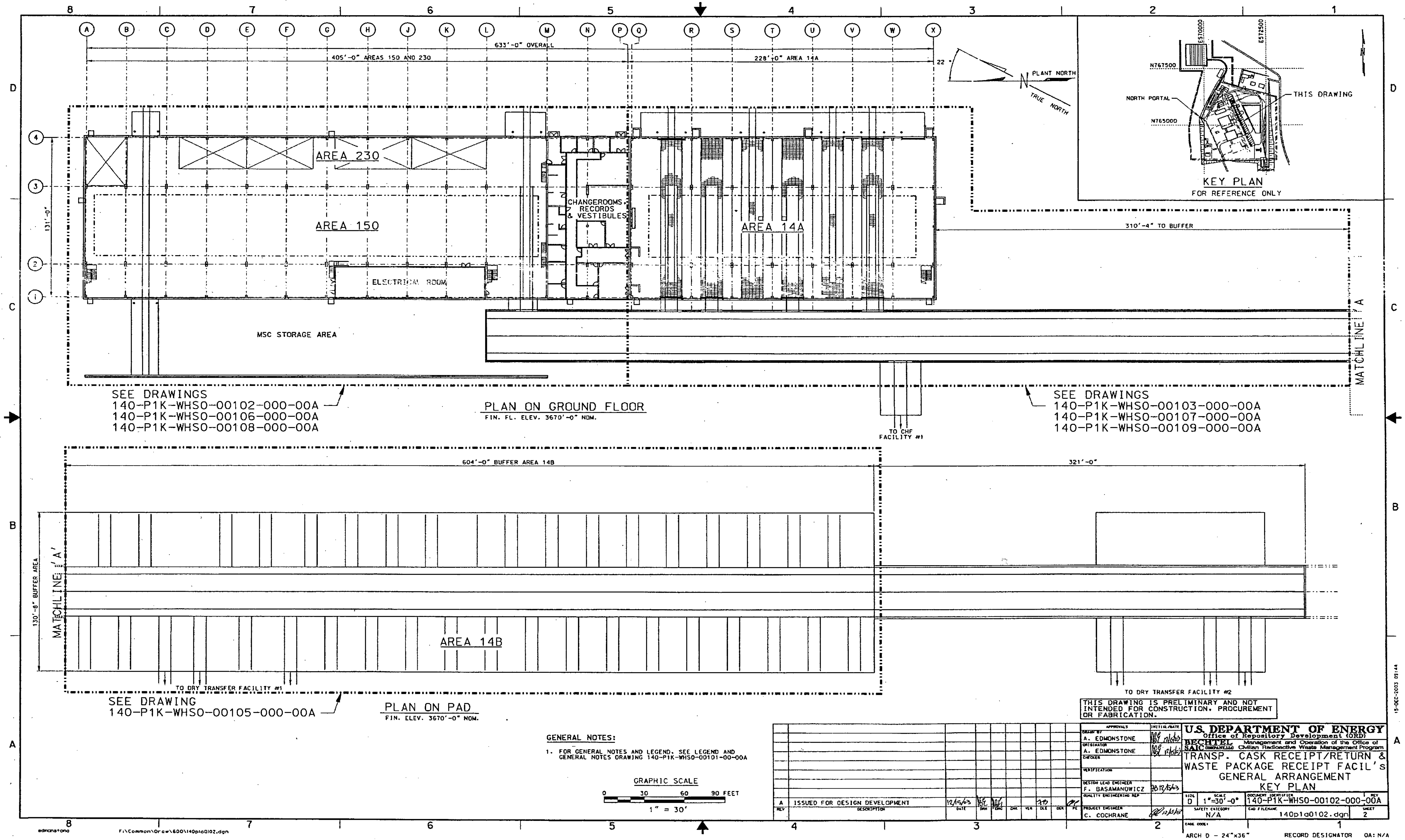
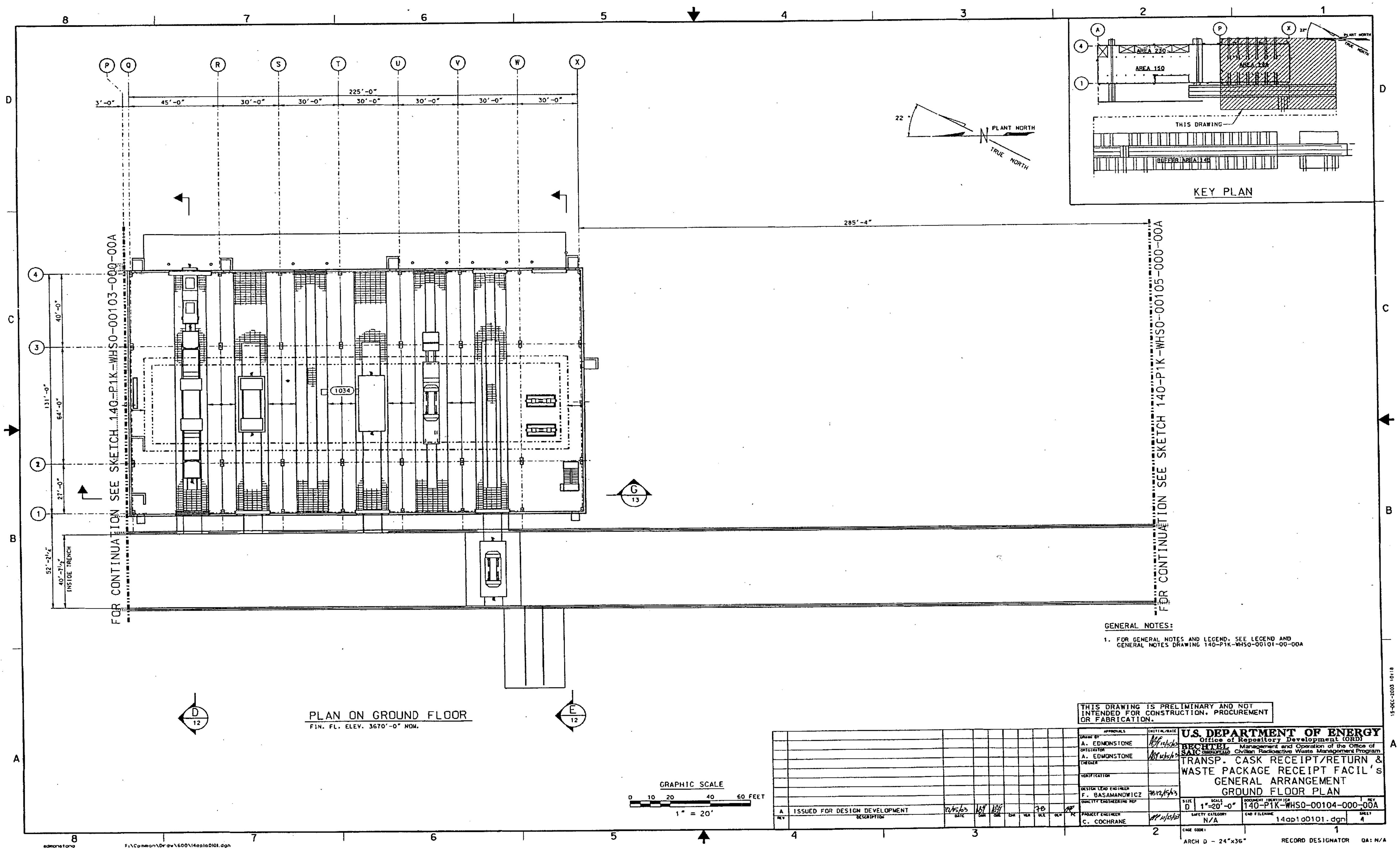
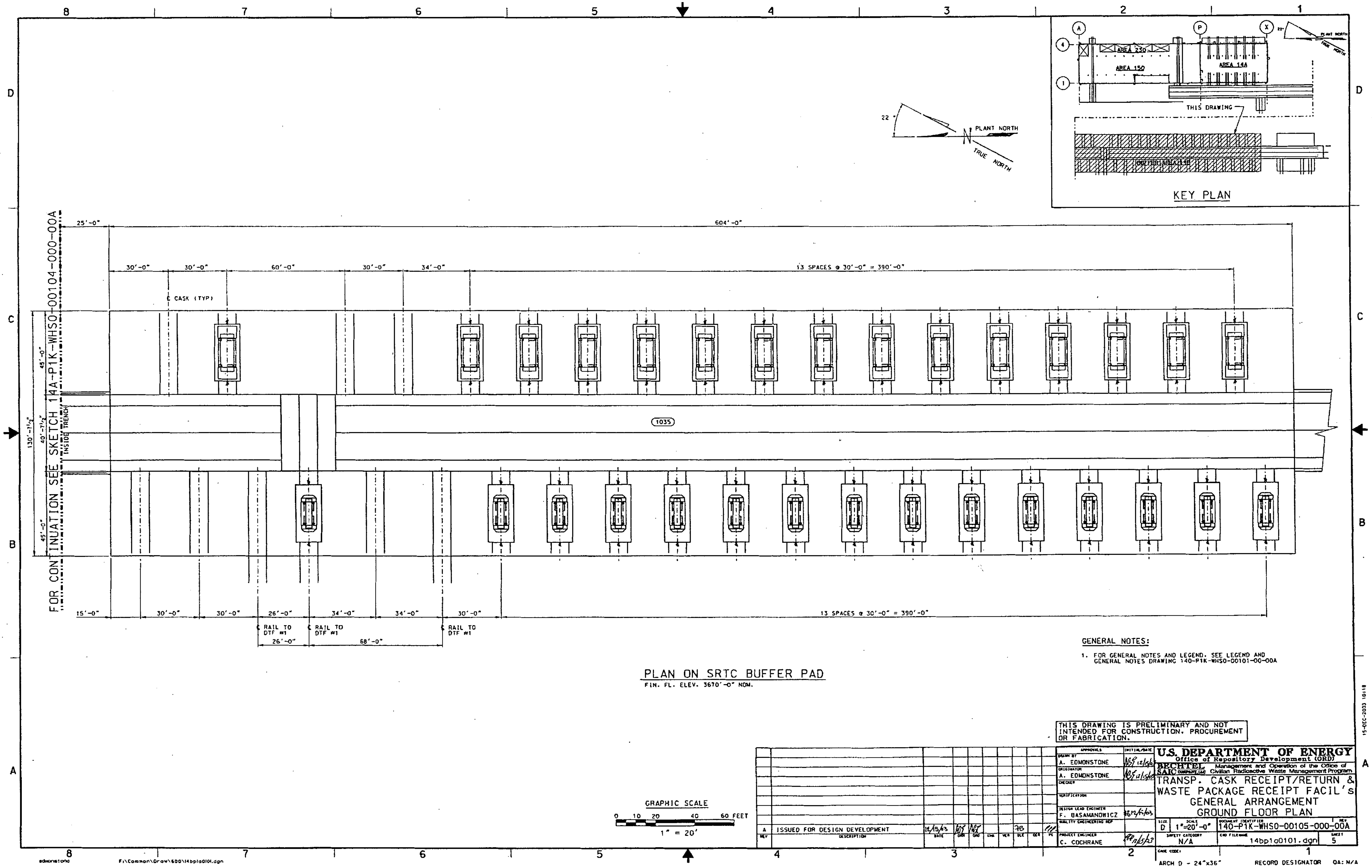
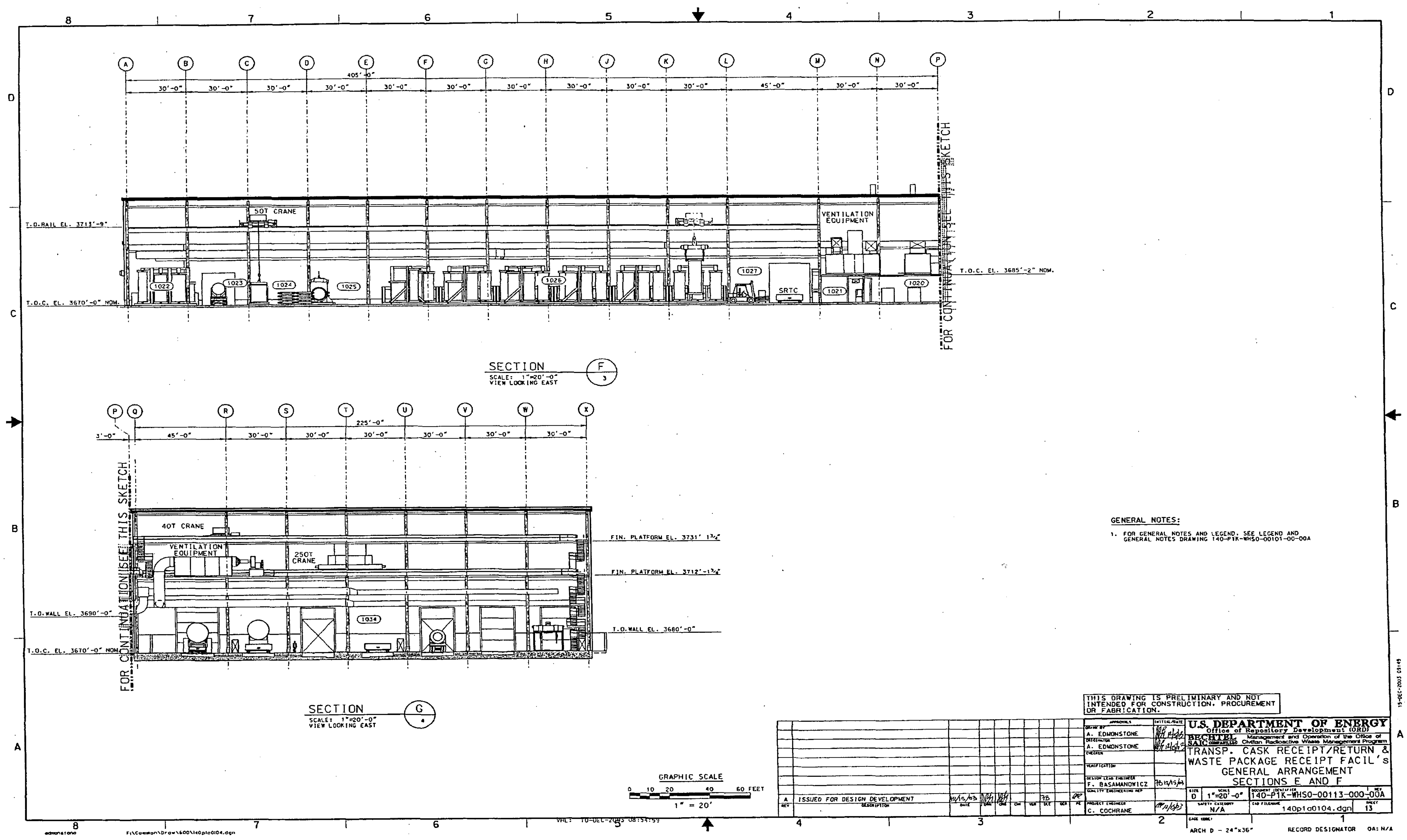
01/28/2005	08:20a	9,171	BWR/SURR/star8wR
01/28/2005	08:20a	461,449	BWR/SURR/star8wI.out
01/28/2005	08:20a	9,175	BWR/SURR/star8wI
01/31/2005	09:29a	461,639	BWR/SURR/star8fe.out
01/31/2005	09:29a	9,199	BWR/SURR/star8fe
