6.7.5 BWR Fuel Characterization

Fuel definitions listed in Section 6.4 are the result of grouping the large range of commercial fuel types by core type, number of fuel rods, and key criticality characteristics. These characteristics are primarily associated with the assembly moderator ratio and fuel mass and include pellet diameter, active fuel length, fuel rod diameter and clad thickness, and water rod configuration. Another variable for BWR assemblies is the presence, and thickness, of the channel.

Characterization studies are based on the 87-assembly basket configuration. For assemblies exceeding the USL at the enrichment specified in the studies either, the 82-assembly basket configuration or reduced maximum enrichments are required. Enrichment limits for the 82-assembly and 87-assembly basket configurations are provided in Section 6.7.6.

Lattice Configuration and Channel Studies

BWR fuel assemblies are typically undermoderated in the basket structure (H/U ratio below optimum levels). Therefore, initial criticality analysis extracts from each assembly type the following characteristics.

- Minimum fuel rod outer diameter
- Minimum clad thickness (only relevant to flooded pellet-to-clad gap scenarios)
- Minimum water rod outer diameter and thickness
- Maximum rod pitch (assemblies are grouped by core type and, therefore, typically have single nominal pitch)

Based on the maximum H/U set of characteristics, the reactivity of each assembly is determined under various conditions. Evaluated is a dry and flooded pellet-to-clad gap. Since relative reactivity for the assembly design and flood conditions are evaluated, the models are based on nominal basket characteristics with the assemblies centered in the tube and developed cell. Comparisons are performed at a 4 wt.% enrichment level.

Results of the analysis at various clad-to-gap conditions are shown in Table 6.7.5-1. Flooding the pellet-to-clad gap raised system reactivity across the majority of fuel types, indicating that the fuel assemblies are significantly undermoderated in the basket. No statistically significant reactivity decrease occurs as a result of flooding the gap for any of the fuel types. The channel thickness study documented in Table 6.7.5-2 demonstrates that modeling the maximum channel thickness is conservative and that it is permissible to load assemblies without channel.

The evaluation presented previously assumed that the assemblies are undermoderated and that choosing the corresponding set of parameters maximizes system reactivity. This assumption is supported by the pellet-to-clad gap flood evaluation, which clearly demonstrates that providing additional moderator to the lattice increases reactivity. This assumption is further validated by evaluating a subset of the fuel assembly types for a variation in the lattice parameters. As typical assemblies loaded into the cask are expected to be intact (no leak), the pellet-to-clad gap is specified to be dry for these analyses. Fuel assemblies are evaluated in a nominal configuration basket with fuel assemblies centered in the tube. As this evaluation is concerned with relative reactivity differences due to lattice parameter changes, the results of this analysis may be applied to the maximum reactivity basket configuration. Each assembly hybrid is evaluated over its range of nominal lattice parameters.

Rather than evaluating individual parameter effects separately, the fuel characteristics analysis is divided into distinct regions.

Fuel rod lattice unit cell
- H/U ratio controlled by rod pitch, rod diameter, and clad thickness

Water rod unit cell (note that not all BWR assemblies contain water rods)
- H/U controlled by water rod diameter and thickness

Pellet diameter (NUREG-6716 [9] indicates the possibility of a minimum pellet diameter increasing system reactivity)

Monte Carlo evaluation results of the nominal assembly parameter ranges provided limited useful information, as the majority of reactivity changes were not resolvable within a two or three sigma uncertainty band. Statistically significant results were obtained from an additional calculation set applying increased variances to each of the parameters. The results of the increased variance evaluation for 4.0 wt.% enriched cases are shown in Table 6.7.5-3. As shown, the cases containing maximum H/U ratio in the fuel rod lattice location, maximum H/U in the water rod location (minimum water rod diameter and thickness), and maximum pellet diameter produce a maximum reactivity configuration system. The result set also demonstrates that water rod dimensions are not a crucial to system criticality control. Critical assemblies characteristics are listed below.

Number of fuel rods

Minimum fuel rod outer diameter

Minimum clad thickness

Maximum rod pitch

Maximum active fuel length (not evaluated but based on neutron leakage maximum active fuel length results in a bounding payload definition)

Homogeneous versus Heterogeneous Assembly Enrichment Evaluation

BWR fuel assemblies are typically loaded with a heterogeneous enrichment scheme of multiple fuel pin enrichments in one assembly. For the criticality analysis presented previously, an initial peak planar-average enrichment is used. The initial peak planar-average enrichment is the maximum planar-average enrichment at any height along the axis of the fuel assembly. This section demonstrates that the use of a planar-average enrichment provides a conservative k_{eff} compared to the heterogeneous fuel assembly. Sample fuel assembly loading patterns are evaluated using both homogeneous and heterogeneous enrichment schemes and the resulting k_{eff} are compared. No gadolinium poisons are included in any of the models.

Fuel assembly types studied are the GE 8×8 60 and 62 fuel rod and GE 9×9 74 fuel rod assembly types. Each of the fuel assemblies is evaluated at a planar-average homogeneous enrichment and the actual documented enrichment pattern. Results of the analysis, listed in Table 6.7.5-4, show that for all cases, the heterogeneous enrichment produces a lower k_{eff} than the homogeneous planar average (in this case assembly average) enrichment case. This demonstrates that applying the maximum planar-average enrichment provides a conservative estimate of the cask k_{eff}. The maximum pin enrichments in each of the assemblies evaluated are included in Table 6.7.5-4.

Table 6.7.5-1 System Reactivity Response to BWR Fuel Type and Pellet-to-Clad Condition

Assembly Type	Dry Gap k_{eff}	Wet Gap k_{eff}	Dry Gap to Wet Gap $\Delta k_{eff}/\sigma$
B7_48A	0.91765	0.92232	4.2
B7_49A	0.92470	0.93034	5.4
B7_49B	0.92610	0.93136	4.8
B8_59A	0.91930	0.92592	6.2
B8_60A	0.92497	0.93054	5.2
B8_60B	0.92589	0.93186	5.5
B8_61B	0.92650	0.93161	4.9
B8_62A	0.93055	0.93352	2.7
B8_63A	0.92687	0.93557	8.0
B8_64A	0.92594	0.93140	5.0
B8_64B	0.94157	0.94661	4.8
B9_72A	0.93299	0.93695	3.7
B9_74A	0.94392	0.94364	-0.3
B9_76A	0.95063	0.94997	-0.6
B9_79A	0.94155	0.94264	1.0
B9_80A	0.92757	0.93214	4.3
B10_91A	0.92961	0.93362	3.8
B10_92A	0.92366	0.92975	5.6
B10_96A	0.93807	0.94274	4.6
B10_100A	0.93827	0.94478	6.1

Table 6.7.5-2 System Reactivity Response to BWR Fuel Type and Channel Thickness

Assembly Type	120 mil Channel k_{eff}	80 mil Channel k_{eff}	No Channel k_{eff}	120 mil to No Channel $\Delta k_{eff}/\sigma$
B7_48A	0.91765	0.91549	0.91525	-2.2
B7_49A	0.92470	0.92250	0.92091	-3.6
B7_49B	0.92610	0.92429	0.92316	-2.8
B8_59A	0.91930	0.91846	0.91865	-0.6
B8_60A	0.92497	0.92290	0.92020	-4.3
B8_60B	0.92589	0.92519	0.92307	-2.7
B8_61B	0.92650	0.92572	0.92190	-4.3
B8_62A	0.93055	0.92618	0.92355	-6.4
B8_63A	0.92687	0.92697	0.92528	-1.5
B8_64A	0.92594	0.92314	0.92202	-3.6
B8_64B	0.94157	0.93918	0.93761	-3.6
B9_72A	0.93299	0.92914	0.92862	-4.2
B9_74A	0.94392	0.94160	0.93910	-4.5
B9_76A	0.95063	0.94770	0.94725	-3.2
B9_79A	0.94155	0.93869	0.93711	-4.2
B9_80A	0.92757	0.92482	0.92120	-5.8
B10_91A	0.92961	0.92519	0.92590	-3.5
B10_92A	0.92366	0.92230	0.92224	-1.3
B10_96A	0.93807	0.93718	0.93597	-2.1
B10_100A	0.93827	0.93701	0.93622	-1.9

Table 6.7.5-3 BWR Lattice Parameter Reactivity Study (Increased Variance)

	2	1	3	4	5	6	7	8
Fuel Pin Cell H/U	Max	Max	Max	Max	Min	Min	Min	Min
Pellet Dia.	Max	Max	Min	Min	Max	Max	Min	Min
WR Thick & Dia.	Min	Max	Max	Min	Max	Min	Max	Min
B7_49A	0.92730	0.92730	0.92056	0.92056	0.91586	0.91586	0.90754	0.90754
B8_62A	0.93236	0.93074	0.92250	0.92221	0.92329	0.92487	0.91509	0.91531
B8_64B	0.94490	0.94490	0.94492	0.94492	0.94077	0.94077	0.94024	0.94024
B9_76A	0.95166	0.95339	0.93279	0.93515	0.92594	0.92475	0.90617	0.90821
B9_79A	0.94460	0.94312	0.92833	0.92976	0.91394	0.91460	0.89807	0.90005
B10_92A	0.92811	0.92719	0.92661	0.92590	0.92079	0.92305	0.92089	0.91909
B10_96A	0.94037	0.94037	0.94109	0.94109	0.93618	0.93618	0.93490	0.93490
		Case 2 To Case 1 $\Delta k_{eff}/\sigma$	Case 2 To Case 3 $\Delta k_{eff}/\sigma$	Case 2 to Case 4 $\Delta k_{eff}/\sigma$	Case 2 to Case 5 $\Delta k_{eff}/\sigma$	Case 2 to Case 6 $\Delta k_{eff}/\sigma$	Case 2 to Case 7 $\Delta k_{eff}/\sigma$	Case 2 To Case 8 $\Delta k_{eff}/\sigma$
B7_49A		--	-6.2	-6.2	-10.9	-10.9	-18.9	-18.9
B8_62A		-1.4	-8.8	-8.8	-8.0	-6.6	-15.6	-15.4
B8_64B		--	0.0	0.0	-3.8	-3.8	-4.3	-4.3
B9_76A		1.7	-18.2	-18.2	-24.1	-25.2	-43.5	-41.5
B9_79A		-1.5	-15.4	-15.4	-29.7	-29.1	-45.7	-43.8
B10_92A		-0.9	-1.4	-1.4	-6.8	-4.7	-6.7	-8.4
B10_96A		--	0.7	0.7	-4.2	-4.2	-5.5	-5.5

Table 6.7.5-4 BWR Heterogeneous vs. Homogeneous Enrichment Analysis Results

Assembly Type	Avg. Enrichment (wt ^{235}U)	Max. Pellet Enrichment (wt % ^{235}U)	Pattern	k_{eff}	$\Delta k_{eff}/\sigma$
B8_60B	3.40	3.40	Homog.	0.88886	--
B8_60B	3.40	3.95	Variable	0.88371	-4.8
B8_60B	4.00	4.00	Homog.	0.92589	--
B8_60B	4.00	4.64	Variable	0.92017	-5.4
B8_60B	4.20	4.20	Homog.	0.93765	--
B8_60B	4.20	4.87	Variable	0.93229	-5.1
B8_62A	2.80	2.80	Homog.	0.84529	--
B8_62A	2.80	3.80	Variable	0.83869	-6.3
B8_62A	3.50	3.50	Homog.	0.89956	--
B8_62A	3.50	4.71	Variable	0.88756	-11.8
B8_62A	4.00	4.00	Homog.	0.93055	--
B8_62A	4.00	5.38	Variable	0.91787	-11.3
B9_74A	3.50	3.50	Homog.	0.91161	--
B9_74A	3.50	4.20	Variable	0.90810	-3.3
B9_74A	4.10	4.10	Homog.	0.94574	--
B9_74A	4.10	4.90	Variable	0.94391	-1.8
B9_74A	4.20	4.20	Homog.	0.95367	--
B9_74A	4.20	5.04	Variable	0.95139	-2.2

6.7.6 BWR Undamaged Fuel Criticality Evaluation

6.7.6.1 Optimum System Configuration

Enrichment limits are based on a maximum reactivity configuration system. To determine the maximum reactivity system, the following system perturbations are evaluated:

- TSC interior moderator elevation variations (partial flooding)
- Moderator density changes from void to full density (inside and outside the TSC)
- Basket fabrication tolerance
- Component shift scenarios

All system perturbation analyses are based on fuel assemblies at the maximum lattice moderator (H/U) ratio. Justification for this fuel assembly configuration is provided in Section 6.7.5. Only transfer cask cases are used in these evaluations since the transfer cask is the only cask body in which TSC flooding occurs. In the dry concrete cask, the TSC has a low reactivity, $k_{eff} < 0.5$.

All elevations in this section are based on full-length rods in all assemblies. Partial length rods are addressed in the loading tables. Optimum system configuration studies are based on the 87-assembly basket configuration and a 4.0 wt % ^{235}U initial enrichment, unless otherwise stated. Certain assembly types and configurations exceed the USL at the 4.0 wt % ^{235}U in the 87-assembly basket configuration. These assemblies require the use of either the 82-assembly basket configuration or reduced maximum enrichments.

Partial Flooding

Partial flood cases drain the TSC to the top of the active fuel region. The partial flood reactivity cases investigate reactivity difference between a water reflector over the active fuel region and reflection from the steel lid. The results of the partial flooding study, documented in Table 6.7.6-1, demonstrate that BWR system reactivity is independent of TSC moderator elevations.

Moderator Density Variations

Moderator density variation cases are based on a cask array model generated by surrounding a single cask body with a cylindrical reflecting enclosure. The reflecting body is spaced 20 cm from the cask body to allow exterior moderator density conditions to affect the results. Reactivities calculated for various moderator densities are graphically illustrated in Figure 6.7.6-1 and Figure 6.7.6-2 for the 87-assembly and 82-assembly basket configurations, respectively. Moderator density curves are based on the B9_79A assembly hybrid at an initial enrichment of 4.0 wt % ^{235}U and a flooded pellet-to-clad gap. Reactivity increases in the system as TSC interior moderator density rises. Exterior moderator conditions have no significant effect on system reactivity for a flooded TSC. The k_{eff} of the dry TSC is less than 0.5 under all exterior conditions.

Fabrication Tolerances and Component Shift

Fabrication tolerances and shift effects are evaluated using representative fuel types from the major core configurations. Nominal fuel assembly characteristics are employed in the tolerance and shifting evaluations.

Fabrication Tolerance

The basket is composed of a set of fuel tubes, pinned together in the tube corners, and located in the TSC cavity with side and corner weldments. Tube location in the basket is controlled by the diagonal dimension across the exterior face of the fuel tube corners. This value is a key dimension for tube array and developed cell size. The tube diagonal is referred to as tube "interface width" in the analysis discussions. Similar to the PWR model, neutron absorber and tube tolerances are evaluated. Neutron absorber thickness studies are based on the minimum ^{10}B areal density allowed for the design. As such, variations in absorber thickness require adjustments in the sheet composition. The results of the tolerance evaluation for centered fuel assemblies and basket components are included in Table 6.7.6-2. As indicated in the table, little statistically significant information (>3σ) is available from this study. None of the fabrication-related tolerances, with the exception of maximum tube wall thickness, produce significant reactivity increases when taken independently.

Further evaluations of the component tolerances, including combinations of tolerances, are performed in conjunction with the shifted component configuration.

Component Shift

In addition to the component tolerances, a reactivity study on component shifts is required. Based on the pinned tube arrangement, the only radial shift to be evaluated is the shift of the fuel assembly within the tubes. The tubes are restrained in the corner by pins, eliminating a tube movement study. The results of shift evaluations are shown in Table 6.7.6-2, indicating that shifting the fuel assembly towards the basket center clearly increases system reactivity.

Combined Shift and Tolerance Study

This section evaluates the effect of combining various basket tolerances with the maximum reactivity shift configuration (radial in). The results for this evaluation are shown in Table

6.7.6-3. Similar to the results of the independent basket tolerance evaluation, only fuel tube thickness affects system reactivity to a statistically significant level.

While no statistically significant reactivity difference is found between the cases with and without tolerances applied, the maximum reactivity configuration chosen for the evaluations of all fuel hybrids is as follows.

Minimum tube width and interface width
Maximum tube thickness
Minimum absorber width and maximum thickness
Fuel assemblies shifted to basket center

This configuration produced reactivities within a 3σ uncertainty band of the maximum reported value for all fuel types evaluated, and provides for the minimum separation between adjacent assemblies. The minimum separation reduces the amount of moderation and the corresponding effectiveness of the absorber sheet, which depend on the ^{10}B neutron capture cross-section in the thermal energy range.

Shift and tolerance evaluations were based on a full, 87-assembly, basket loading. While fabrication tolerance impacts relate to tube and developed cell unit behavior, a limited set of evaluations is performed to verify that the radial shifting in a fuel assembly pattern remains bounding for the 82-assembly basket configuration. The results of this evaluation are shown in Table 6.7.6-4 and demonstrate that the radial shifting in a fuel assembly pattern is limiting.

Neutron Absorber Modifications

Design options permit the replacement or removal of up to 24 neutron absorber sheets in the 87-assembly basket peripheral fuel tubes or up to 16 neutron absorber sheets in the 82-assembly basket. Locations for the optional absorber sheets are shown in Figure 6.7.6-3 and Figure 6.7.6-4, respectively. Replacement sheets for the neutron absorber in the peripheral basket locations are composed of unborated aluminum. Using the most reactive basket and fuel assembly shifting specified in Section 6.7.6.1, each BWR fuel type specified in Section 6.7.5 was analyzed at 4.0 wt % ^{235}U for the 87-assembly basket and 4.5 wt % ^{235}U for the 82-assembly basket. As shown in Table 6.7.6-5 and Table 6.7.6-6, no statistically significant reactivity changes are associated with the absorber sheet removal or replacement in the model. Results were calculated using unborated water in the pellet-to-clad gap. Results for the 87-assembly basket may exceed the USL at 4.0 wt% ^{235}U. For assemblies exceeding the USL, a lower enrichment or the use of the 82-assembly basket configuration is required.

Design enhancements introduced after completion of the primary criticality evaluations replaced the single column of weld posts down the tube face centerline with a two-column weld post configuration. The weld post columns are located 1.8 in from the tube centerline. As demonstrated in Table 6.7.6-7, the increased number of weld posts does not significantly change system reactivity. Results were calculated using unborated water in the pellet-to-clad gap.

As the combined reactivity effect of a reduced number of absorber sheets and an increased number of weld posts may exceed the statistically significant threshold (> 3σ) or potentially result in a k_{eff} + 2σ > USL if added as 'a Δk, the maximum allowed enrichments are calculated with a model containing the reduced number of absorber sheets and the increased number of weld posts.

6.7.6.2 Allowable Loading Definitions and Maximum System Reactivities

Based on the most reactive basket configuration, each of the fuel assembly types is evaluated at various enrichment levels to determine the maximum enrichment at which k_{eff} + 2σ remains below the USL. The results for these evaluations are listed in Table 6.7.6-8. The pellet-to-clad gap is flooded in these evaluations. Load limits are listed in Table 6.7.6-9.

Maximum system reactivities are summarized as follows. Analysis results represent maximum reactivity basket and fuel geometry. There are no design basis off-normal or accident transfer cask conditions affecting system reactivity. Therefore, only normal condition results are presented. An accident condition for the concrete cask represents a flooding of the concrete cask to canister annulus. Concrete cask results are based on the maximum fuel mass assembly at the highest allowed enrichment (4.5 wt % ^{235}U).

Condition	Pellet to Clad Gap Condition	Maximum Multiplication Factors (k_{eff} + 2σ)	
		Transfer Cask	Concrete Cask
Normal	Dry	0.92900	0.43685
Normal	Wet	0.93679	N/A
Accident / Off-Normal	Dry	N/A	0.42991

Note that there is no statistical difference between normal and accident condition cases, which differ only by the flooding of the pellet-to-clad gap under the "accident condition."