01/31/2005	09:29a	463,943	BWR/SURR/star8co.out
01/31/2005	09:29a	9,716	BWR/SURR/star8co
02/01/2005	10:33a	486,911	BWR/MOD/star8bpO.out
02/01/2005	10:33a	13,536	BWR/MOD/star8bpO
01/28/2005	08:19a	459,844	BWR/MOD/star8bO.out
01/28/2005	08:19a	8,876	BWR/MOD/star8bO


633'-0" OVERALL
405'-0" AREAS 150 AND 230
228'-0" AREA 14A
PLANT NORTH
TRUE NORTH
AREA 230
AREA 150
CHANGEROOMS RECORDS & VESTIBULES
AREA 14A
ELECTRICAL ROOM
MSC STORAGE AREA
310'-4" TO BUFFER
MATCHLINE 'A'
KEY PLAN
FOR REFERENCE ONLY
NORTH PORTAL
THIS DRAWING
SEE DRAWINGS
140-P1K-WHS0-00102-000-00A
140-P1K-WHS0-00106-000-00A
140-P1K-WHS0-00108-000-00A
PLAN ON GROUND FLOOR
FIN. FL. ELEV. 3670'-0" NOM.
TO CHF FACILITY #1
SEE DRAWINGS
140-P1K-WHS0-00103-000-00A
140-P1K-WHS0-00107-000-00A
140-P1K-WHS0-00109-000-00A
604'-0" BUFFER AREA 14B
321'-0"
130'-8" BUFFER AREA
AREA 14B
TO DRY TRANSFER FACILITY #1
TO DRY TRANSFER FACILITY #2
SEE DRAWING
140-P1K-WHS0-00105-000-00A
PLAN ON PAD
FIN. ELEV. 3670'-0" NOM.
GENERAL NOTES:
1. FOR GENERAL NOTES AND LEGEND, SEE LEGEND AND GENERAL NOTES DRAWING 140-P1K-WHS0-00101-00-00A
GRAPHIC SCALE
0 30 60 90 FEET
1" = 30'
THIS DRAWING IS PRELIMINARY AND NOT INTENDED FOR CONSTRUCTION, PROCUREMENT OR FABRICATION.