Figure 6.7.6-1 87-Assembly Basket BWR Water Density Variations

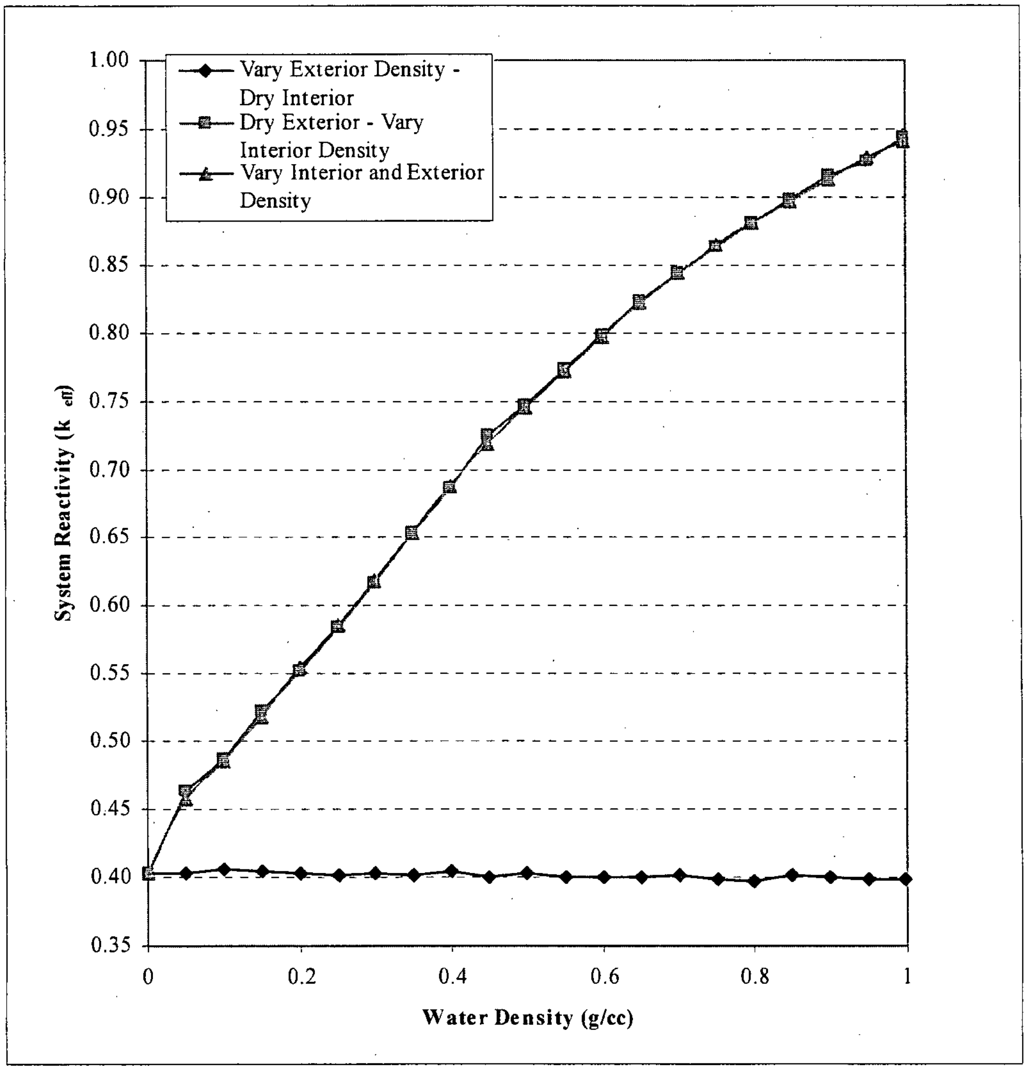


Figure 6.7.6-2 82-Assembly Basket BWR Water Density Variations

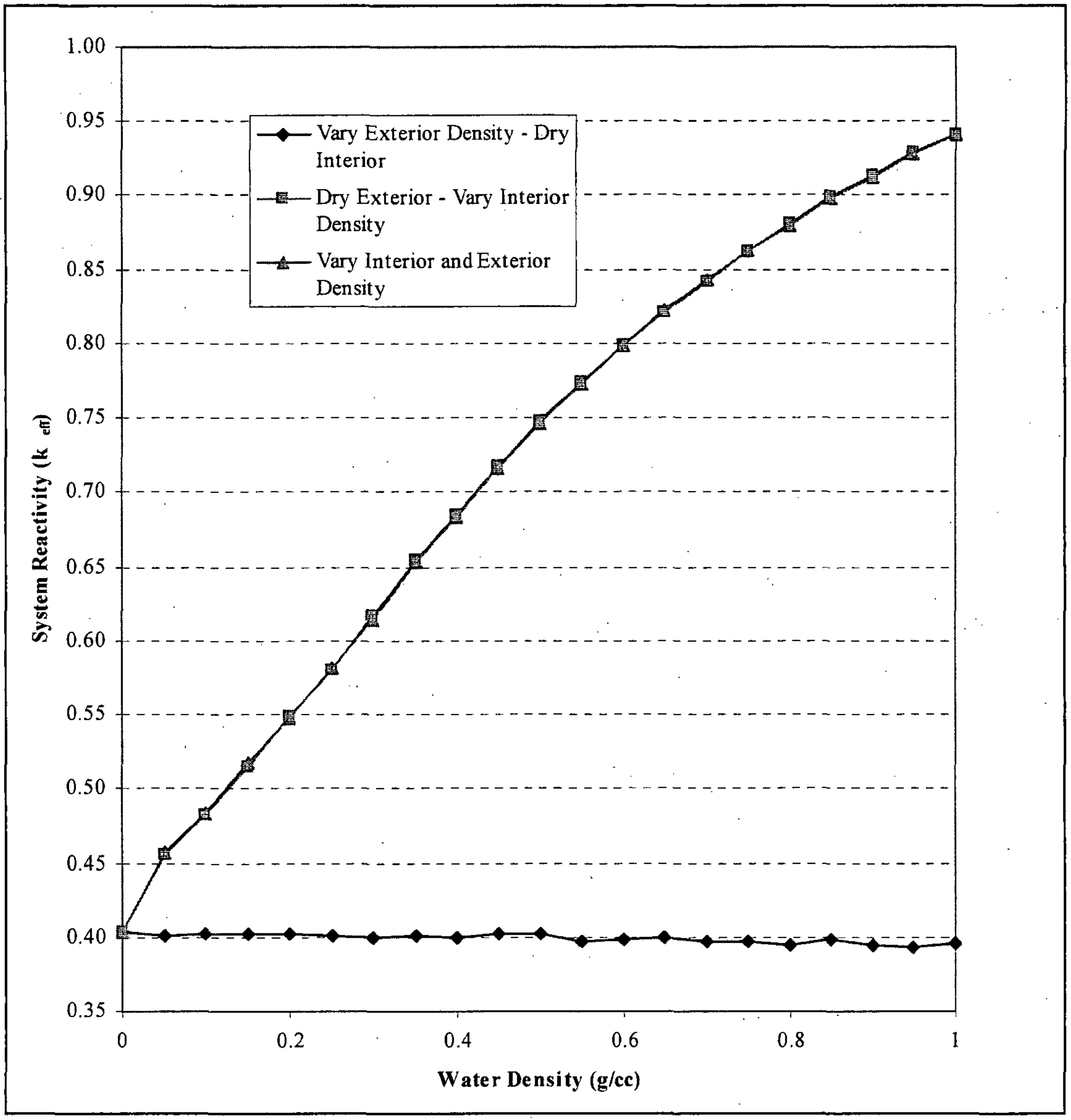
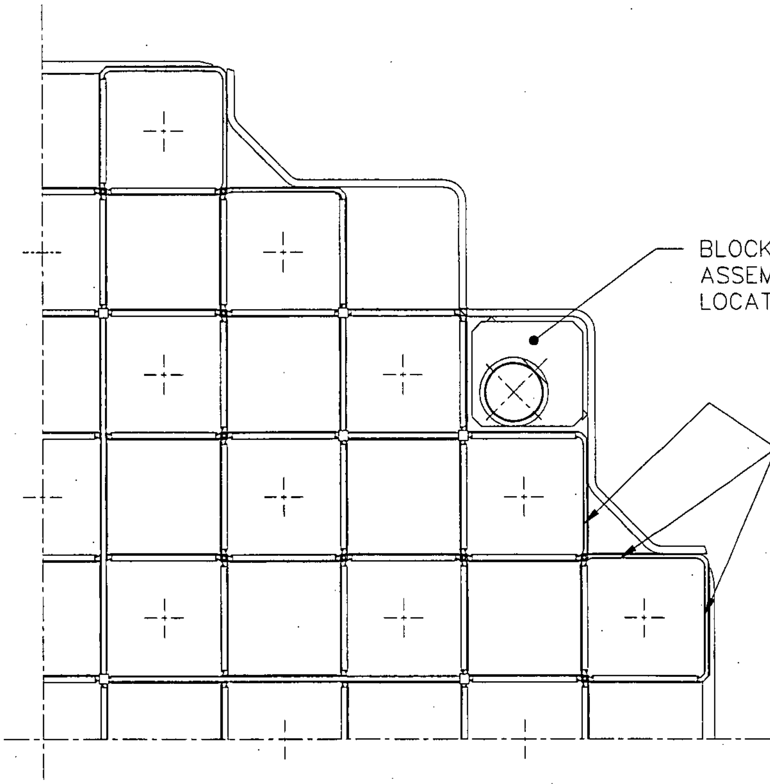
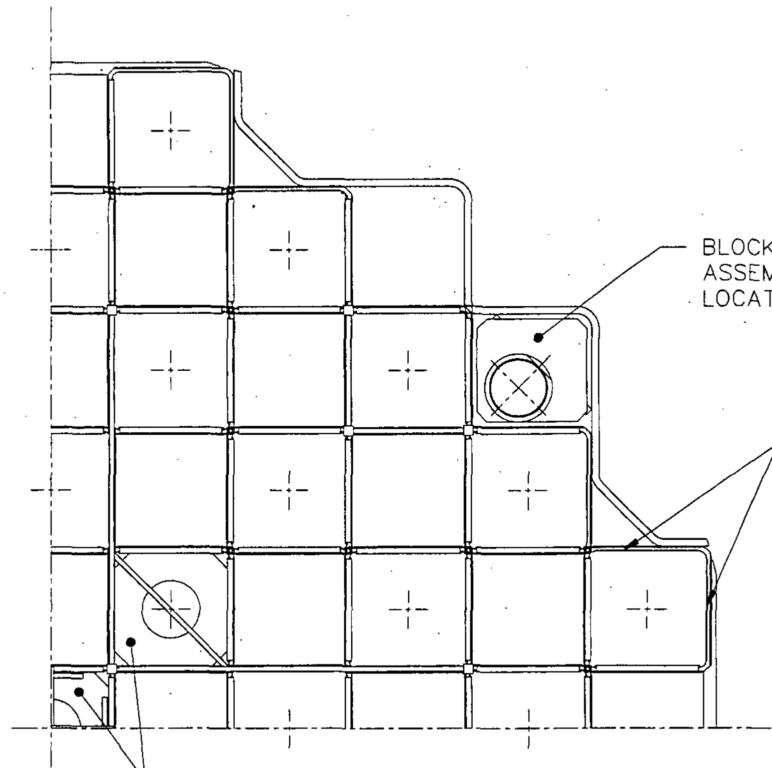


Figure 6.7.6-3 BWR 87-Assembly Basket Optional Neutron Absorber Sheet Locations[a]



[a] Quarter basket model is shown for clarity. Symmetric locations are affected in all four basket quadrants.

Figure 6.7.6-4 BWR 82-Assembly Basket Optional Neutron Absorber Sheet Locations[a]



[a] Quarter basket model is shown for clarity. Symmetric locations are affected in all four basket quadrants.

Table 6.7.6-1 BWR System Partial TSC Flood Evaluation

Assembly Type	Dry Gap Full Flood k_{eff}	Dry Gap Partial Flood k_{eff}	$\Delta k_{eff}/\sigma$
B7_48A	0.91765	0.91775	0.1
B7_49A	0.92470	0.92290	-1.7
B7_49B	0.92610	0.92573	-0.3
B8_59A	0.91930	0.92071	1.3
B8_60A	0.92497	0.92501	0.0
B8_60B	0.92589	0.92556	-0.3
B8_61B	0.92650	0.92508	-1.3
B8_62A	0.93055	0.93021	-0.3
B8_63A	0.92687	0.92707	0.2
B8_64A	0.92594	0.92381	-2.0
B8_64B	0.94157	0.94100	-0.5
B9_72A	0.93299	0.93281	-0.2
B9_74A	0.94392	0.94389	0.0
B9_76A	0.95063	0.94907	-1.5
B9_79A	0.94155	0.94044	-1.1
B9_80A	0.92757	0.92671	-0.8
B10_91A	0.92961	0.92853	-1.0
B10_92A	0.92366	0.92532	1.5
B10_96A	0.93807	0.93749	-0.6
B10_100A	0.93827	0.93829	0.0

Table 6.7.6-2 BWR 87-Assembly Basket Component Tolerance and Shift Study Results (Independent Variations)

Tube			Absorber		Shift	B7_49A		B8_62A		B9_76A		B9_79A		B10_92A	
Outer Width	Thick.	Interface Width	Width	Thick.	Rad Fuel	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$
Nom	Nom	Nom	Nom	Nom	Centered	0.92470	--	0.93055	--	0.95063	--	0.94155	--	0.92366	--
Nom	Nom	Nom	Min	Nom	Centered	0.92478	0.1	0.92946	-1.0	0.94894	-2.3	0.94026	-1.2	0.92559	1.8
Nom	Nom	Nom	Max	Nom	Centered	0.92400	-0.7	0.92923	-1.2	0.94751	-4.2	0.94124	-0.3	0.92542	1.7
Nom	Nom	Nom	Nom	Min	Centered	0.92329	-1.3	0.92996	-0.5	0.94914	-2.0	0.94168	0.1	0.92401	0.3
Nom	Nom	Nom	Nom	Max	Centered	0.92434	-0.3	0.92879	-1.6	0.94899	-2.2	0.94198	0.4	0.92519	1.4
Min	Nom	Nom	Nom	Nom	Centered	0.92485	0.1	0.93045	-0.1	0.94778	-3.8	0.94244	0.8	0.92430	0.6
Max	Nom	Nom	Nom	Nom	Centered	0.92329	-1.3	0.92768	-2.6	0.94892	-2.3	0.94192	0.3	0.92402	0.3
Nom	Min	Nom	Nom	Nom	Centered	0.92187	-2.8	0.92582	-4.2	0.94667	-5.2	0.93917	-2.2	0.92227	-1.3
Nom	Max	Nom	Nom	Nom	Centered	0.92660	1.8	0.93193	1.2	0.95095	0.4	0.94512	3.4	0.92850	4.5
Nom	Nom	Min	Nom	Nom	Centered	0.92481	0.1	0.92988	-0.6	0.94915	-2.0	0.94341	1.8	0.92487	1.1
Nom	Nom	Max	Nom	Nom	Centered	0.92248	-2.1	0.92926	-1.1	0.94718	-4.4	0.94155	--	0.92641	2.6
Nom	Nom	Nom	Nom	Nom	In	0.92890	3.9	0.93293	2.1	0.95324	3.5	0.94634	4.6	0.93168	7.5
Nom	Nom	Nom	Nom	Nom	Out	0.91191	-12.2	0.91606	-13.0	0.93809	-16.6	0.93148	-9.6	0.91466	-8.6

Table 6.7.6-3 BWR 87-Assembly Basket Component Tolerance and Shift Study Results (Combined Variations; Radial In Shift)

Tube			Absorber		Shift	B7_49A		B8_62A		B9_76A		B9_79A		B10_92A	
Outer Width	Thick.	Interface Width	Width	Thick.	Rad Fuel	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$
Nom	Nom	Nom	Nom	Nom	In	0.92890	--	0.93293	--	0.95324	--	0.94634	--	0.93168	--
Min	Nom	Nom	Nom	Nom	In	0.93004	1.0	0.93433	1.3	0.95538	2.8	0.94814	1.7	0.93194	0.2
Max	Nom	Nom	Nom	Nom	In	0.92936	0.4	0.93435	1.3	0.95432	1.4	0.94558	-0.7	0.92987	-1.7
Nom	Min	Nom	Nom	Nom	In	0.92927	0.3	0.93188	-1.0	0.95412	1.2	0.94467	-1.5	0.92868	-2.7
Nom	Max	Nom	Nom	Nom	In	0.93194	2.8	0.93775	4.4	0.95475	2.0	0.94882	2.3	0.93563	3.7
Nom	Nom	Min	Nom	Nom	In	0.92865	-0.2	0.93379	0.8	0.95386	0.8	0.94770	1.3	0.93227	0.6
Nom	Nom	Max	Nom	Nom	In	0.92957	0.6	0.93290	0.0	0.95358	0.5	0.94679	0.4	0.93059	-1.0
Nom	Nom	Nom	Min	Nom	In	0.92964	0.7	0.93441	1.3	0.95188	-1.8	0.94832	1.8	0.93072	-0.9
Nom	Nom	Nom	Max	Nom	In	0.92801	-0.8	0.93396	1.0	0.95660	4.5	0.94514	-1.1	0.93082	-0.8
Nom	Nom	Nom	Nom	Min	In	0.93042	1.4	0.93469	1.6	0.95418	1.3	0.94708	0.7	0.93190	0.2
Nom	Nom	Nom	Nom	Max	In	0.92931	0.4	0.93533	2.3	0.95344	0.3	0.94530	-1.0	0.93019	-1.4
Min	Min	Min	Min	Min	In	0.92717	-1.6	0.93238	-0.5	0.95125	-2.6	0.94416	-2.0	0.92825	-3.2
Min	Nom	Min	Min	Nom	In	0.93058	1.6	0.93526	2.1	0.95631	4.0	0.94802	1.6	0.93081	-0.8
Max	Nom	Min	Min	Nom	In	0.92953	0.6	0.93465	1.6	0.95320	-0.1	0.94916	2.7	0.93372	1.9
Nom	Nom	Min	Min	Nom	In	0.93044	1.4	0.93504	1.9	0.95433	1.5	0.94750	1.1	0.93135	-0.3
Nom	Max	Nom	Nom	Max	In	0.93320	3.8	0.93701	3.8	0.95615	3.9	0.94918	2.7	0.93378	2.0
Min	Max	Min	Min	Max	In	0.93284	3.6	0.93816	4.9	0.95791	6.2	0.95034	3.8	0.93442	2.6

Table 6.7.6-4 BWR 82-Assembly Basket Component Tolerance and Shift Study Results (Combined Variations; Radial In Shift)

Tube			Absorber		Shift	B7_49A		B8_62A		B9_76A		B9_79A		B10_92A	
Outer Width	Thick.	Interface Width	Width	Thick.	Rad Fuel	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$	k_{eff}	$\Delta k_{eff}/\sigma$
Min	Max	Min	Min	Max	In	0.88693	--	0.89367	--	0.91528	--	0.90858	--	0.88953	--
Min	Max	Min	Min	Max	Centered	0.88706	0.1	0.89379	0.1	0.91574	0.7	0.90671	-1.7	0.89070	1.1
Min	Max	Min	Min	Max	Out	0.88251	-4.0	0.88855	-4.8	0.91035	-6.8	0.90190	-6.1	0.88389	-5.4

Table 6.7.6-5 BWR 87-Assembly Basket Neutron Absorber Removal & Replacement Study Results

Assembly	Enrichment (wt % ^{235}U)	Nominal Absorber k_{eff}	Absorber Removal			Absorber Replacement		
			k_{eff}	Δk	Δk/σ	k_{eff}	Δk	Δk/σ
B7_48A	4.0	0.93146	0.93023	-0.00123	-1.7	0.93170	0.00024	0.3
B7_49A	4.0	0.94139	0.93975	-0.00164	-2.2	0.94033	-0.00106	-1.4
B7_49B	4.0	0.93978	0.93960	-0.00018	-0.2	0.93971	-0.00007	-0.1
B8_59A	4.0	0.93354	0.93489	0.00135	1.8	0.93408	0.00054	0.7
B8_60A	4.0	0.93932	0.93854	-0.00078	-1.1	0.93844	-0.00088	-1.2
B8_60B	4.0	0.93981	0.93974	-0.00007	-0.1	0.93870	-0.00111	-1.4
B8_61B	4.0	0.94021	0.94108	0.00087	1.2	0.94021	0.00000	0.0
B8_62A	4.0	0.94468	0.94274	-0.00194	-2.5	0.94248	-0.00220	-2.8
B8_63A	4.0	0.94427	0.94310	-0.00117	-1.5	0.94277	-0.00150	-2.0
B8_64A	4.0	0.94133	0.94113	-0.00020	-0.3	0.93912	-0.00221	-3.0
B8_64B	4.0	0.95409	0.95256	-0.00153	-2.1	0.95382	-0.00027	-0.4
B9_72A	4.0	0.94508	0.94404	-0.00104	-1.5	0.94493	-0.00015	-0.2
B9_74A	4.0	0.95198	0.95062	-0.00136	-1.8	0.94971	-0.00227	-2.9
B9_76A	4.0	0.95816	0.95864	0.00048	0.6	0.95749	-0.00067	-0.9
B9_79A	4.0	0.95125	0.95033	-0.00092	-1.2	0.94961	-0.00164	-2.1
B9_80A	4.0	0.93990	0.93934	-0.00056	-0.7	0.93960	-0.00030	-0.4
B10_91A	4.0	0.94279	0.94220	-0.00059	-0.8	0.94135	-0.00144	-2.0
B10_92A	4.0	0.93784	0.93967	0.00183	2.4	0.93990	0.00206	2.8
B10_96A	4.0	0.95060	0.95001	-0.00059	-0.8	0.95152	0.00092	1.2
B10_100A	4.0	0.95219	0.95225	0.00006	0.1	0.95175	-0.00044	-0.6

Table 6.7.6-6 BWR 82-Assembly Basket Neutron Absorber Removal & Replacement Study Results

Assembly	Enrichment (wt % ^{235}U)	Nominal Absorber k_{eff}	Absorber Removal			Absorber Replacement		
			k_{eff}	Δk	Δk/σ	k_{eff}	Δk	Δk/σ
B7_48A	4.5	0.91329	0.91427	0.00098	1.3	0.91435	0.00106	1.3
B7_49A	4.5	0.92148	0.92211	0.00063	0.8	0.92311	0.00163	2.1
B7_49B	4.5	0.92249	0.92244	-0.00005	-0.1	0.92115	-0.00134	-1.7
B8_59A	4.5	0.91678	0.91828	0.00150	2.0	0.91841	0.00163	2.2
B8_60A	4.5	0.92379	0.92406	0.00027	0.4	0.92460	0.00081	1.0
B8_60B	4.5	0.92363	0.92505	0.00142	2.0	0.92319	-0.00044	-0.6
B8_61B	4.5	0.92485	0.92597	0.00112	1.5	0.92466	-0.00019	-0.2
B8_62A	4.5	0.92685	0.92669	-0.00016	-0.2	0.92737	0.00052	0.6
B8_63A	4.5	0.92725	0.92723	-0.00002	0.0	0.92680	-0.00045	-0.5
B8_64A	4.5	0.92408	0.92392	-0.00016	-0.2	0.92524	0.00116	1.5
B8_64B	4.5	0.93936	0.93977	0.00041	0.5	0.93877	-0.00059	-0.8
B9_72A	4.5	0.93060	0.92841	-0.00219	-2.9	0.92850	-0.00210	-2.8
B9_74A	4.5	0.93649	0.93629	-0.00020	-0.3	0.93681	0.00032	0.4
B9_76A	4.5	0.94314	0.94277	-0.00037	-0.5	0.94299	-0.00015	-0.2
B9_79A	4.5	0.93237	0.93400	0.00163	2.1	0.93292	0.00055	0.7
B9_80A	4.5	0.92417	0.92364	-0.00053	-0.7	0.92458	0.00041	0.5
B10_91A	4.5	0.92684	0.92476	-0.00208	-2.7	0.92630	-0.00054	-0.7
B10_92A	4.5	0.92191	0.92287	0.00096	1.2	0.92232	0.00041	0.5
B10_96A	4.5	0.93438	0.93508	0.00070	0.9	0.93597	0.00159	2.0
B10_100A	4.5	0.93701	0.93720	0.00019	0.3	0.93767	0.00066	0.9

Table 6.7.6-7 BWR 87-Assembly Basket Neutron Absorber Attachment Modification Study Results

		Base Evaluation		Modified Attachment			
Assembly	Enrichment (wt % ^{235}U)	Weld Posts	k_{eff}	Weld Posts	k_{eff}	Δk	Δk/σ
B7_48A	4.1	4	0.93806	28	0.93891	0.00085	1.1
B7_49A	3.9	4	0.93303	28	0.93474	0.00171	2.3
B7_49B	3.9	4	0.93311	28	0.93471	0.00160	2.1
B8_59A	4.0	4	0.93354	28	0.93469	0.00115	1.6
B8_60A	3.9	4	0.93370	28	0.93473	0.00103	1.4
B8_60B	3.9	4	0.93355	28	0.93450	0.00095	1.3
B8_61B	3.9	4	0.93582	28	0.93547	-0.00035	-0.5
B8_62A	3.9	4	0.93668	28	0.93831	0.00163	2.1
B8_63A	3.8	4	0.93264	28	0.93369	0.00105	1.5
B8_64A	3.9	4	0.93416	28	0.93579	0.00163	2.2
B8_64B	3.7	4	0.93588	28	0.93778	0.00190	2.6
B9_72A	3.8	4	0.93198	28	0.93369	0.00171	2.3
B9_74A	3.7	4	0.93331	28	0.93392	0.00061	0.8
B9_76A	3.6	4	0.93391	28	0.93491	0.00100	1.3
B9_79A	3.7	4	0.93261	28	0.93227	-0.00034	-0.5
B9_80A	3.9	4	0.93383	28	0.93479	0.00096	1.3
B10_91A	3.8	4	0.93081	28	0.93256	0.00175	2.3
B10_92A	3.8	4	0.92729	28	0.92907	0.00178	2.4
B10_96A	3.7	4	0.93175	28	0.93355	0.00180	2.4
B10_100A	3.7	4	0.93318	28	0.93395	0.00077	1.0

Table 6.7.6-8 BWR System Maximum Reactivity Summary

		87-Assembly Basket		82-Assembly Basket	
Assembly Type	Number of Fuel Rods	Max Initial Enrich. (wt % ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt % ^{235}U)	Reactivity $k_{eff} + 2\sigma$
B7_48A	48	4.00%	0.93601	4.50%	0.91816
B7_49A	49	3.80%	0.93206	4.50%	0.92623
B7_49B	49	3.80%	0.93335	4.50%	0.92750
B8_59A	59	3.90%	0.93132	4.50%	0.92395
B8_60A	60	3.80%	0.93167	4.50%	0.92748
B8_60B	60	3.80%	0.93143	4.50%	0.93014
B8_61B	61	3.80%	0.93322	4.50%	0.92787
B8_62A	62	3.80%	0.93469	4.50%	0.93102
B8_63A	63	3.80%	0.93679	4.50%	0.93126
B8_64A	64	3.80%	0.93298	4.50%	0.92949
B8_64B	64	3.60%	0.93222	4.30%	0.93539
B9_72A	72	3.80%	0.93632	4.50%	0.93408
B9_74A	74	3.70%	0.93578	4.40%	0.93440
B9_76A	76	3.50%	0.92937	4.20%	0.93158
B9_79A	79	3.70%	0.93665	4.40%	0.93406
B9_80A	80	3.80%	0.93143	4.50%	0.92882
B10_91A	91	3.80%	0.93566	4.50%	0.93093
B10_92A	92	3.90%	0.93620	4.50%	0.92773
B10_96A	96	3.70%	0.93534	4.40%	0.93498
B10_100A	100	3.60%	0.93295	4.40%	0.93505
B9_74A[a]	74	3.70%	0.93575	4.30%	0.93223
B10_91A[a]	91	3.70%	0.92844	4.50%	0.93477
B10_92A[a]	92	3.80%	0.93488	4.50%	0.93570
B10_96A[a]	96	3.70%	0.93368	4.30%	0.93310

[a] Assemblies contain partial length fuel rods. Partial length rod assemblies are evaluated by removing partial length rods from the lattice. This configuration bounds an assembly with full length rods and combinations of full and partial length rods.

Table 6.7.6-9 BWR System Generic Load Limits

Assembly Type	Number of Fuel Rods	Number of Partial Length Rods	Max Pitch (inch)	Min Clad OD (inch)	Min Clad Thick. (inch)	Max Pellet OD (inch)	Max Active Length (inch)	Max Loading (MTU)	87-Assy. Max Enrichment (wt % ^{235}U)	82-Assy Max Enrichment (wt % ^{235}U)
B7_48A	48	N/A	0.7380	0.5700	0.03600	0.4900	144.0	0.1981	4.00%	4.50%
B7_49A	49	N/A	0.7380	0.5630	0.03200	0.4880	146.0	0.2034	3.80%	4.50%
B7_49B	49	N/A	0.7380	0.5630	0.03200	0.4910	150.0	0.2115	3.80%	4.50%
B8_59A	59	N/A	0.6400	0.4930	0.03400	0.4160	150.0	0.1828	3.90%	4.50%
B8_60A	60	N/A	0.6417	0.4840	0.03150	0.4110	150.0	0.1815	3.80%	4.50%
B8_60B	60	N/A	0.6400	0.4830	0.03000	0.4140	150.0	0.1841	3.80%	4.50%
B8_61B	61	N/A	0.6400	0.4830	0.03000	0.4140	150.0	0.1872	3.80%	4.50%
B8_62A	62	N/A	0.6417	0.4830	0.02900	0.4160	150.0	0.1921	3.80%	4.50%
B8_63A	63	N/A	0.6420	0.4840	0.02725	0.4195	150.0	0.1985	3.80%	4.50%
B8_64A	64	N/A	0.6420	0.4840	0.02725	0.4195	150.0	0.2017	3.80%	4.50%
B8_64B	64	N/A	0.6090	0.4576	0.02900	0.3913	150.0	0.1755	3.60%	4.30%
B9_72A	72	N/A	0.5720	0.4330	0.02600	0.3740	150.0	0.1803	3.80%	4.50%
B9_74A	74[a]	8	0.5720	0.4240	0.02390	0.3760	150.0	0.1873	3.70%	4.30%
B9_76A	76	N/A	0.5720	0.4170	0.02090	0.3750	150.0	0.1914	3.50%	4.20%
B9_79A	79	N/A	0.5720	0.4240	0.02390	0.3760	150.0	0.2000	3.70%	4.40%
B9_80A	80	N/A	0.5720	0.4230	0.02950	0.3565	150.0	0.1821	3.80%	4.50%
B10_91A	91[a]	8	0.5100	0.3957	0.02385	0.3420	150.0	0.1906	3.70%	4.50%
B10_92A	92[a]	14	0.5100	0.4040	0.02600	0.3455	150.0	0.1966	3.80%	4.50%
B10_96A	96[a]	12	0.4880	0.3780	0.02430	0.3224	150.0	0.1787	3.70%	4.30%
B10_100A	100	N/A	0.4880	0.3780	0.02430	0.3224	150.0	0.1861	3.60%	4.40%

Note: Assembly characteristics represent cold, unirradiated, nominal configurations.

[a] Assemblies contain partial length fuel rods. Partial length rod assemblies are evaluated by removing partial length rods from the lattice. This configuration bounds an assembly with full length rods and combinations of full and partial length rods.

6.7.7 Critical Benchmarks

From the International Handbook of Evaluated Criticality Safety Benchmark Experiments [8], 186 experiments are selected as basis of the MCNP benchmarking. Experiments were selected for compatibility of materials and geometry with the spent fuel casks. Of particular interest are benchmarks with rectangular arrays of low enriched uranium oxide fuel rods in which reactivity is controlled by soluble boron or borated plates (tubes).

MCNP benchmark cases represent a collection of files composed of inputs directly obtained from references (with cross-section sets adjusted to those used in the cask analysis), NAC modified input files representing unique geometries based on reference input files, and input files constructed from the experimental material and geometry information. All cases were reviewed on a "preparer/checker" principle for modeling consistency with the cask models and the choice of code options. Due to large variations in the benchmark complexities, not all options employed in the cask models are reflected in each of the benchmarks (e.g., UNIVERSE structure). A review of the criticality results did not indicate any result trend due to particular modeling choices (e.g., using the UNIVERSE structure versus a single universe, or employing KSRC versus SDEF sampling).

Key system parameters, the experimental uncertainty, and calculated k_{eff} and σ for each experiment are shown in Table 6.7.7-1. Stochastic Monte Carlo error is kept within ±0.2% and each output is checked to assure that the MCNP build-in statistical checks on the results are passed and that all fissile material is sampled.

Scatter plots of k_{eff} versus system parameters for 183 data point sets (full set minus three high lethargy points above 0.35 eV) are created (see Figure 6.7.7-1 through Figure 6.7.7-9). Included in these scatter plots are linear regression lines with a corresponding correlation coefficient (R^2) to statistically indicate any trend or lack thereof. Scatter plates are created for k_{eff} versus the following.

Enrichment in ^{235}U (wt % ^{235}U)
Fuel rod pitch (cm)
Fuel pellet outer diameter (cm)
Fuel rod outer diameter (cm)
Hydrogen/uranium (^{235}U) atom ratio
Soluble boron (ppm by weight)
Cluster gap spacing (spacing between assemblies in cm)
Boron (^{10}B) plate loading (g/cm^2)
Energy of average neutron lethargy causing fission (eV)