U.S. DEPARTMENT OF ENERGY
Office of Repository Development (ORD)
BECHTEL SAIC
TRANSP. CASK RECEIPT/RETURN & WASTE PACKAGE RECEIPT FACIL'S GENERAL ARRANGEMENT KEY PLAN
A. EDMONSTONE
F. GASAMANOWICZ
C. COCHRANE
A ISSUED FOR DESIGN DEVELOPMENT
D 1"=30'-0" 140-P1K-WHS0-00102-000-00A
N/A 140p1a0102.dgn 2
ARCH D - 24"x36"


KEY PLAN
PLANT NORTH
TRUE NORTH
FOR CONTINUATION SEE SKETCH 140-P1K-WHS0-00103-000-00A
FOR CONTINUATION SEE SKETCH 140-P1K-WHS0-00105-000-00A
PLAN ON GROUND FLOOR
FIN. FL. ELEV. 3670'-0" NOM.
GENERAL NOTES:
1. FOR GENERAL NOTES AND LEGEND, SEE LEGEND AND GENERAL NOTES DRAWING 140-P1K-WHS0-00101-00-00A
THIS DRAWING IS PRELIMINARY AND NOT INTENDED FOR CONSTRUCTION, PROCUREMENT OR FABRICATION.
GRAPHIC SCALE
1" = 20'
ISSUED FOR DESIGN DEVELOPMENT
A. EDMONSTONE
F. BASAMANOWICZ
C. COCHRANE
U.S. DEPARTMENT OF ENERGY
Office of Repository Development (ORD)
BECHTEL SAIC
TRANSP. CASK RECEIPT/RETURN & WASTE PACKAGE RECEIPT FACIL's GENERAL ARRANGEMENT GROUND FLOOR PLAN
140-P1K-WHS0-00104-000-00A
14ap1a0101.dgn
ARCH D - 24"x36"
RECORD DESIGNATOR
QA: N/A


KEY PLAN
AREA 230
AREA 150
AREA 14A
THIS DRAWING
PLANT NORTH
TRUE NORTH
FOR CONTINUATION SEE SKETCH 14A-P1K-WHS0-00104-000-00A
604'-0"
13 SPACES @ 30'-0" = 390'-0"
℄ CASK (TYP)
1035
INSIDE TRENCH
℄ RAIL TO DTF #1
PLAN ON SRTC BUFFER PAD
FIN. FL. ELEV. 3670'-0" NOM.
GENERAL NOTES:
1. FOR GENERAL NOTES AND LEGEND, SEE LEGEND AND GENERAL NOTES DRAWING 140-P1K-WHS0-00101-00-00A
GRAPHIC SCALE
1" = 20'
THIS DRAWING IS PRELIMINARY AND NOT INTENDED FOR CONSTRUCTION, PROCUREMENT OR FABRICATION.
A ISSUED FOR DESIGN DEVELOPMENT
A. EDMONSTONE
F. UASAMANOWICZ
C. COCHRANE
U.S. DEPARTMENT OF ENERGY
Office of Repository Development (ORD)
BECHTEL SAIC
TRANSP. CASK RECEIPT/RETURN & WASTE PACKAGE RECEIPT FACIL'S GENERAL ARRANGEMENT GROUND FLOOR PLAN
1"=20'-0"
140-P1K-WHS0-00105-000-00A
14bp1o0101.dgn
ARCH D - 24"x36"
RECORD DESIGNATOR


SECTION F
SCALE: 1"=20'-0"
VIEW LOOKING EAST
50T CRANE
VENTILATION EQUIPMENT
SRTC
FOR CONTINUATION SEE THIS SKETCH
SECTION G
SCALE: 1"=20'-0"
VIEW LOOKING EAST
40T CRANE
250T CRANE
GENERAL NOTES:
1. FOR GENERAL NOTES AND LEGEND, SEE LEGEND AND GENERAL NOTES DRAWING 140-P1K-WHS0-00101-00-00A
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U.S. DEPARTMENT OF ENERGY
Office of Repository Development (ORD)
TRANSP. CASK RECEIPT/RETURN & WASTE PACKAGE RECEIPT FACIL'S
GENERAL ARRANGEMENT
SECTIONS E AND F
140-P1K-WHS0-00113-000-00A
A ISSUED FOR DESIGN DEVELOPMENT
A. EDMONSTONE
F. BASAMANOWICZ
C. COCHRANE
GRAPHIC SCALE
1" = 20'
ARCH D - 24"x36"