Figure 6.7.7-1 k_{eff} versus Fuel Enrichment

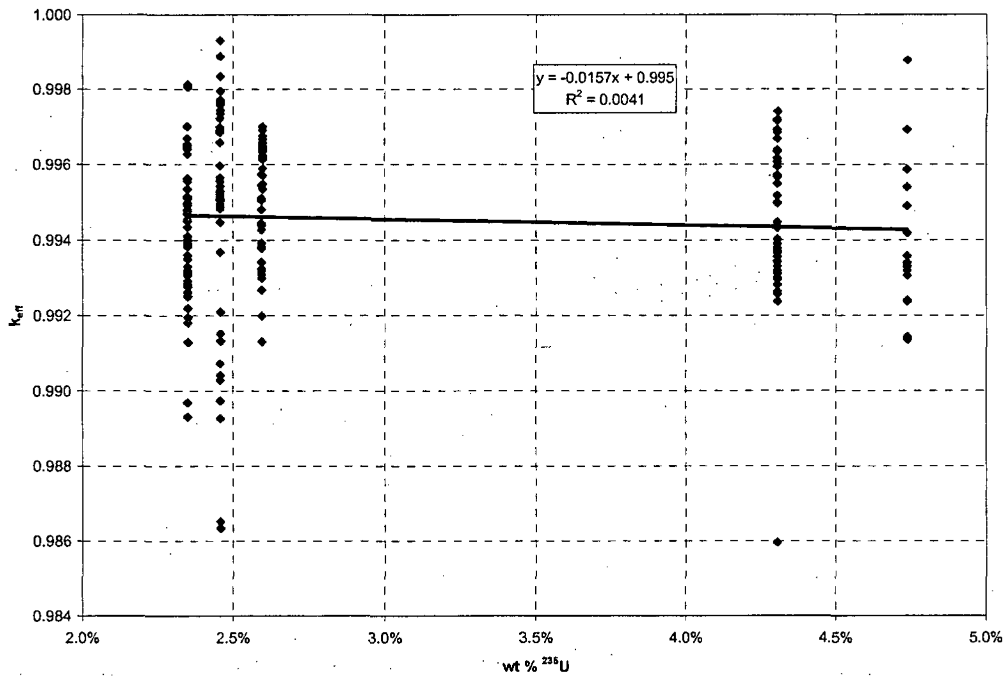


Figure 6.7.7-2 k_{eff} versus Rod Pitch

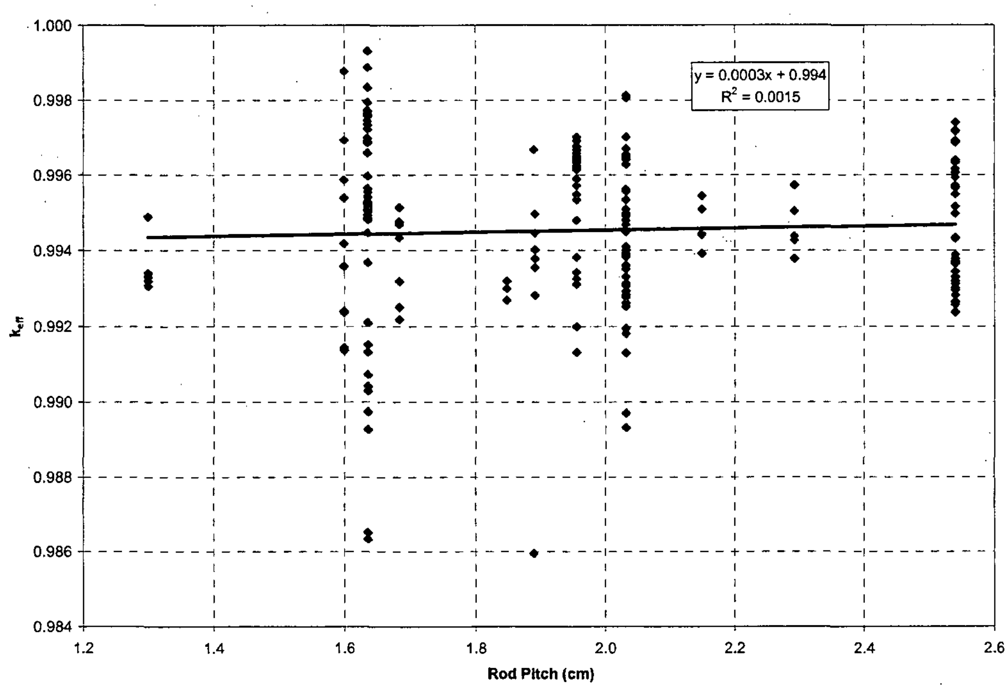


Figure 6.7.7-3 k_{eff} versus Fuel Pellet Diameter

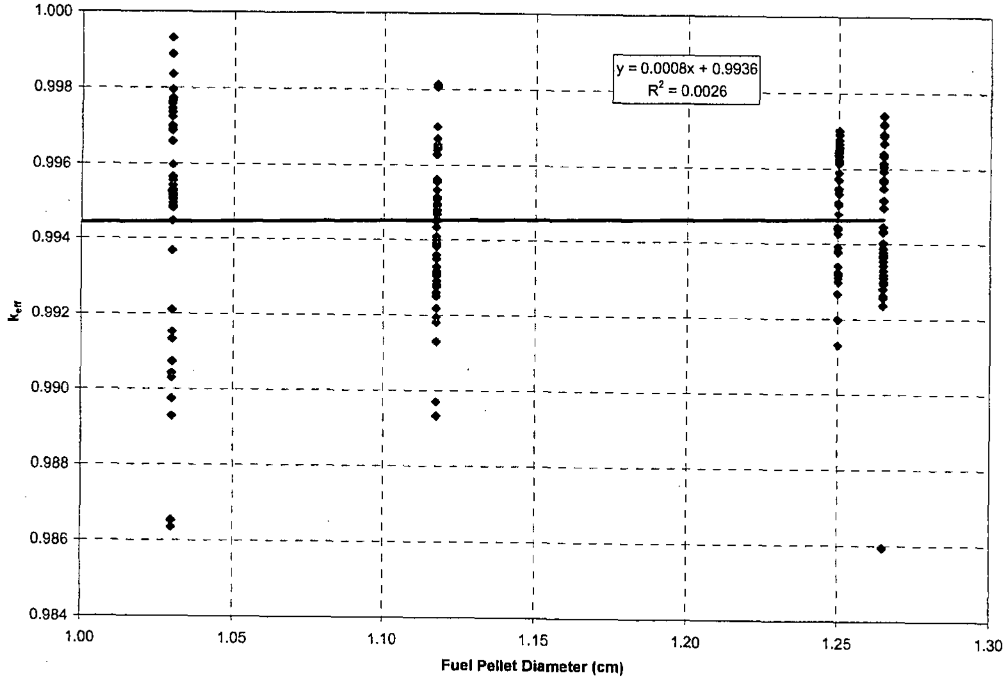


Figure 6.7.7-4 k_{eff} versus Fuel Rod Outside Diameter

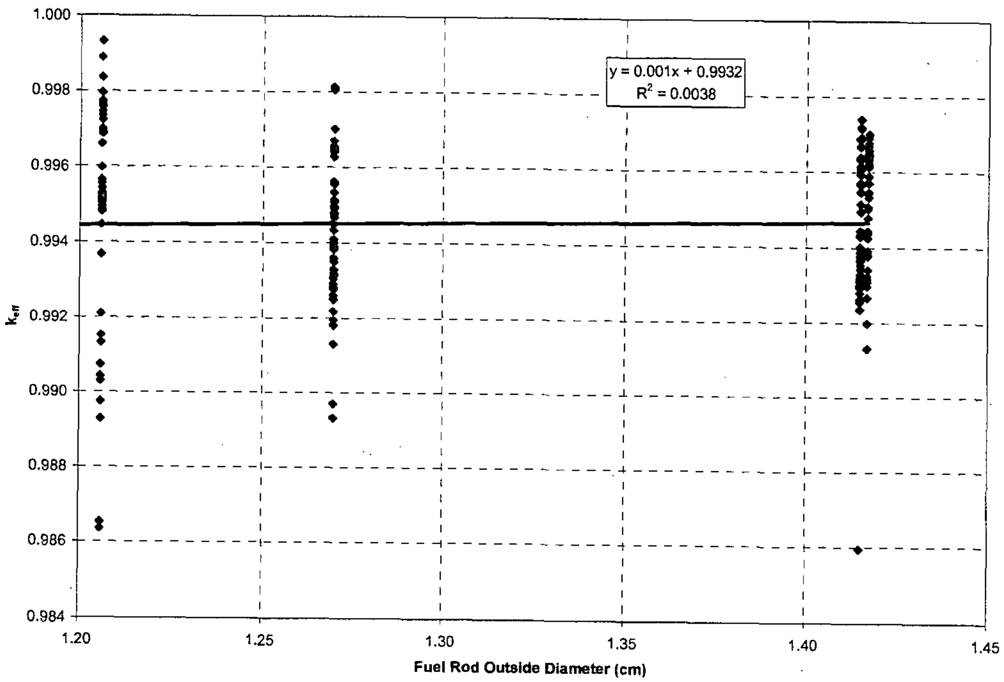


Figure 6.7.7-5 k_{eff} versus Hydrogen/^{235}U Atom Ratio

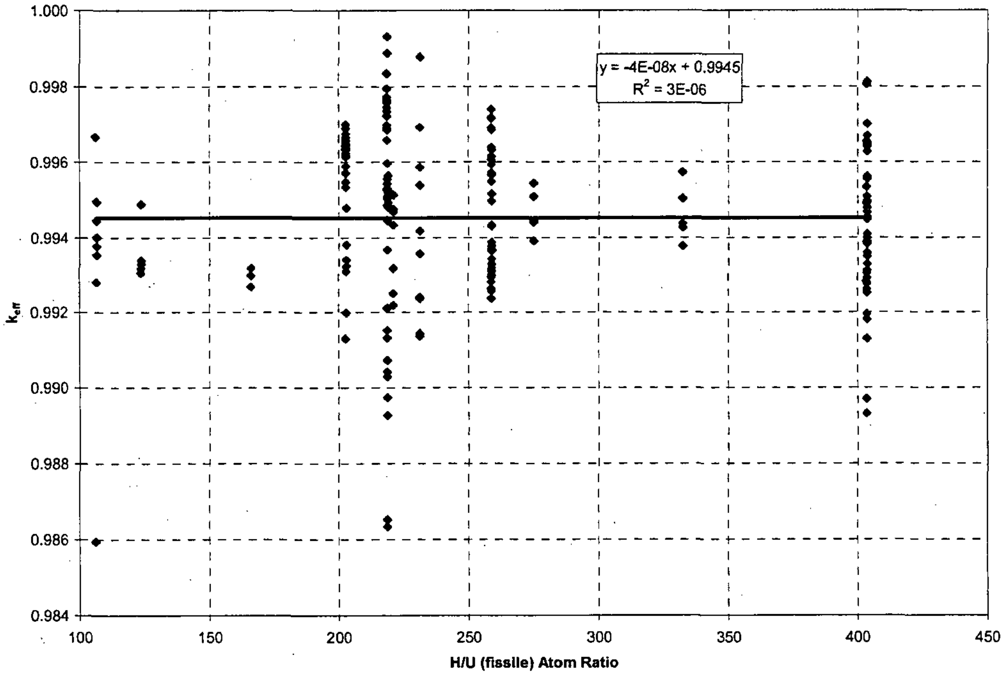


Figure 6.7.7-6 k_{eff} versus Soluble Boron Concentration

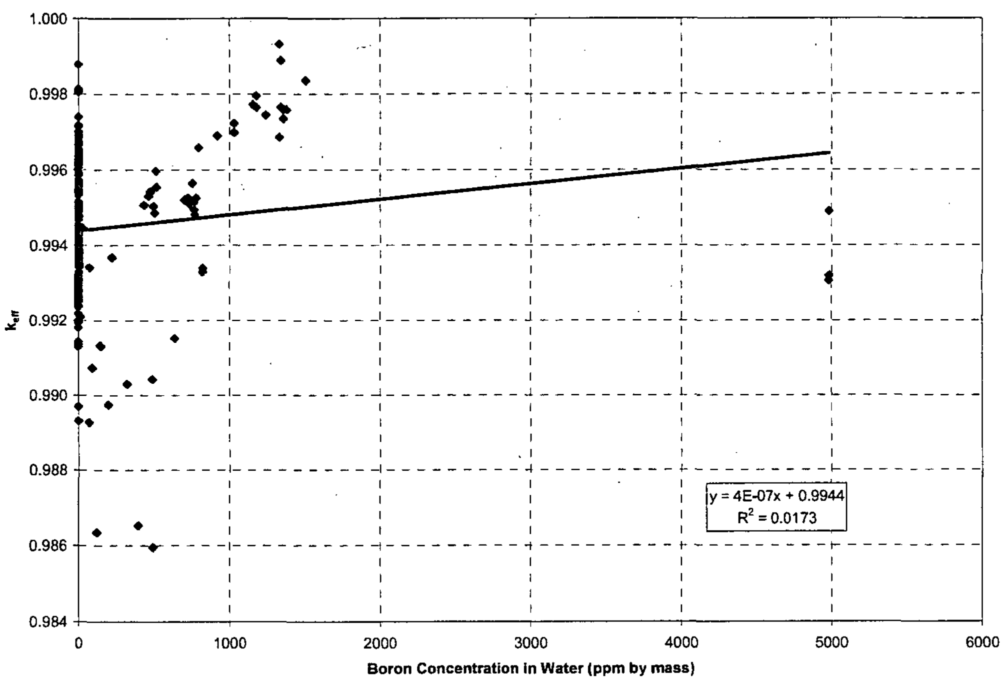


Figure 6.7.7-7 k_{eff} versus Cluster Gap Thickness

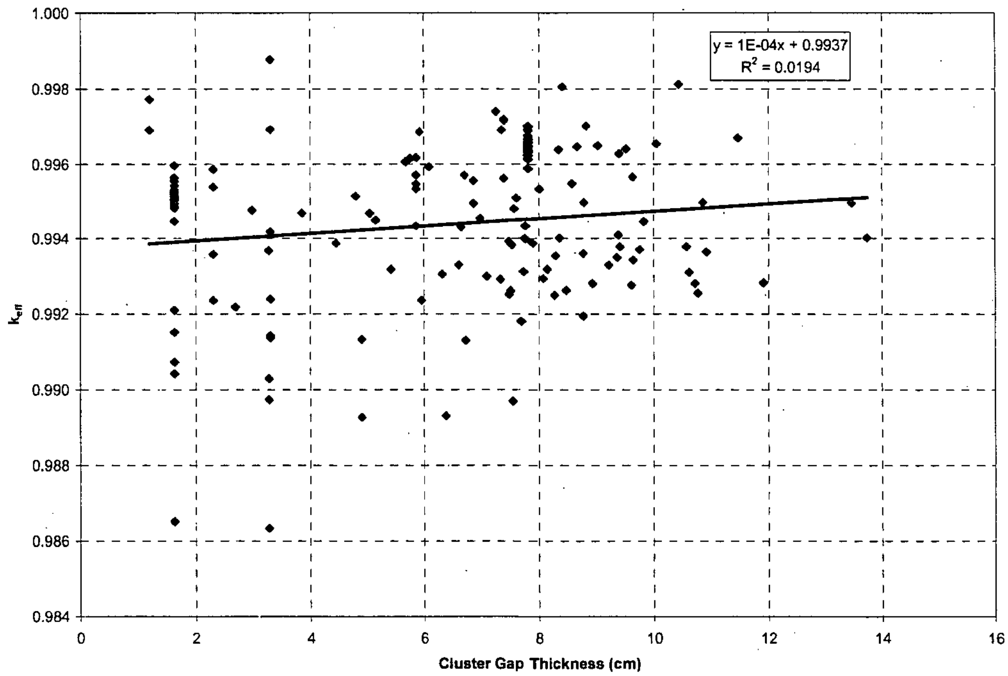


Figure 6.7.7-8 k_{eff} versus ^{10}B Plate Loading

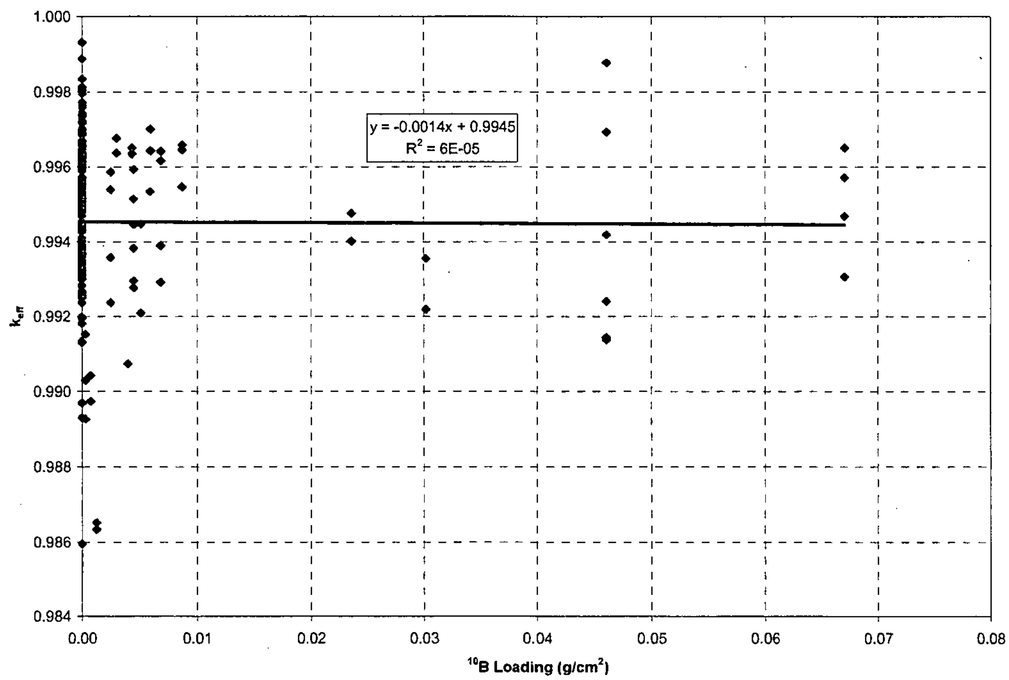


Figure 6.7.7-9 k_{eff} versus Energy of Average Neutron Lethargy Causing Fission

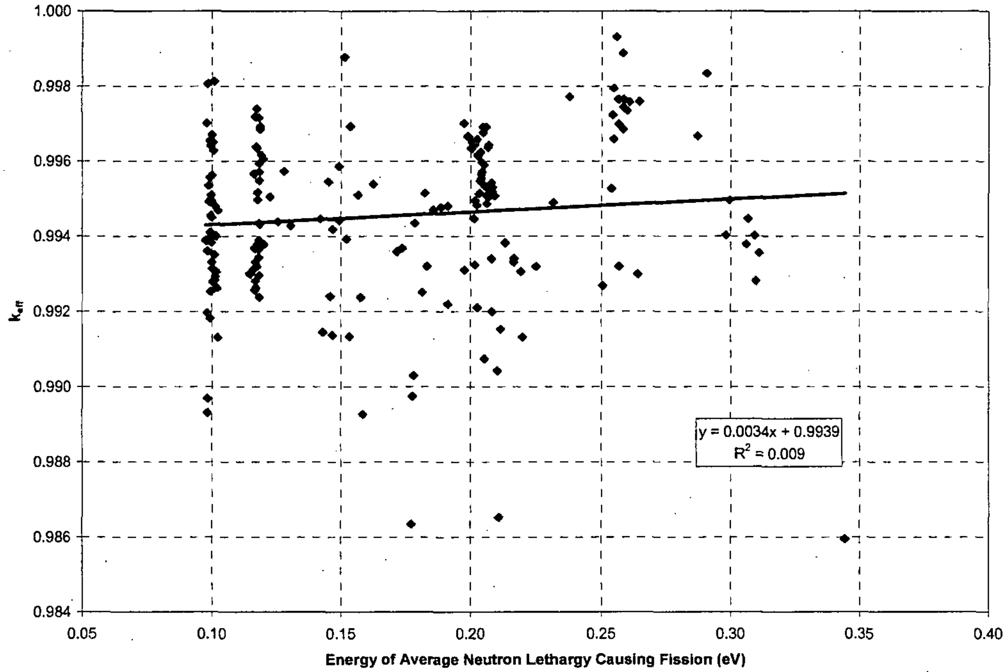


Table 6.7.7-1 MCNP Validation Statistics

Case	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08
Clusters	1	3	3	3	3	3	3	3
Enrichment (wt %^{235}U)	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%
Pitch (cm)	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032
Fuel OD (cm)	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118
Clad OD (cm)	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270
Clad Mat'l	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	404	404	404	404	404	404	404	404
Soluble B (ppm)	-	-	-	-	-	-	-	-
Absorber Type	-	-	-	-	-	-	-	-
Cluster Gap (cm)	-	11.9	8.4	10.1	6.4	8.0	4.5	7.6
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-	-	-	-
EALCF (MeV)	9.916E-8	1.010E-7	9.838E-8	9.933E-8	9.837E-8	9.874E-8	9.781E-8	9.826E-8
Exp. σ	0.0030	0.0030	0.0030	0.0030	0.0030	0.0030	0.0031	0.0030
k_{eff}	0.99491	0.99283	0.99806	0.99655	0.98931	0.99534	0.99388	0.98969
σ	0.00165	0.00155	0.00155	0.00165	0.00169	0.00162	0.00150	0.00152

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	2.01	2.02	2.03	2.04	2.05
Clusters	1	1	1	3	3
Enrichment (wt %^{235}U)	4.31%	4.31%	4.31%	4.31%	4.31%
Pitch (cm)	2.540	2.540	2.540	2.540	2.540
Fuel OD (cm)	1.265	1.265	1.265	1.265	1.265
Clad OD (cm)	1.415	1.415	1.415	1.415	1.415
Clad Material	Al	Al	Al	Al	Al
H/U (fissile)	259	259	259	259	259
Soluble B (ppm)	-	-	-	-	-
Absorber Type	-	-	-	-	-
Cluster Gap (cm)	-	-	-	10.6	7.1
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-
EALCF (MeV)	1.177E-7	1.164E-7	1.175E-7	1.161E-7	1.146E-7
Exp. σ	0.0020	0.0020	0.0020	0.0018	0.0019
k_{eff}	0.99516	0.99367	0.99634	0.99311	0.99300
σ	0.00195	0.00157	0.00190	0.00193	0.00161

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	6.01	6.02	6.03	6.04	6.05	6.06	6.07	6.08	6.09
Clusters	1	1	1	1	1	1	1	1	1
Enrichment (wt %^{235}U)	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%
Pitch (cm)	1.849	1.849	1.849	1.956	1.956	1.956	1.956	1.956	2.150
Fuel OD (cm)	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250
Clad OD (cm)	1.417	1.417	1.417	1.417	1.417	1.417	1.417	1.417	1.417
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	166	166	166	203	203	203	203	203	275
Soluble B (ppm)	-	-	-	-	-	-	-	-	-
Absorber Type	-	-	-	-	-	-	-	-	-
Cluster Gap (cm)	-	-	-	-	-	-	-	-	-
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-	-	-	-	-
EALCF (MeV)	2.506E-7	2.568E-7	2.642E-7	1.915E-7	1.978E-7	2.018E-7	2.085E-7	2.136E-7	1.422E-7
Exp. σ	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
k_{eff}	0.99268	0.99319	0.99299	0.99479	0.99310	0.99324	0.99199	0.99382	0.99445
σ	0.00065	0.00076	0.00074	0.00074	0.00069	0.00070	0.00071	0.00071	0.00069

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	6.10	6.11	6.12	6.13	6.14	6.15	6.16	6.17	6.18
Clusters	1	1	1	1	1	1	1	1	1
Enrichment (wt %^{235}U)	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%
Pitch (cm)	2.150	2.150	2.150	2.150	2.293	2.293	2.293	2.293	2.293
Fuel OD (cm)	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250
Clad OD (cm)	1.417	1.417	1.417	1.417	1.417	1.417	1.417	1.417	1.417
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	275	275	275	275	332	332	332	332	332
Soluble B (ppm)	-	-	-	-	-	-	-	-	-
Absorber Type	-	-	-	-	-	-	-	-	-
Cluster Gap (cm)	-	-	-	-	-	-	-	-	-
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-	-	-	-	-
EALCF (MeV)	1.453E-7	1.496E-7	1.523E-7	1.568E-7	1.202E-7	1.227E-7	1.257E-7	1.280E-7	1.306E-7
Exp. σ	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
k_{eff}	0.99544	0.99441	0.99392	0.99509	0.99378	0.99504	0.99438	0.99573	0.99427
σ	0.00073	0.00071	0.00078	0.00076	0.00070	0.00075	0.00067	0.00070	0.00076

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	8.01	8.02	8.03	8.04	8.05	8.06	8.07	8.08
Clusters	3 x 3	3 x 3	3 x 3	3 x 3	3 x 3	3 x 3	3 x 3	3 x 3
Enrichment (wt %^{235}U)	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%
Pitch (cm)	1.636	1.636	1.636	1.636	1.636	1.636	1.636	1.636
Fuel OD (cm)	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030
Clad OD (cm)	1.206	1.206	1.206	1.206	1.206	1.206	1.206	1.206
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	219	219	219	219	219	219	219	219
Soluble B (ppm)	1511	1336	1336	1182	1182	1033	1033	794
Absorber Type	-	-	-	-	-	-	-	-
Cluster Gap (cm)	-	-	-	-	-	-	-	-
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-	-	-	-
EALCF (MeV)	2.907E-7	2.583E-7	2.559E-7	2.548E-7	2.566E-7	2.568E-7	2.544E-7	2.548E-7
Exp. σ	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012
k_{eff}	0.99835	0.99686	0.99931	0.99795	0.99765	0.99699	0.99723	0.99659
σ	0.00060	0.00063	0.00032	0.00063	0.00069	0.00061	0.00066	0.00073

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	8.09	8.10	8.11	8.12	8.13	8.14	8.15	8.16	8.17
Clusters	3 x 3	3 x 3	3 x 3	3 x 3	3 x 3	3 x 3	3 x 3	5	5 x 5
Enrichment (wt %^{235}U)	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%
Pitch (cm)	1.636	1.636	1.636	1.636	1.636	1.636	1.636	1.636	1.636
Fuel OD (cm)	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030
Clad OD (cm)	1.206	1.206	1.206	1.206	1.206	1.206	1.206	1.206	1.206
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	219	219	219	219	219	219	219	219	219
Soluble B (ppm)	779	1245	1384	1348	1348	1363	1363	1158	921
Absorber Type	-	-	-	-	-	-	-	-	-
Cluster Gap (cm)	-	-	-	-	-	-	-	1.2	1.2
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-	-	-	-	-
EALCF (MeV)	2.538E-7	2.586E-7	2.647E-7	2.587E-7	2.582E-7	2.600E-7	2.609E-7	2.379E-7	2.063E-7
Exp. σ	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012
k_{eff}	0.99526	0.99745	0.99759	0.99765	0.99888	0.99735	0.99758	0.99772	0.99691
σ	0.00072	0.00065	0.00068	0.00065	0.00070	0.00067	0.00071	0.00070	0.00062

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	9.01	9.02	9.03	9.04	9.05	9.06	9.07	9.08	9.09	9.10	9.11	9.12	9.13
Clusters	3	3	3	3	3	3	3	3	3	3	3	3	3
Enrichment (wt $\%^{235}U$)	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%
Pitch (cm)	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540
Fuel OD (cm)	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265
Clad OD (cm)	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	259	259	259	259	259	259	259	259	259	259	259	259	259
Soluble B (ppm)	-	-	-	-	-	-	-	-	-	-	-	-	-
Absorber Type	304L SS (no B)	304L SS (no B)	304L SS (no B)	304L SS (no B)	304L SS (1.05% B)	304L SS (1.05% B)	304L SS (1.62% B)	304L SS (1.62% B)	Boral	Cu	Cu	Cu	Cu
Cluster Gap (cm)	8.6	9.7	9.2	9.8	6.1	8.1	5.8	7.9	6.7	8.2	9.4	8.5	9.6
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading ($g^{10}B/cm^2$)	0.00000	0.00000	0.00000	0.00000	0.00455	0.00455	0.00690	0.00690	0.06704	-	-	-	-
EALCF(MeV)	1.183E-7	1.181E-7	1.168E-7	1.179E-7	1.182E-7	1.182E-7	1.191E-7	1.182E-7	1.183E-7	1.173E-7	1.176E-7	1.169E-7	1.163E-7
Exp. σ	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021
k_{eff}	0.99548	0.99343	0.99330	0.99371	0.99593	0.99295	0.99616	0.99389	0.99571	0.99319	0.99378	0.99263	0.99566
σ	0.00191	0.00182	0.00187	0.00192	0.00174	0.00193	0.00198	0.00175	0.00209	0.00153	0.00178	0.00191	0.00177

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	9.14	9.15	9.16	9.17	9.18	9.19	9.20	9.21	9.22	9.23	9.24	9.25	9.26	9.27
Clusters	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Enrichment (wt %^{235}U)	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%
Pitch (cm)	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540	2.540
Fuel OD (cm)	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265	1.265
Clad OD (cm)	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415	1.415
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	259	259	259	259	259	259	259	259	259	259	259	259	259	259
Soluble B (ppm)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Absorber Type	Cu (0.989 wt % Cd)	Cu (0.989 wt % Cd)	Cd	Cd	Cd	Cd	Cd	Cd	Cd	Cd	Al (no B)	Al (no B)	Zircaloy-4	Zircaloy-4
Cluster Gap (cm)	6.7	8.4	5.9	7.4	6.0	7.4	5.9	7.4	5.7	7.3	10.7	10.8	10.9	10.9
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-	-	-	-	-	-	0.00000	0.00000	-	-
EALCF(MeV)	1.186E-7	1.171E-7	1.186E-7	1.183E-7	1.183E-7	1.168E-7	1.182E-7	1.187E-7	1.199E-7	1.173E-7	1.167E-7	1.165E-7	1.181E-7	1.177E-7
Exp. σ	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021
k_{eff}	0.99431	0.99639	0.99686	0.99716	0.99237	0.99719	0.99434	0.99692	0.99606	0.99740	0.99281	0.99256	0.99365	0.99497
σ	0.00188	0.00207	0.00183	0.00166	0.00194	0.00187	0.00179	0.00183	0.00189	0.00206	0.00168	0.00197	0.00197	0.00193

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	11.03	11.04	11.05	11.06	11.07	11.08	11.09
Clusters	3	3	3	3	3	3	3
Enrichment (wt %^{235}U)	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%
Pitch (cm)	1.636	1.636	1.636	1.636	1.636	1.636	1.636
Fuel OD (cm)	1.030	1.030	1.030	1.030	1.030	1.030	1.030
Clad OD (cm)	1.206	1.206	1.206	1.206	1.206	1.206	1.206
Clad Material	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	219	219	219	219	219	219	219
Soluble B (ppm)	769	764	762	753	739	721	702
Absorber Type	-	-	-	-	-	-	-
Cluster Gap (cm)	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-	-	-
EALCF [MeV]	2.027E-7	2.020E-7	2.035E-7	2.044E-7	2.065E-7	2.068E-7	2.085E-7
Exp. σ	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032	0.0032
k_{eff}	0.99482	0.99494	0.99514	0.99564	0.99508	0.99526	0.99520
σ	0.00031	0.00030	0.00030	0.00030	0.00031	0.00030	0.00031

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	13.01	13.02	13.03	13.04	13.05	13.06	13.07
Clusters	3	3	3	3	3	3	3
Enrichment (wt %^{235}U)	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%	4.31%
Pitch (cm)	1.892	1.892	1.892	1.892	1.892	1.892	1.892
Fuel OD (cm)	1.265	1.265	1.265	1.265	1.265	1.265	1.265
Clad OD (cm)	1.415	1.415	1.415	1.415	1.415	1.415	1.415
Clad Material	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	107	107	107	107	107	107	107
Soluble B (ppm)	-	-	-	-	-	-	-
Absorber Type	304L SS (no B)	304L SS (1.05% B)	Boral B	Boroflex	Cd	Cu	Cu (0.989 wt % Cd)
Cluster Gap (cm)	13.8	9.8	8.3	8.4	8.9	13.5	10.6
Reflector	Steel	Steel	Steel	Steel	Steel	Steel	Steel
Plate Loading (g^{10}B /cm^2)	0.00000	0.00455	0.03022	0.02361	-	-	-
EALCF (MeV)	2.982E-7	3.068E-7	3.111E-7	3.094E-7	3.097E-7	2.998E-7	3.061E-7
Exp. σ	0.0018	0.0018	0.0018	0.0018	0.0032	0.0018	0.0018
k_{eff}	0.99402	0.99446	0.99355	0.99401	0.99281	0.99496	0.99378
σ	0.00068	0.00064	0.00064	0.00064	0.00066	0.00063	0.00062

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	14.01	14.02	14.05	14.06	14.07
Clusters	1	1	1	1	1
Enrichment (wt %^{235}U)	4.31%	4.31%	4.31%	4.31%	4.31%
Pitch (cm)	1.890	1.890	1.890	1.715	1.715
Fuel OD (cm)	1.265	1.265	1.265	1.265	1.265
Clad OD (cm)	1.415	1.415	1.415	1.415	1.415
Clad Material	Al	Al	Al	Al	Al
H/U (fissile)	106	106	106	73	73
Soluble B (ppm)	0	491	2539	0	1030
Absorber Type	-	-	-	-	-
Cluster Gap (cm)	-	-	-	-	-
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-
EALCF (MeV)	2.873E-7	3.447E-7	6.003E-7	5.175E-7	7.722E-7
Exp. σ	0.0019	0.0077	0.0069	0.0033	0.0051
k_{eff}	0.99668	0.98595	1.00221	1.00245	0.99973
σ	0.00044	0.00045	0.00043	0.00045	0.00044

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	16.01	16.02	16.03	16.04	16.05	16.06	16.07	16.08	16.09	16.10
Clusters	3	3	3	3	3	3	3	3	3	3
Enrichment [wt %^{235}U]	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%
Pitch (cm)	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032
Fuel OD (cm)	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118
Clad OD (cm)	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	404	404	404	404	404	404	404	404	404	404
Soluble B (ppm)	-	-	-	-	-	-	-	-	-	-
Absorber Type	304L SS (no B)	304L SS (no B)	304L SS (no B)	304L SS (no B)	304L SS (no B)	304L SS (no B)	304L SS (no B)	304L SS (1.05% B)	304L SS (1.05% B)	304L SS (1.62% B)
Cluster Gap (cm)	6.9	7.6	7.5	7.4	7.8	10.4	11.5	7.6	9.6	7.4
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00455	0.00455	0.00690
EALCF (MeV)	1.000E-7	9.983E-8	9.947E-8	1.001E-7	1.002E-7	1.009E-7	1.001E-7	9.993E-8	1.004E-7	1.012E-7
Exp. σ	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031
k_{eff}	0.99494	0.99509	0.99252	0.99562	0.99313	0.99813	0.99670	0.99383	0.99277	0.99292
σ	0.00171	0.00153	0.00157	0.00162	0.00173	0.00179	0.00175	0.00172	0.00157	0.00162

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	16.11	16.12	16.13	16.14	16.15	16.16	16.17	16.18	16.19	16.20	16.21	16.22
Clusters	3	3	3	3	3	3	3	3	3	3	3	3
Enrichment [wt %^{235}U]	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%
Pitch(cm)	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032
Fuel OD (cm)	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118
Clad OD (cm)	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	404	404	404	404	404	404	404	404	404	404	404	404
Soluble B (ppm)	-	-	-	-	-	-	-	-	-	-	-	-
Absorber Type	304L SS (1.62% B)	Boral	Boral	Boral	Cu	Cu	Cu	Cu	Cu	Cu (0.989 wt % Cd)	Cd	Cd
Cluster Gap (cm)	9.5	6.3	9.0	5.1	6.6	7.7	7.5	6.9	7.0	5.2	6.7	7.6
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	0.00690	0.06704	0.06704	0.06704	-	-	-	-	-	-	-	-
EALCF (MeV)	9.962E-8	1.016E-7	1.006E-7	1.025E-7	1.000E-7	9.944E-8	9.904E-8	9.919E-8	9.971E-8	1.001E-7	1.024E-7	1.014E-7
Exp. σ	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031
k_{eff}	0.99641	0.99306	0.99650	0.99468	0.99330	0.99181	0.99392	0.99556	0.99454	0.99449	0.99130	0.99480
σ	0.00154	0.00161	0.00152	0.00162	0.00157	0.00153	0.00155	0.00172	0.00165	0.00155	0.00166	0.00157

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	16.23	16.24	16.25	16.26	16.27	16.28	16.29	16.30	16.31	16.32
Clusters	3	3	3	3	3	3	3	3	3	3
Enrichment [wt %^{235}U]	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%
Pitch(cm)	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032	2.032
Fuel OD (cm)	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118	1.118
Clad OD (cm)	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270	1.270
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	404	404	404	404	404	404	404	404	404	404
Soluble B (ppm)	-	-	-	-	-	-	-	-	-	-
Absorber Type	Cd	Cd	Cd	Cd	Cd	Al (no B)	Al (no B)	Al (no B)	Zircaloy-4	Zircaloy-4
Cluster Gap cm)	9.4	7.8	9.4	7.5	9.4	8.7	8.8	8.8	8.8	8.8
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-	0.00000	0.00000	0.00000	-	-
EALCF (MeV)	1.010E-7	1.018E-7	1.006E-7	1.019E-7	9.948E-8	9.991E-8	9.843E-8	9.807E-8	9.964E-8	9.834E-8
Exp. σ	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031	0.0031
k_{eff}	0.99350	0.99400	0.99628	0.99262	0.99410	0.99647	0.99360	0.99702	0.99497	0.99195
σ	0.00184	0.00152	0.00169	0.00151	0.00168	0.00166	0.00157	0.00160	0.00163	0.00172

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	35.01	35.02	40.01	40.02	40.03	40.04	40.05	40.06	40.07	40.08	40.09	40.10
Clusters	1	1	4	4	4	4	4	4	4	4	4	4
Enrichment (wt %^{235}U)	2.60%	2.60%	4.74%	4.74%	4.74%	4.74%	4.74%	4.74%	4.74%	4.74%	4.74%	4.74%
Pitch (cm)	1.956	1.956	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600	1.600
Fuel OD (cm)	1.250	1.250	0.790	0.790	0.790	0.790	0.790	0.790	0.790	0.790	0.790	0.790
Clad OD (cm)	1.417	1.417	0.940	0.940	0.940	0.940	0.940	0.940	0.940	0.940	0.940	0.940
Clad Material	Al	Al	Al alloy	Al alloy	Al alloy	Al alloy	Al alloy	Al alloy	Al alloy	Al alloy	Al alloy	Al alloy
H/U (fissile)	203	203	231	231	231	231	231	231	231	231	231	231
Soluble B (ppm)	70	148	-	-	-	-	-	-	-	-	-	-
Absorber Type	-	-	Z2 CN18/10 SS (1.10% B)	Z2 CN18/10 SS (1.10% B)	Z2 CN18/10 SS (1.10% B)	Z2 CN18/10 SS (1.10% B)	Boral	Boral	Boral	Boral	Boral	Boral
Cluster Gap (cm)	-	-	2.3	2.3	2.3	2.3	3.3	3.3	3.3	3.3	3.3	3.3
Reflector	H_2O	H_2O	H_2O	Lead	Lead	Lead	H_2O	Lead	Lead	Lead	Steel	Steel
Plate Loading (g^{10}B /cm^2)	-	-	0.00252	0.00252	0.00252	0.00252	0.04608	0.04608	0.04608	0.04608	0.04608	0.04608
EALCF (MeV)	2.170E-7	2.202E-7	1.493E-7	1.717E-7	1.625E-7	1.576E-7	1.432E-7	1.515E-7	1.470E-7	1.459E-7	1.537E-7	1.469E-7
Exp. σ	0.0018	0.0019	0.0039	0.0041	0.0041	0.0041	0.0042	0.0044	0.0044	0.0044	0.0046	0.0046
k_{eff}	0.99341	0.99131	0.99586	0.99358	0.99539	0.99237	0.99144	0.99878	0.99418	0.99240	0.99693	0.99137
σ	0.00070	0.00078	0.00195	0.00192	0.00203	0.00194	0.00193	0.00196	0.00224	0.00216	0.00190	0.00208

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	42.01	42.02	42.03	42.04	42.05	42.06	42.07
Clusters	3	3	3	3	3	3	3
Enrichment (wt %^{235}U)	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%	2.35%
Pitch (cm)	1.684	1.684	1.684	1.684	1.684	1.684	1.684
Fuel OD (cm)	1.118	1.118	1.118	1.118	1.118	1.118	1.118
Clad OD (cm)	1.270	1.270	1.270	1.270	1.270	1.270	1.270
Clad Materiall	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	221	221	221	221	221	221	221
Soluble B (ppm)	-	-	-	-	-	-	-
Absorber Type	304L SS (no B)	304L SS (1.05% B)	Boral B	Boroflex	Cd	Cu	Cu-Cd
Cluster Gap (cm)	8.3	4.8	2.7	3.0	3.9	7.8	5.4
Reflector	Steel	Steel	Steel	Steel	Steel	Steel	Steel
Plate Loading (g^{10}B /cm^2)	0.00000	0.00455	0.03022	0.02361	-	-	-
EALCF (MeV)	1.813E-7	1.824E-7	1.915E-7	1.887E-7	1.857E-7	1.786E-7	1.833E-7
Exp. σ	0.0016	0.0016	0.0016	0.0017	0.0033	0.0016	0.0018
k_{eff}	0.99250	0.99514	0.99219	0.99476	0.99469	0.99434	0.99319
σ	0.00171	0.00183	0.00169	0.00169	0.00161	0.00191	0.00157

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	50.03	50.03	50.03	50.03	50.03
Clusters	1	1	1	1	1
Enrichment (wt %^{235}U)	4.74%	4.74%	4.74%	4.74%	4.74%
Pitch (cm)	1.300	1.300	1.300	1.300	1.300
Fuel OD (cm)	0.790	0.790	0.790	0.790	0.790
Clad OD (cm)	0.940	0.940	0.940	0.940	0.940
Clad Material	Al alloy	Al alloy	Al alloy	Al alloy	Al alloy
H/U (fissile)	124	124	124	124	124
Soluble B (ppm)	821	821	4986	4986	4986
Absorber Type	-	-	-	-	-
Cluster Gap (cm)	-	-	-	-	-
Reflector	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O
Plate Loading (g^{10}B /cm^2)	-	-	-	-	-
EALCF (MeV)	2.170E-7	2.083E-7	2.318E-7	2.252E-7	2.195E-7
Exp. σ	0.0010	0.0010	0.0010	0.0010	0.0010
k_{eff}	0.99330	0.99340	0.99489	0.99319	0.99306
σ	0.00080	0.00071	0.00075	0.00075	0.00080

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	51.01	51.02	51.03	51.04	51.05	51.06	51.07	51.08	51.09
Clusters	9	9	9	9	9	9	9	9	9
Enrichment (wt %^{235}U)	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%
Pitch (cm)	1.636	1.636	1.636	1.636	1.636	1.636	1.636	1.636	1.636
Fuel OD (cm)	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030
Clad OD (cm)	1.206	1.206	1.206	1.206	1.206	1.206	1.206	1.206	1.206
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	219	219	219	219	219	219	219	219	219
Soluble B (ppm)	143	510	514	501	493	474	462	432	217
Absorber Type	none	SS	SS	SS	SS	SS	SS	SS	SS
Cluster Gap (cm)	4.9	1.6	1.6	1.6	1.6	1.6	1.6	1.6	3.3
Reflector	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O
Plate Loading (g^{10}B /cm^2)	0.00000	-	-	-	-	-	-	-	-
EALCF (MeV)	1.535E-7	2.045E-7	2.043E-7	2.067E-7	2.074E-7	2.083E-7	2.085E-7	2.098E-7	1.737E-7
Exp. σ	0.0020	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0019
k_{eff}	0.99133	0.99597	0.99555	0.99486	0.99504	0.99542	0.99530	0.99507	0.99368
σ	0.00033	0.00035	0.00033	0.00034	0.00034	0.00034	0.00034	0.00034	0.00033

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	51.10	51.11	51.12	51.13	51.14	51.15	51.16	51.17	51.18	51.19
Clusters	9	9	9	9	9	9	9	9	9	9
Enrichment (wt %^{235}U)	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%	2.46%
Pitch (cm)	1.636	1.636	1.636	1.636	1.636	1.636	1.636	1.636	1.636	1.636
Fuel OD (cm)	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030	1.030
Clad OD (cm)	1.206	1.206	1.206	1.206	1.206	1.206	1.206	1.206	1.206	1.206
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	219	219	219	219	219	219	219	219	219	219
Soluble B (ppm)	15	28	92	395	121	487	197	634	320	72
Absorber Type	B/Al Set 5	B/Al Set 5A	B/Al Set 4	B/Al Set 3	B/Al Set 3	B/Al Set 2	B/Al Set 2	B/Al Set 1	B/Al Set 1	B/Al Set 1
Cluster Gap (cm)	1.6	1.6	1.6	1.6	3.3	1.6	3.3	1.6	3.3	4.9
Reflector	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O	Borated H_2O
Plate Loading ($g^{10}B/cm^2$)	0.00517	0.00519	0.00403	0.00128	0.00128	0.00078	0.00078	0.00032	0.00032	0.00032
EALCF (MeV)	2.029E-7	2.015E-7	2.056E-7	2.112E-7	1.773E-7	2.106E-7	1.775E-7	2.119E-7	1.780E-7	1.587E-7
p. σ	0.0019	0.0019	0.0019	0.0022	0.0019	0.0024	0.0020	0.0027	0.0021	0.0019
keff	0.99210	0.99447	0.99073	0.98652	0.98634	0.99042	0.98974	0.99152	0.99029	0.98927
σ	0.00034	0.00034	0.00034	0.00034	0.00034	0.00034	0.00034	0.00034	0.00035	0.00035

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	65.01	65.02	65.03	65.04	65.05	65.06	65.07	65.08
Clusters	2	2	2	2	2	2	2	2
Enrichment (wt %^{235}U)	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%
Pitch (cm)	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956
Fuel OD (cm)	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250
Clad OD (cm)	1.417	1.417	1.417	1.417	1.417	1.417	1.417	1.417
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	203	203	203	203	203	203	203	203
Soluble B (ppm)	-	-	-	-	-	-	-	-
Absorber Type	none	304L SS (No B)	304L SS (0.67% B)	304L SS (0.98% B)	none	304L SS (No B)	304L SS (No B)	304L SS (No B)
Cluster Gap (cm)	5.9	5.9	5.9	5.9	7.8	7.8	7.8	7.8
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	-	0.00000	0.00599	0.00875	-	0.00000	0.00000	0.00000
EALCF [MeV]	2.045E-7	2.030E-7	2.054E-7	2.038E-7	2.049E-7	2.030E-7	2.055E-7	2.040E-7
Exp. σ	0.0014	0.0014	0.0015	0.0015	0.0014	0.0014	0.0014	0.0016
k_{eff}	0.99571	0.99618	0.99534	0.99547	0.99691	0.99614	0.99589	0.99624
σ	0.00023	0.00022	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023

Table 6.7.7-1 MCNP Validation Statistics (cont.)

Case	65.09	65.10	65.11	65.12	65.13	65.14	65.15	65.16	65.17
Clusters	2	2	2	2	2	2	2	2	2
Enrichment (wt %^{235}U)	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%	2.60%
Pitch (cm)	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956	1.956
Fuel OD (cm)	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250	1.250
Clad OD (cm)	1.417	1.417	1.417	1.417	1.417	1.417	1.417	1.417	1.417
Clad Material	Al	Al	Al	Al	Al	Al	Al	Al	Al
H/U (fissile)	203	203	203	203	203	203	203	203	203
Soluble B (ppm)	-	-	-	-	-	-	-	-	-
Absorber Type	304L SS (No B)	304L SS (0.67% B)	304L SS (0.67% B)	304L SS (0.67% B)	304L SS (0.67% B)	304L SS (0.98% B)	304L SS (0.98% B)	304L SS (0.98% B)	304L SS (0.98% B)
Cluster Gap (cm)	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
Reflector	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
Plate Loading (g^{10}B /cm^2)	0.00000	0.00299	0.00299	0.00599	0.00599	0.00438	0.00438	0.00875	0.00875
EALCF [MeV]	1.993E-7	2.050E-7	2.069E-7	2.072E-7	1.977E-7	2.010E-7	2.004E-7	2.027E-7	2.017E-7
Exp. σ	0.0015	0.0016	0.0016	0.0017	0.0016	0.0016	0.0016	0.0017	0.0016
k_{eff}	0.99667	0.99676	0.99637	0.99643	0.99701	0.99650	0.99634	0.99658	0.99645
σ	0.00022	0.00022	0.00023	0.00023	0.00022	0.00023	0.00023	0.00022	0.00023

Chapter 7
Confinement

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7 CONFINEMENT

The MAGNASTOR TSC provides confinement for its radioactive contents in long-term storage. The confinement boundary provided by the TSC is closed by welding, creating a solid barrier to the release of contents in the design basis normal conditions and off-normal or accident events. The welds are visually inspected and nondestructively examined to verify integrity.

The sealed TSC contains a pressurized inert gas (helium). The confinement boundary retains the helium and also prevents the entry of outside air into the TSC in long-term storage. The exclusion of air precludes fuel rod cladding oxidation failures during storage.

The TSC confinement system meets the requirements of 10 CFR 72.24 [1] for protection of the public from release of radioactive material. The design of the TSC allows the recovery of stored spent fuel should it become necessary per the requirements of 10 CFR 72.122. The TSC meets the requirements of 10 CFR 72.122 (h) for protection of the spent fuel contents in long-term storage such that future handling of the contents would not pose an operational safety concern.

The MAGNASTOR TSC provides an austenitic stainless steel closure design sealed by welding, precluding the need for continuous monitoring. The analysis for normal conditions and off-normal or accident events shows that the integrity of the confinement boundary is maintained in all of the evaluated conditions. Consequently, there is no release of radionuclides from the TSC resulting in site boundary doses in excess of regulatory requirements. Therefore, the confinement design of MAGNASTOR meets the regulatory requirements of 10 CFR 72 and the acceptance criteria defined in NUREG-1536 [2].

7.1 Confinement Boundary

The welded TSC is the confinement vessel for the PWR or BWR spent fuel assembly contents.

The confinement boundary of the TSC consists of the TSC shell, bottom plate, TSC closure lid, closure ring, the redundant vent and drain port covers, and the welds that join these components. The confinement boundary is shown in Figure 7.1-1. The confinement boundary does not incorporate bolted closures or mechanical seals. The confinement boundary welds are described in Table 7.1-1.

7.1.1 Confinement Vessel

The TSC consists of three principal components: the TSC shell, bottom plate, and closure lid. The TSC shell is a right circular cylinder constructed of rolled Type 304/304L (dual certified) stainless steel plate with the edges of the plate joined by full penetration welds. It is closed at the bottom end by a circular plate joined to the shell by a full penetration weld. The TSC has two lengths to accommodate different fuel lengths. The TSC shell is helium leak tested following fabrication.

After loading, the TSC is closed at the top by a closure lid fabricated from Type 304 stainless steel. It is joined to the TSC shell using a field-installed groove weld. The closure lid-to-TSC shell weld is analyzed, installed, and examined in accordance with ISG-15 [6] guidance. This closure lid-to-TSC shell weld is a partial penetration weld progressively examined at the root, midplane, and final surface by liquid penetrant (PT) examination. Following NDE of the closure lid-to-TSC shell weld, the TSC cavity is reflooded and the TSC vessel is hydrostatically pressure tested as described in the Operating Procedures of Chapter 9 and the Acceptance Test Program of Chapter 10. The acceptance criteria for the test are no leakage and no loss of pressure during the minimum 10-minute test duration.

After successful completion of the hydrostatic pressure test, the Type 304 stainless steel closure ring is installed in the TSC-to-closure lid weld groove, and welded to both the closure lid and the TSC shell. The closure ring welds are inspected by PT examination of the final weld surfaces. The closure ring provides the double weld redundant sealing of the confinement boundary, as required by 10 CFR 72.236(e).

The closure lid incorporates drain and vent penetrations, which provide access to the TSC cavity for canister draining, drying and helium backfilling operations during TSC closure and preparation for placement into storage. The design of the penetrations incorporates features to provide adequate shielding for the operators during these operations and closure welding.

Following final helium backfill and pressurization, the vent and drain port penetrations are closed with Type 304 stainless steel inner port covers that are partial-penetration welded in place. Each inner port cover weld is helium leak tested. Each inner port cover weld final surface is then PT examined. A second (outer) port cover is then installed and welded to the closure lid at each of the ports to provide the double weld redundant sealing of the confinement boundary. The outer port cover weld final surfaces are inspected by PT examination.

Prior to sealing, the TSC cavity is backfilled and pressurized with helium. The minimum helium purity level of 99.995% (minimum) specified in the Operating Procedures maintains the quantity of oxidizing contaminants to less than one mole per canister for all loading conditions. Based on the maximum empty canister free volume of 10,400 liters and the design basis helium density (Section 4.4.4), an empty canister would contain approximately 2,000 moles of gases. Conservatively, assuming that all of the impurities in the helium are oxidants, a maximum of 0.1 moles of oxidants could exist in the largest canister during storage. By limiting the amount of oxidants to less than one mole, the recommended limits for preventing cladding degradation found in the PNL-6365 [4] are satisfied.

The thermal analysis of the loaded TSC is based, in part, on heat transfer from the fuel to the TSC shell by convection within the TSC. The provision of a specific density of high-purity helium, which ensures the establishment of internal convection in the TSC, also ensures that a positive pressure exists within the TSC during the design life of the system. The maintenance of a positive helium pressure eliminates any potential for in-leakage of air into the TSC cavity during storage operations.

The closure lid weld completed in the field is not helium leakage tested. Interim Staff Guidance (ISG)-18 [5] provides that an adequate confinement boundary is established for stainless steel spent fuel storage canisters that are closed using a closure weld that meets the guidance of ISG-15 [6]. The TSC closure weld meets the ISG-15 guidance in that the analysis of the weld considers a stress reduction factor of 0.8. The weld is qualified and performed in accordance with the ASME Code, Section IX requirements [7]; and the weld is dye penetrant examined after the root, midplane, and final surface passes. The final surfaces of the welds joining the closure ring to the closure lid and shell, and joining the redundant port covers to the closure lid are PT examined. The inner port cover welds are helium leakage tested as defined in Chapter 10.

During fabrication, the TSC shell and bottom plate welds are volumetrically inspected and the shell assembly is shop helium leakage tested to the leaktight criteria of 1×10^{-7} ref cm^3/sec, or

2×10^{-7} cm^3/sec (helium), in accordance with ANSI N14.5 [8] using the evacuated envelope test method. A minimum test sensitivity of 1×10^{-7} cm^3/sec (helium) is required.

Based on the shop helium leakage testing of the TSC shell, bottom plate and the joining welds; the design analyses and qualifications of the closure lid and port cover welds; the performance of a TSC field hydrostatic pressure test of the closure lid-to-TSC shell weld; the helium leakage test performed on the inner vent and drain port covers; and the multiple NDE performed on all of the confinement boundary welds, the loaded TSC is considered and analyzed as having no credible leakage.

The confinement boundary details at the top of the TSC are shown in Figure 7.1-1. The closure is welded by qualified welders using weld procedures qualified in accordance with ASME Code, Section IX. Over its 50-year design life, the TSC precludes the release of radioactive contents to the environment and the entry of air, or water, that could potentially damage the cladding of the stored spent fuel.

7.1.2 Confinement Penetrations

Two penetrations fitted with quick-disconnect fittings are provided in the TSC closure lid for operational functions during system loading and sealing operations. The drain port accesses a drain tube that extends into a sump located in the bottom plate. The vent port extends to the underside of the closure lid and accesses the top of the TSC cavity.

After the completion of the closure lid-to-TSC shell weld, TSC pressure test, closure ring welding and cavity draining, the vent and drain penetrations are utilized for drying the TSC internals and contents, and for helium backfilling and pressurizing the TSC. After backfilling to a specific helium density, both penetrations are closed with redundant port covers welded to the closure lid. As presented for storage, the TSC has no exposed or accessible penetrations, has no mechanical closures, and does not employ seals to maintain confinement.

7.1.3 Seals and Welds

The confinement boundary welds consist of the field-installed welds that close and seal the TSC, and the shop welds that join the bottom plate to the TSC and that join the rolled plates that form the TSC shell. The TSC shell may incorporate both longitudinal and circumferential weld seams in joining the rolled plates. No elastomer or metallic seals are used in the confinement boundary of the TSC.

All cutting, machining, welding, and forming of the TSC vessel are performed in accordance with Section III, Article NB-4000 of the ASME Code, unless otherwise specified in the approved fabrication drawings and specifications. Code alternatives are listed in Table 2.1-2.

Weld procedures, welders, and welding machine operators shall be qualified in accordance with ASME Code, Section IX. Refer to Chapter 10 for the acceptance criteria for the TSC weld visual inspections and nondestructive examinations (NDE).

The loaded TSC is closed using field-installed welds. The closure lid to TSC shell weld is liquid penetrant examined at the root, at the midplane level and the final surface. After the completion of TSC hydrostatic pressure testing, the closure ring is installed and welded to the TSC shell and closure lid. The final surface of each of the closure ring welds is liquid penetrant examined. Following draining, drying, and helium backfilling operations, the vent and drain ports are closed with redundant port covers that are welded in place. The inner port cover welds are helium leakage tested. The final surface of each port cover to closure lid weld is liquid penetrant examined.

Shop and field examinations of TSC confinement boundary welds are performed by personnel qualified in accordance with American Society of Nondestructive Testing Recommended Practice No. SNT-TC-1A [9]. Weld examinations are documented in written reports.

7.1.4 Closure

The closure of the TSC consists of the welded closure lid, the welded closure ring, and the welded redundant vent and drain port covers. There are no bolted closures or mechanical seals in the confinement boundary.

Figure 7.1-1 TSC Confinement Boundary

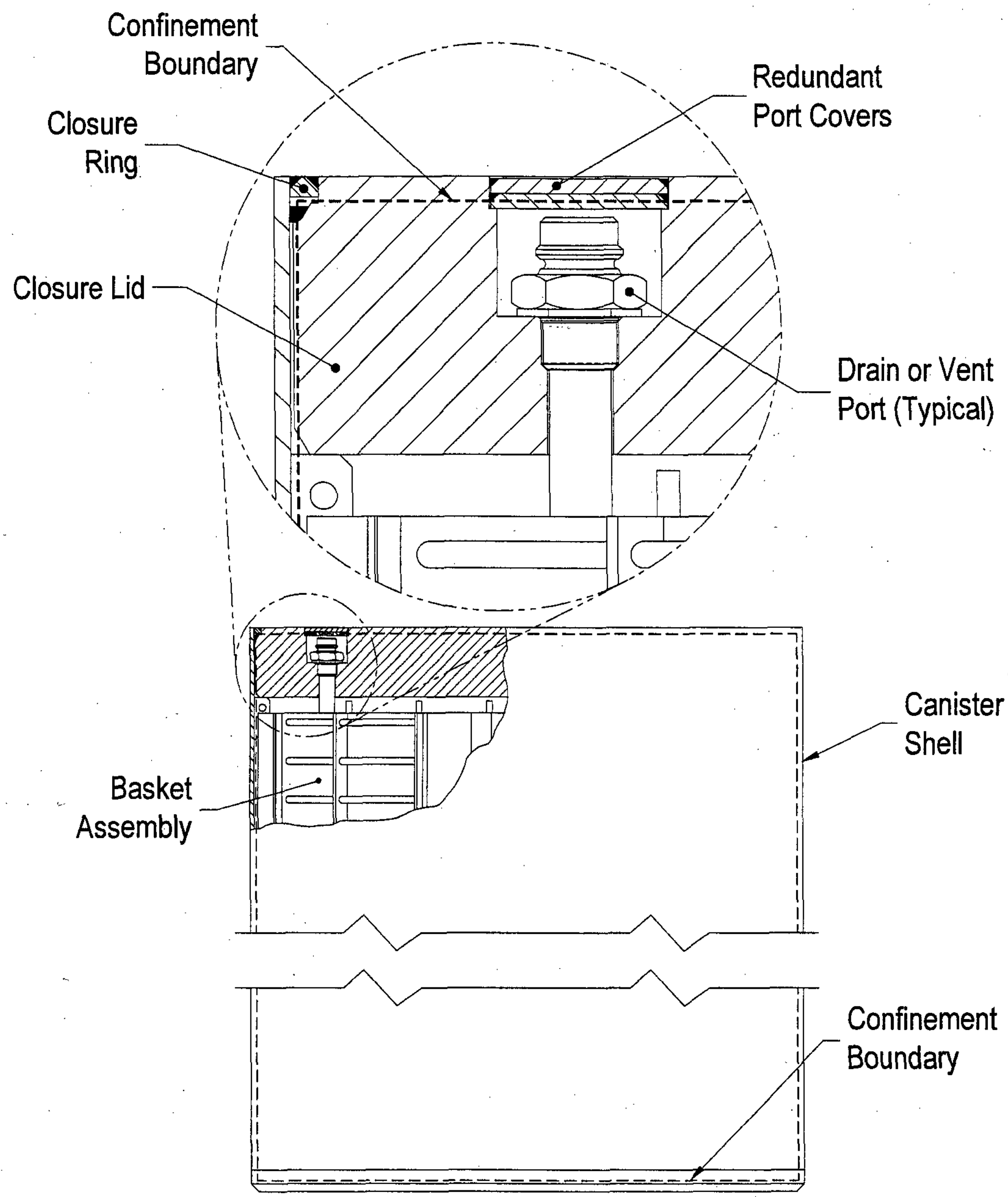

Table 7.1-1 TSC Confinement Boundary Welds

Weld Location	Weld Type	ASME Code Category (Section III, Subsection NB)
Shell longitudinal	Full penetration groove (Shop weld)	A
Shell circumferential (if used)	Full penetration groove (Shop weld)	B
Bottom plate to shell	Full penetration groove (Shop weld)	C
TSC closure lid to shell	Groove (field weld)	C
Redundant vent and drain port covers to closure lid	Bevel (field weld)	C
Closure ring to TSC shell and to closure lid	Bevel (field weld)	C

7.2 Requirements for Normal Conditions of Storage

The TSC is transferred to a concrete cask using a transfer cask. Once the TSC is placed inside of the concrete cask, it is effectively protected from direct structural loading due to natural phenomena, such as wind, snow, and ice loading. The principal direct loading for normal operating conditions results from increased internal pressure caused by decay heat, solar insolation, and ambient temperature. Loading due to transient handling may occur during the transfer of the loaded TSC to the concrete cask.

7.2.1 Release of Radioactive Material

The structural analysis of the TSC for normal conditions of storage presented in Chapter 3 demonstrates that the confinement boundary is not breached in any of the normal operating events. Therefore, there is no release of radioactive material during normal storage conditions.

7.2.2 Pressurization of the Confinement Vessel

The TSC cavity is dried and pressurized with helium prior to installing and welding the vent and drain port covers. Under normal conditions, the internal pressure increases due to an increase in temperature of the helium and the postulated normal storage cladding failure of 1% of the stored fuel rods, which is assumed to release 30% of the available fission gases in the rods.

The TSC, closure lid, fittings, and the basket assembly are fabricated from materials that either do not react with ordinary or borated spent fuel pool water to generate gases, or which have an electroless nickel plating to significantly reduce, or eliminate, the potential for interaction with water. Refer to Chapter 8 for a description of the electroless nickel plating and process. The neutron absorber sheets in the fuel baskets, as described in Chapter 8, and the stainless steel covers are held in place by weld posts attached to the fuel tubes. The neutron absorber is a borated aluminum composite, which is protected by an oxide film that forms shortly after fabrication of the plates. This oxide layer effectively precludes further oxidation that could result in the generation of gases in the TSC.

As the TSC is dried and helium backfilled prior to sealing, no significant moisture or other gases, such as air, remain in the TSC. Consequently, there is no potential that radiolytic decomposition could cause an increase in TSC internal pressure or result in a buildup of explosive gases in the TSC. Foreign materials will be excluded from the cavity to ensure that explosive levels of gases due to radiological decomposition will not be generated.

The calculated TSC pressure for normal conditions of storage is presented in Chapter 4 and is less than the pressure evaluated in Chapter 3 for the maximum normal operating pressure. Consequently, there is no adverse consequence due to the internal pressure resulting from normal storage conditions.

As the confinement boundary is closed by welding and does not contain seals or O-rings, and the boundary is not ruptured or otherwise compromised under any normal handling event, the release of contents during normal conditions of storage is precluded.

7.3 Confinement Requirements for Hypothetical Accident Conditions

The results of the structural analyses of the TSC for off-normal and accident events of storage, presented in Chapter 12, show that the TSC is not breached in any of the evaluated events. Consequently, based on the welded closure TSC confinement boundary and the leakage tests described in Section 10.1.3, the TSC has no credible leakage and, therefore, there is no release of radioactive material during off-normal or accident events of storage.

A hypothetical accident condition assumes the cladding failure of all the fuel rods stored in the TSC. This postulated event results in an increase in TSC internal pressure due to the release of the fission product and fuel rod charge gases. The accident condition internal pressures for the PWR and BWR configurations are calculated in Chapter 4 and are shown to be less than the design pressure. Consequently, the integrity of the TSC confinement boundary is maintained and there is no release of radioactive material under off-normal or accident events of storage.

Since no release occurs as the result of accident events, the resulting site boundary dose due to a hypothetical accident is less than the 5 rem whole body or organ (including skin) dose at the 100 meter minimum boundary specified by 10 CFR 72.106 (b) for accident exposures.

7.4 References

1. 10 CFR 72, Code of Federal Regulations, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste," US Nuclear Regulatory Commission, Washington, DC.
2. NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," Nuclear Regulatory Commission, Washington, DC, January 1997.
3. Deleted
4. PNL-6365, "Evaluation of Cover Gas Impurities and Their Effects on the Dry Storage of LWR Spent Fuel," Pacific Northwest Laboratory, Richland, Washington, November, 1987.
5. ISG-18, "The Design/Qualification of Final Closure Welds on Austenitic Stainless Steel Canisters as Confinement Boundary for Spent Fuel Storage and Containment Boundary for Spent Fuel Transportation," US Nuclear Regulatory Commission, Washington, DC, May 2003.
6. ISG-15, "Materials Evaluation," US Nuclear Regulatory Commission, Washington, DC, Revision 0, January 10, 2001.
7. ASME Boiler and Pressure Vessel Code, Section IX, "Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
8. ANSI N14.5-1997. "American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment," American National Standards Institute, Washington, DC, 1997.
9. Recommended Practice No. SNT-TC-1A, "Personnel Qualification and Certification in Nondestructive Testing," The American Society for Nondestructive Testing, Inc., Columbus, OH, edition as invoked by the applicable ASME Code.

Chapter 8
Materials Evaluation

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8 MATERIALS EVALUATION

This chapter provides the detailed descriptions of the materials selected for use in the components of MAGNASTOR. The component materials are specified in the license drawings. The significant physical, chemical, mechanical, and thermal properties of materials used in components of MAGNASTOR are defined, and the material specifications, tests and acceptance conditions important to material use are identified in this chapter. The MAGNASTOR materials are consistent with the application of the accepted design criteria, codes, standards, and specifications described in Chapter 2.

8.1 Material Selection

Type 304 stainless steel is used in the TSC. It is selected for this use because of its high strength, ductility, resistance to corrosion and brittle fracture, and metallurgical stability for long-term storage. The steels used in the fabrication of the TSC are as follows.

Shell	ASME SA240, Type 304/304L dual-certified, stainless steel
Bottom	ASME SA240, Type 304/304L dual-certified, stainless steel
Closure Lid	ASME SA240/SA182, Type 304 stainless steel
Closure Ring	ASME SA276, Type 304 stainless steel
Port Covers	ASME SA240, Type 304 stainless steel

Note: SA182 Type F304 stainless steel may be substituted for SA240 Type 304 stainless steel for the closure lid, provided that the SA182 material has yield and ultimate strengths greater than, or equal to, those of the SA240 material.

The carbon steels used in the fuel baskets are selected based on their strength and thermal conductivity. After fabrication, the basket components are electroless nickel-coated to improve resistance to corrosion and to significantly reduce the potential for the formation of flammable gases during in-pool loading. The materials used in the fabrication of the fuel baskets are:

Basket Supports, Plates and Gussets	ASME SA537, Class 1, Carbon Steel
Corner Support Bars	ASME SA695, Type B, Grade 40 or SA696, Grade C Carbon Steel
Fuel Tubes	ASME SA537, Class 1, Carbon Steel
Connector Pins	ASME SA695, Type B, Grade 40 or SA696, Grade C Carbon Steel
Mounting Bolts	ASME SA193, Gr B6 stainless steel
Neutron Absorber	Borated Metal Matrix Composite, Borated Aluminum Alloy, or Boral

The materials used in the concrete cask fabrication are:

Shell	ASTM A36 Carbon Steel
Pedestal Plate	ASTM A36 Carbon Steel
Base and Top Plates	ASTM A537, Class 2, Carbon Steel
Lift Lugs and Anchors	ASTM A537, Class 2, Carbon Steel
Lift Lug Bolts	ASME SB637, Grade NO7718 nickel alloy
Reinforcing bar	ASTM A615/A615M Carbon Steel
Concrete	ASTM C150 Type II Portland Cement

The materials used in the transfer cask fabrication are:

Inner Shell	ASTM A588 low alloy steel
Outer Shell	ASTM A588 low alloy steel
Bottom Forging	ASTM A516, Grade 70
Top Forging	ASTM A516, Grade 70
Trunnions	ASTM A350, LF2 low alloy steel
Shield Doors and Rails	ASTM A350, LF2 low alloy steel
Retaining Block Pins	ASTM A516, Grade 70
Retaining Block	ASTM A693/A564 17-4 PH stainless steel
Gamma Shield Brick	ASTM B29 Lead-Chemical Copper Grade
Neutron Shield	NS-4-FR

8.1.1 Fracture Toughness

The TSC structural material is austenitic stainless steel. In accordance with ASME Code, Section III, Subsection NB, Article NB-2311, these materials do not require testing for fracture toughness.

The fuel basket is comprised of welded tubes and supports primarily fabricated from ASME Code SA537, Class 1, carbon steel. Fuel basket materials will meet ASME Code, Section III, Subsection NG, Article NG-2300 requirements for impact tests and will be tested in accordance with paragraph NG-2320. A procurement/fabrication specification will describe fracture toughness testing of these materials for each heat of material subjected to the equivalent forming/bending process or heat-treated condition. Acceptance values shall be per ASTM A370, Section 26.1, with values meeting the requirements of Table NG-2331(a)(1) at a Lowest Service Temperature (LST) of -40°F.

The concrete cask lift lugs and anchors are fabricated from two-inch thick, ASTM A537 Class 2, carbon steel plate. Utilization of the lift lugs and anchors for handling the concrete cask is considered a noncritical lift and will be restricted for use only when the surrounding air temperature is ≥ 0°F. Therefore, impact testing of the material is not required.

The structural components of the transfer cask are fabricated from low alloy carbon steels selected based on their low-temperature facture toughness. The nil ductility transition temperature for these steels is established as –40°F. Based on Regulatory Guide 7.11 [1], the minimum temperature for use is 40°F above the transition temperature, with no credit taken for heat produced by the contents of the transfer cask. Consequently, a minimum ambient temperature of 0°F for use of the transfer cask is established. This condition is administratively controlled by procedure and is consistent with the analysis. Since the use of the transfer cask is restricted to conditions when the surrounding air temperature is greater than, or equal to, 0°F, impact testing of the transfer cask materials is not required.

8.2 Applicable Codes and Standards

The principal codes and standards applied to MAGNASTOR components are the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, the American Society for Testing and Materials (ASTM), and the American Concrete Institute (ACI). Materials meeting the requirements of these codes and/or standards conform to acceptable minimum thickness, chemical content and formulation specifications and are fabricated using controlled processes and procedures.

The TSC steel components and associated weld filler materials are procured in accordance with the ASME Code, Section III, Subsection NB [3] requirements, except as listed in the Code Alternatives in Table 2.1-2. The fuel basket steel components and associated weld filler materials are procured in accordance with ASME Code, Section III, Subsection NG [4] requirements, except as stated in the Code Alternatives in Table 2.1-2.

The transfer cask steel components, associated weld filler materials and lead gamma shield materials are procured in accordance with the requirements of the applicable ASTM standards. The NS-4-FR material in the transfer cask is a commercially available product specifically designed for neutron attenuation and absorption.

The concrete cask steel components and associated weld filler materials are procured in accordance with the requirements of the applicable ASTM standards. The concrete portion of the cask is procured in accordance with the requirements of ACI 318 [2], as supplemented by applicable ASTM standards.

8.3 Material Properties

The mechanical properties of steels used in the fabrication of the MAGNASTOR components are presented in Table 8.3-1 through Table 8.3-16. The thermal properties of materials used in the fabrication and evaluation of the storage system are shown in Table 8.3-17 through Table 8.3-28. Derivation of effective thermal conductivities is described in Chapter 4. Table 8.3-17 through Table 8.3-28 include only the materials that form the heat transfer pathways employed in the thermal analysis models. Materials for small components, which are not explicitly modeled, are not included in the property tabulation.

Mechanical material properties for irradiated zircaloy cladding are taken from a PNNL publication by Geelhood and Beyer [36]. Modulus of elasticity and material yield strength are conservatively defined at their minimum value through the maximum normal operating temperature of 752°F , i.e., $E = 10.47 \times 10^6$ psi and $S_y = 69,600$ psi.

Table 8.3-1 Mechanical Properties of SA240, Type 304, Stainless Steel

Property (units)	Value at Temperature (°F)									
	-40	-20	70	200	300	400	500	650	800	900
Ultimate strength, S_u (ksi) [a]	75.0	75.0	75.0	71.0	66.2	64.0	63.4	63.4	62.8	60.8
Yield Stress, S_y (ksi) [a]	30.0	30.0	30.0	25.0	22.4	20.7	19.4	18.0	16.9	16.2
Design Stress Intensity, S_m (ksi) [a]	20.0	20.0	20.0	20.0	20.0	18.7	17.5	16.2	15.2	14.6 [b]
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	28.8	28.7	28.3	27.6	27.0	26.5	25.8	25.1	24.1	23.5
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	8.13 [b]	8.2 [b]	8.5	8.9	9.2	9.5	9.7	9.9	10.1	10.2
Poisson's Ratio [a]	0.31									
Density (lb/in^3) [c]	0.29									

Note: SA182 Type F304 stainless steel may be substituted for SA240 Type 304 stainless steel, provided that the SA182 Type F304 material yield and ultimate strengths are equal to, or greater than, those of the SA240 Type 304 material. Both materials are austenitic stainless steels, which do not experience a ductile-to-brittle transition for the range of temperatures considered in this Safety Analysis Report. Therefore, fracture toughness is not a concern.

[a] ASME Boiler and Pressure Vessel Code [5]

[b] Extrapolated value

[c] Metals Handbook Desk Edition [23]

Table 8.3-2 Mechanical Properties of A693/A564, Type 630, 17-4 PH Stainless Steel

Property (units)	Value at Temperature (°F)							
	-40	70	200	300	400	500	600	700
Ultimate strength, S_u (ksi) [a]	135.0	135.0	135.0	135.0	131.2	128.6	126.7	123.8
Yield Stress, S_y (ksi) [a]	111.7	105.0	97.1	93.0	89.7	87.0	84.7	82.5
Design Stress Intensity, S_m (ksi) [a]	45.0	45.0	45.0	45.0	43.7	42.9	42.2	41.3 [b]
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	29.4	28.5	27.8	27.2	26.6	26.1	25.5	24.9
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	5.9							
Poisson's Ratio [a]	0.31							
Density (lb/in^3) [c]	0.29							

Table 8.3-3 Mechanical Properties of A350, Grade LF 2, Class 1, Low Alloy Steel

Property (units)	Value at Temperature (°F)						
	-40	70	200	300	400	500	700
Ultimate strength, S_u (ksi) [a]	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Yield strength, S_y (ksi) [a]	36.0	36.0	33.0	31.8	30.8	29.3	25.8
Design Stress Intensity, S_m (ksi) [a]	23.3	23.3	22.0	21.2	20.5	19.6	17.2
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	29.7	29.2	28.5	28.0	27.4	27.0	25.3
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	6.13	6.4	6.7	6.9	7.1	7.3	7.6
Poisson's Ratio [a]	0.31						
Density (lb/in^3) [c]	0.284						

[a] ASME Boiler and Pressure Vessel Code [5]

[b] Extrapolated

[c] Metals Handbook Desk Edition [23]

Table 8.3-4 Mechanical Properties of SA516/A-516, Grade 70, Carbon Steel

Property (units)	Value at Temperature (°F)						
	-40	70	200	300	400	500	700
Ultimate strength, S_u (ksi) [a]	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Yield Stress, S_y (ksi) [a]	40.7	38.0	34.8	33.6	32.5	31.0	27.2
Design Stress Intensity, S_m (ksi) [a]	23.3	23.3	23.2	22.4	21.6	20.6	18.1
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	29.8	29.3	28.6	28.1	27.5	27.1	25.3
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	6.13	6.4	6.7	6.9	7.1	7.3	7.6
Thermal Conductivity, k, (Btu/hr-ft-°F) [a]	27.4	27.5	27.6	27.2	26.7	25.9	24.0
Poisson's Ratio [a]	0.31						
Density (lb/in^3) [b]	0.284						

Table 8.3-5 Mechanical Properties of SA537, Class 1, Carbon Steel

Property (units)	Value at Temperature (°F)							
	-40	70	200	300	400	500	700	800
Ultimate strength, S_u (ksi) [a]	70.0	70.0	70.0	69.1	68.4	68.4	68.4	65.4
Yield Stress, S_y (ksi) [a]	54.9	50.0	44.2	40.5	37.6	35.4	32.3	30.5
Design Stress Intensity, S_m (ksi) [a]	23.3	23.3	23.3	22.9	22.9	22.9	21.4	20.3[c]
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	30.0	29.5	28.8	28.3	27.7	27.3	25.5	24.2
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	6.1	6.4	6.7	6.9	7.1	7.3	7.6	7.8
Thermal Conductivity, k, (Btu/hr-ft-°F) [a]	27.4	27.5	27.6	27.2	26.7	25.9	24.0	27.5
Poisson's Ratio [a]	0.31							
Density (lb/in^3) [b]	0.284							

[a] ASME Boiler and Pressure Vessel Code [5]

[b] Metals Handbook Desk Edition [23]

[c] Code Case N-707 [34]. Code Case N-707 requires that the material creep strain is to be negligible. The only primary load for the normal condition of the basket is dead weight. Since only the top 3 feet of the basket are above 700°F, the maximum stress due to dead weight is 36×0.284 or 10 psi. The stress level is considered to be negligible and the dead weight loading at the top of the basket results in a negligible level of creep. Therefore, the requirements of Code Case N-707 are satisfied.

Table 8.3-6 Mechanical Properties of A537, Class 2, Carbon Steel

Property (units)	Value at Temperature (°F)						
	-40	70	200	300	400	500	700
Ultimate strength, S_u (ksi) [a]	80.0	80.0	80.0	78.9	78.2	78.1	78.1
Yield Stress, S_y (ksi) [a]	60.0	60.0	53.0	48.6	45.1	42.4	38.7
Design Stress Intensity, S_m (ksi) [a]	26.7	26.7	26.7	26.7	26.7	26.7	24.3
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	30.0	29.5	28.8	28.3	27.7	27.3	25.5
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	6.1	6.4	5.9	6.3	6.6	6.9	7.4
Thermal Conductivity, k, (Btu/hr-ft-°F) [a]	27.4	27.5	27.6	27.2	26.7	25.9	24.0
Poisson's Ratio [a]	0.31						
Density (lb/in^3) [b]	0.284						

[a] ASME Boiler and Pressure Vessel Code [5]
[b] Metals Handbook Desk Edition [23]

Table 8.3-7 Mechanical Properties of SA695, Type B, Grade 40, and SA696, Type C, Carbon Steel

Property (units)	Value at Temperature (°F)							
	-40	**70**	**200**	**300**	**400**	**500**	**700**	**800**
Ultimate strength, S_u (ksi) [a]	70.0	70.0	70.0	70.0	70.0	70.0	70.0	64.3
Yield Stress, S_y (ksi) [a]	40.0	40.0	36.6	35.4	34.2	32.6	28.6	26.8
Design Stress Intensity, S_m (ksi) [a]	23.3	23.3	23.3	23.3	22.8	21.7	19.2	--
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	29.8	29.3	28.6	28.1	27.5	27.1	25.3	24.0
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	6.13	6.4	6.7	6.9	7.1	7.3	7.6	7.8
Thermal Conductivity, k, (Btu/hr-ft-°F) [a]	27.4	27.5	27.6	27.2	26.7	25.9	24.0	27.5
Poisson's Ratio [a]	0.31							
Density (lb/in³) [b]	0.284							

Table 8.3-8 Mechanical Properties of A588, Type A and B, Carbon Steel, Small Plates

Property (units)	Value at Temperature (°F)								
	-40	100	200	300	400	500	600	650	700
Ultimate strength, S_u (ksi) [a]	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Yield Stress, S_y (ksi) [a]	53.5	50.0	47.5	45.6	43.0	41.8	39.9	38.9	37.9
Design Stress Intensity, S_m (ksi) [a]	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	29.7	29.0	28.5	28.0	27.4	27.0	26.4	25.9	25.3
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	6.13	6.5	6.7	6.9	7.1	7.3	7.4	7.5	7.6
Poisson's Ratio [a]	0.31								
Density (lb/in³) [b]	0.284								

[a] ASME Boiler and Pressure Vessel Code [5]
[b] Metals Handbook Desk Edition [23]

Table 8.3-9 Mechanical Properties of A36 Carbon Steel

Property (units)	Value at Temperature (°F)								
	-40	100	200	300	400	500	600	650	700
Ultimate strength, S_u (ksi) [a]	58.0	58.0	58.0	58.0	58.0	58.0	58.0	58.0	58.0
Yield Stress, S_y (ksi) [a]	36.0	36.0	33.0	31.8	30.8	29.3	27.6	26.7	25.8
Design Stress Intensity, S_m (ksi) [a]	19.3	19.3	19.3	19.3	19.3	19.3	18.4	17.8	17.3
Modulus of Elasticity, E (× 10^6 psi) [a]	29.95	29.3	28.8	28.3	27.7	27.3	26.7	26.1	25.5
Coefficient of Thermal Expansion, α (×10^{-6} in/in/°F) [a]	6.13	6.5	6.7	6.9	7.1	7.3	7.4	7.5	7.6
Poisson's Ratio [a]	0.31								
Density (lb/in^3) [b]	0.284								

Table 8.3-10 Mechanical Properties of SA193, Grade B6, High Alloy Bolting Steel

Property (units)	Value at Temperature (°F)							
	-40	-20	70	200	300	400	500	700
Ultimate strength, S_u (ksi) [c]	110.0	110.0	110.0	104.9	101.4	98.3	95.6	90.6
Yield Stress, S_y (ksi) [c]	85.0	85.0	85.0	81.1	78.4	76.0	73.9	70.0
Design Stress Intensity, S_m (ksi) [a]	28.3	28.3	28.3	27.0	26.1	25.3	24.6	23.3
Bolt Stress Intensity, S_{mbm} (ksi) [a]	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2
Modulus of Elasticity, E (× 10^6 psi) [a]	29.8	29.7	29.2	28.5	27.9	27.3	26.7	25.6
Coefficient of Thermal Expansion, α (×10^{-6} in/in/°F) [a]	5.65 [d]	5.69 [d]	5.90	6.20	6.30	6.40	6.50	6.60
Poisson's Ratio [a]	0.31							
Density (lb/in^3) [b]	0.28							

[a] ASME Boiler and Pressure Vessel Code [5]

[b] Metals Handbook Desk Edition [23]

[c] Calculated based on design stress intensity $\frac{S_{mtemp}}{S_{m70°F}}(S_{u70°F}) = S_{utemp}$

[d] Extrapolated value

Table 8.3-11 Mechanical Properties of SB637, Grade N07718, Nickel Alloy Bolting Steel

Property (units)	Value at Temperature (°F)						
	-40	70	200	300	400	500	700
Ultimate strength, S_u (ksi) [a]	185.0	185.0	177.6	173.5	170.6	168.7	165.8
Yield Stress, S_y (ksi) [a]	150.0	150.0	144.0	140.7	138.3	136.8	134.4
Design Stress Intensity, S_m (ksi) [b]	50.0	50.0	48.0	46.9	46.1	45.6	44.8
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	29.6 [c]	29.0	28.3	27.8	27.6	27.1	26.4
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [c]	7.0	7.1	7.2	7.3	7.5	7.6	7.8
Poisson's Ratio [b]	0.31						
Density (lb/in^3) [a]	0.297						

Table 8.3-12 Mechanical Properties of A615, Grade 60

Property (units)	A615, Grade 60
Ultimate Strength (ksi) [d]	90.0
Yield Strength (ksi) [f]	60.0
Modulus of Elasticity, E ($\times 10^6$ psi) [d]	29.88
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [d]	6.1
Density (lbm/in^3) [e]	0.284

[a] Calculated based on design stress intensity $\frac{S_{m\,temp}}{S_{m\,70°F}}(S_{u\,70°F}) = S_{u\,temp}$

[b] ASME Boiler and Pressure Vessel Code [5]

[c] Interpolated

[d] Metallic Materials Specification Handbook [6]

[e] Standard Handbook for Mechanical Engineers [13]

[f] Annual Book of ASTM Standards [25]

Table 8.3-13 Mechanical Properties of Chemical Copper Grade Lead

Property (units)	Value at Temperature (°F)					
	-40	-20	70	200	300	600
Tensile Yield Stress, S_y (psi) [a]	700 [b]	680	640	490	380	200
Modulus of Elasticity, E (× 10^6 psi) [c]	2.45 [b]	2.42	2.28	2.06	1.94	1.5
Coefficient of Thermal Expansion, α (×10^{-6} in/in/°F) [c]	15.6 [b]	15.7	16.1	16.6	17.2	20.2
Poisson's Ratio [d]	0.4					
Density (lb/in^3) [d]	0.41					

[a] Determination of the Mechanical Properties of High Purity Lead and a 0.05% Copper-Lead Alloy [26]

[b] Extrapolated value

[c] NUREG/CR-0481 [27]

[d] Standard Handbook for Mechanical Engineers [13]

Table 8.3-14 Mechanical Properties of Concrete

Property (units)	Values at Temperature (°F)						
	-40	70	100	200	300	400	500
Compressive strength (psi) [a]	4000[b]	4000	4000	4000	3800	3600	3400
Modulus of Elasticity, E ($\times 10^6$ psi) [a]	4.0[b]	3.72[b]	3.64	3.38	3.09	2.73	2.43
Coefficient of Thermal Expansion, α ($\times 10^{-6}$ in/in/°F) [a]	5.5[b]	5.5	5.5	5.5	5.5	5.5	5.5
Density (lb/ft³) [c]	145						

Table 8.3-15 Mechanical Properties of NS-4-FR

Property (units)	Value at Temperature (°F)			
	86	158	212	302
Coefficient of Thermal Expansion ($\times 10^{-6}$ in/in/°F) [d]	22.2	47.2	58.8	57.4
Compressive Modulus of Elasticity (ksi) [d]	561			
Density (lbm/in³) [d]	0.0607			

Table 8.3-16 Mechanical Properties of Neutron Absorber

Property (units)	Values at Temperature (°F)									
	-320	-112	-18	75	212	300	400	500	600	700
Ultimate Tensile Strength, S_u (ksi) [e]	25.0	15.0	14.0	13.0	10.0	8.0	6.0	4.0	2.9	2.1
Yield Strength, S_y (ksi) [e]	6.0	5.5	5.0	5.0	4.6	4.2	3.5	2.6	2.0	1.6
Elongation in 2 inches, % [f]	50	43	40	40	45	55	65	75	80	85
Mod. of Elasticity, E (10^6 psi) [f]	11.2	10.5	10.3	10.0	9.6	9.2	8.7	8.1	No value given	
Coefficient of Thermal Expansion, α, (10^{-6} in/in/°F) [f]	8.2	10.3	11.2	12.2	13.0	13.3	13.6	13.9	14.2	N/A
Poisson's Ratio [f]	0.33									
Density, (lb/in³) [f]	0.098									
Boral Core Modulus of Elasticity, E (psi)	1000 (assumed)									
Boral Core Yield Strength, S_y (psi)	10 (assumed)									

[a] Handbook of Concrete Engineering [8]
[b] Extrapolated value
[c] Specified value
[d] NS-4-FR Fire Resistant Neutron and/or Gamma Shielding Material [9]
[e] Aluminum alloy 1100-O properties
[f] ASME Boiler and Pressure Vessel Code, Section II, Part D [5]

Table 8.3-17 Thermal Properties of Dry Air

Property (units)	Value at Temperature (°F) [a]					
	-40	70	100	300	500	700
Conductivity (Btu/hr-in-°F)	0.00101	0.00121	0.00128	0.00161	0.00193	0.00223
Specific Heat (Btu/lbm-°F)	0.241	0.2417	0.240	0.244	0.247	0.253
Density (×10^{-5} lb/in^3)	5.1	4.19	4.11	3.01	2.38	1.97

Table 8.3-18 Thermal Properties of Helium

Property (units)	Value at Temperature (°F) [b]			
	80	260	440	800
Conductivity (Btu/hr-in-°F)	0.00751	0.00915	0.01068	0.01355
	Value at Temperature (°F) [c]			
Property (units)	260	400	600	800
Density (×10^{-6} lb/in^3)	4.83	3.70	3.01	2.52
Specific Heat (Btu/lbm-°F)	1.24			

Property (units)	Value at Temperature (°F) [d]											
	240	300	350	400	450	500	600	650	700	750	800	900
Viscosity (×10^{-7} N-s/m^2)	170	199	221	243	263	283	320	332	350	364	382	414

Table 8.3-19 Thermal Properties of Water

Property (units)	Value at Temperature (°F) [e]					
	70	200	300	400	500	600
Conductivity (Btu/hr-in-°F)	0.029	0.033	0.033	0.032	0.029	0.024
Specific Heat (Btu/lbm-°F)	0.998	1.00	1.03	1.08	1.19	1.51
Density (lbm/in^3)	0.036	0.035	0.033	0.031	0.028	0.025

Property (units)	Value at Temperature (°F) [f]											
	273	275	285	295	305	315	325	335	345	355	365	375
Viscosity (×10^6 N-s/m^2)	1750	1652	1225	959	769	631	528	453	389	343	306	274

[a] Principles of Heat Transfer, Kreith & Bohn, Fifth Edition, Table 2 [15]

[b] Handbook of Thermal Conductivity of Liquids and Gases [18]

[c] Principles of Heat Transfer, Kreith, Fifth Edition [17]

[d] Introduction to Heat Transfer [22], Table A.4

[e] Principles of Heat Transfer, Second Edition [21], Table 3

[f] Introduction to Heat Transfer [22], Table A.6

Table 8.3-20 Thermal Properties of NS-4-FR

Property (units)	Value [a]
Conductivity (Btu/hr-in-°F)	0.0311
Density (borated) (lbm/in^3)	0.0589
Density (nonborated) (lbm/in^3)	0.0607
Specific Heat (Btu/lbm-°F)	0.319

Table 8.3-21 Thermal Properties of Concrete

	Value at Temperature (°F)		
Property (units)	100	200	300
Conductivity (Btu/hr-in-°F) [b]	0.091	0.089	0.086
Specific Heat (Btu/lbm-°F) [c]		0.20	
Emissivity [c]		0.90	
Absorptivity [d]		0.60	

[a] NS-4-FR Fire Resistant Neutron and/or Gamma Shielding Material [9]

[b] Handbook of Concrete Engineering [8], Figure 6-31, Curve 1

[c] Principles of Heat Transfer, Kreith and Bohn, Fifth Edition [15]

[d] Introduction to Heat Transfer [22]

Table 8.3-22 Neutron Absorber Material Minimum Effective Thermal Conductivity - BTU/(hr-in-°F)

Fuel Basket Type	Radial		Axial	
	100°F	500°F	100°F	500°F
PWR	4.565	4.191	4.870	4.754
BWR	4.687	4.335	5.054	5.017

Table 8.3-23 Thermal Properties of Carbon Steel

Property (units)	Value at Temperature (°F)						
	-40	100	200	400	500	700	800
Conductivity (Btu/hr-in-°F) [a]	2.28	2.30	2.30	2.22	2.16	2.0	1.92
Specific Heat (Btu/lbm-°F) [b]	0.113						
Emissivity [c]	0.80						
Density (lb/in^3) [d]	0.284						

Table 8.3-24 Thermal Properties of Chemical Copper Grade Lead

Property (units)	Value at Temperature (°F)					
	-40	70	200	400	600	800
Conductivity (Btu/hr-in-°F) [e]	1.767	1.707	1.636	1.526	1.131	0.309
Specific Heat (Btu/lbm-°F) [e]	0.03 (68°F)					
Emissivity [c]	0.28 (75°F)					
Density (lb/in^3) [e]	0.411 (68°F)					

Table 8.3-25 Thermal Properties of SA240, Type 304/304L, Stainless Steel

Property (units)	Value at Temperature (°F)							
	-40	100	200	400	550	750	800	900
Conductivity (Btu/hr-in-°F) [a]	0.686	0.725	0.775	0.867	0.925	1.0	1.017	1.058
Specific Heat (Btu/lbm-°F) [f]	0.109	0.116	0.12	0.127	0.131	0.136	0.136	0.138
Emissivity [g, h]	0.36 (300°F)							
Density (lb/in^3) [h]	0.29	0.29	0.289	0.287	0.286	0.284	0.283	0.283

Note: The SA240 stainless steel is dual certified as Type 304 and 304L.

[a] ASME Boiler and Pressure Vessel Code, Table TCD [5]

[b] Principles of Heat Transfer, Kreith, Fifth Edition [15]

[c] Standard Handbook for Mechanical Engineers [13]

[d] Metallic Materials Specification Handbook [6]

[e] TRUMP, A Computer Program for Transient and Steady State Temperature Distributions in Multidimensional Systems [16]

[f] Nuclear Systems Materials Handbook [14]

[g] Metallic Materials and Elements for Aerospace Vehicle Structures [7]

[h] Metals Handbook Desk Edition [23]

Table 8.3-26 Thermal Properties of Zirconium-based Alloy Cladding

Property (units)	Value at Temperature (°F)				
	-40[a]	392	572	752	932
Conductivity (Btu/hr-in-°F) [b]	0.594	0.690	0.730	0.800	0.870
Specific Heat (Btu/lbm-°F) [b]	0.067	0.072	0.074	0.076	0.079
Emissivity [b]	0.75 (302°F)				
Density (lb/in^3) [c]	0.237				

Table 8.3-27 Thermal Properties of Fuel (UO_2)

Property (units)	Value at Temperature (°F)					
	-40[a]	100	257	482	707	932
Conductivity (Btu/hr-in-°F) [b]	0.409	0.380	0.347	0.277	0.236	0.212
Specific Heat (Btu/lbm-°F) [b]	0.053	0.057	0.062	0.067	0.071	0.073
Emissivity [b]	0.85 (1,340°F)					
Density (lbm/in^3) [c]	0.396					

Table 8.3-28 Thermal Properties of Nickel-Plated Steel

Property	Value
Emissivity [d]	0.2 – 0.32

[a] Extrapolated value

[b] Matpro-Version 11 A Handbook of Material Properties for Use in the Analysis of Light Water Reactor Rod Behavior [19]

[c] Nuclear Power Plant Engineering [20]

[d] Material Emissivity Properties: Electroless Nickel and Mild Steel [24]

8.4 Weld Design and Specification

The welding operations of the MAGNASTOR components are performed in accordance with the requirements of a number of codes and standards depending on the design and functional requirements of the specific component. The specific requirements met by each component are provided herein.

The TSC and fuel basket assemblies are welded using welding procedures, processes, and welders prepared and qualified in accordance with the ASME Code, Section IX [29] requirements. The specific weld designs and examination requirements for the TSC and fuel basket comply with the applicable subsection of the ASME Code, Section III, which are Subsection NB for the TSC and Subsection NG for the fuel baskets. Alternatives to the Code requirements applicable to these system components are listed in Table 2.1-2. Weld filler materials and processes used in the fabrication of the TSC are in accordance with ASME Code Section II-C requirements for SFA 5.9 and SFA 5.22. For SFA 5.9 and SFA 5.22, respectively, AWS ER 308L and AWS E308LTX-X will be specifically identified in the approved welding procedures.

The steel components of the concrete casks (i.e., liner, baseplate, etc.) and the transfer cask are welded using procedures, processes, and welders prepared, qualified, and certified in accordance with either ASME Section IX or ANSI/AWS D1.1 [28]. The weld design and specification requirements for the steel components of the concrete cask are in accordance with the weld design criteria of the ASME Code, Section VIII, Division 1, Part UW [31] or ANSI/ANS D1.1. The weld design and specification requirements for the transfer cask are in accordance with the weld design criteria of the ASME Code, Section III, Subsection NF [32].

The inspection and examination requirements for all MAGNASTOR component welds, inspector qualification requirements, and the applicable acceptance criteria are specified in Chapter 10 of this SAR.

8.5 Bolts and Fasteners

This section presents information to demonstrate that bolt and fastener materials have been selected for material compatibility to preclude galling during use, and to have the requisite material strength for the application.

The PWR and BWR fuel baskets are assembled using SA-193 Gr B6 stainless steel bolts. The bolts are used initially to assemble the basket by securing the outer fuel tubes to the arrangement of gussets, bars, support plates, and weldments. The applied preload of the bolts provides rigidity to the basket for its installation into the TSC. During certain accident events, the bolts may be subjected to increased tensile loading. The evaluation of these accident conditions is provided in Chapter 3. As shown in that chapter, the bolts have a large margin of safety for the postulated loading conditions.

Stress corrosion cracking does not occur in the bolting materials, as bolts used in assembling the basket are in an inert environment with no significant potential for corrosion to occur. Lifting bolts are not permanently installed. Consequently, cracking that could be induced from the combined influence of tensile stress and a corrosive environment does not occur.

Weld posts are used to attach the neutron absorber plate and retainer to the inside of the fuel tube and are fabricated from SA-479, Type 304 stainless steel. Following installation of the weld post, the backside of the weld post is heated and melted to form a flared head. The Type 304 stainless steel retainer protects the neutron absorber during fuel loading. The weld posts provide structural support to the neutron absorber and retainer to prevent significant movement of the neutron absorber. As shown in this SAR, the weld posts have adequate strength to hold the neutron absorber in place during evaluated normal operating conditions, off-normal events and postulated accident events.

The assembled TSC design does not include bolted or fastened connectors. For vertical lifting and handling of the loaded TSC, hoist rings or other suitable lift fixtures are bolted into the six threaded lift points in the TSC closure lid. The lift attachment points are evaluated in Chapter 3.

The concrete cask, holding a loaded TSC, can be lifted vertically using bolted lugs to move the cask on the ISFSI or to or from a handling site for either installing or removing a loaded TSC. The concrete cask incorporates two lifting load paths, one each on opposite sides of the cask. The load paths are formed by lift anchors embedded in the standard cask or bolted in cavities of the segmented cask. For lifting the segmented cask, eight SB-637 Grade N07718 high-strength lift lug bolts are used for attachment of each lift lug. In the lift configuration, the high-strength bolts connect top and bottom concrete cask sections. The analysis of the attachments, load path and bolts is provided in Chapter 3. As shown in that chapter, based on the material specified, the bolts have adequate margin for the application.

When lifting operations are complete, the lift lugs and bolts are removed and commercial-grade stainless steel bolts are installed to connect the two cask sections. These commercial-grade bolts are used to replace the lift lug bolts, since there are no normal operations or off-normal events, and no credible accident events that apply significant forces to the cask top section.

The cask lid is retained by six commercial-grade stainless steel bolts. Commercial grade bolts are sufficient since only negligible forces are applied to the lid connections during normal operations or off-normal and credible accident events.

The concrete cask includes inlet and outlet screens, a lid, and may have temperature monitors at the outlets. There are no evaluated events that are expected to dislodge these components.

The transfer cask design incorporates a set of three retaining blocks and pins to prevent the inadvertent raising of the loaded TSC through the top of the transfer cask during handling. The retaining blocks and pins are designed to support the weight of the transfer cask if the TSC engages them during lifting. As designed, the retaining block would be loaded in shear if engaged. The retaining blocks are fabricated from ASTM A693/A564 17-4 PH stainless steel. The structural evaluation of the retaining blocks in Chapter 3 demonstrates that the retaining blocks have a significant margin of safety under the evaluated loading conditions.

Lifting of the transfer cask and concrete cask is controlled by procedure and Technical Specifications that restrict lifting operations to times where the ambient temperature is above 0°F. This restriction precludes the potential for brittle fracture of carbon steel bolting or structural components.

8.6 Coatings

The exposed surfaces of carbon steel and concrete components of MAGNASTOR are coated with specially designed and applied coating systems. The coatings are provided to reduce corrosion of exposed carbon steel surfaces, to minimize adverse reactions between dissimilar materials, and to minimize adverse interactions of components with their operating environment during in-pool loading, dry transfer and storage. The details on the various types of coating systems utilized on MAGNASTOR components are discussed in the following sections.

8.6.1 Electroless Nickel

The PWR and BWR fuel baskets are fabricated primarily of carbon steel. The potential for corrosion exists from fabrication through spent fuel loading up to final closure operations. After final closure welding, drying and inert gas backfill of the TSC cavity, the potential for corrosion of the carbon steel baskets is effectively eliminated.

The most critical period, both from a material corrosion aspect and an operational aspect, is the time period when the TSC is submerged in the fuel pool during the fuel loading cycle. Specifically, at PWR sites, the fuel pool water may contain boric acid in solution in the range of 2,500 ppm. To minimize the level of corrosion during fuel loading, the carbon steel components of the fuel baskets will be electroless nickel-coated. The electroless nickel coating provides the appropriate protection to restrict material reduction due to corrosion and minimize the loss of water clarity that can affect the fuel loading process. The electroless nickel coating is also effective in eliminating the potential for production of explosive levels of hydrogen due to cathodic reaction of basket components with spent fuel pool water. The cavity gas volume will be sampled for explosive levels of hydrogen before and during closure lid root pass welding and closure lid weld removal operations.

During the fuel basket assembly process, coating damage can occur. Localized scratches, etc., can result in coating damage, but are considered insufficient to cause concerns relative to the functional and structural performance of the basket. Additionally, due to the configuration of the fuel basket, some areas of the fuel basket may not be completely coated. These areas are also considered minor and insufficient to affect either the functional or operational aspects of the fuel basket.

The electroless nickel coating process applied to the basket components will use ASTM B733 [30] for guidance. The coating thickness will be in the range of coating classifications SC1 to SC3, allowing thickness from 0.0002 inch to 0.001 inch. Alloy Type V, 10% minimum weight percent phosphorus, will be specified with no post-heat treatment invoked. Testing will be performed on batch specimens and acceptance will be based on appearance and adhesion. Specimens will be representative of the material and condition of the pieces to be coated.

8.6.2 Other Coating Systems

The exposed carbon steel surfaces of the transfer cask, other than wear surfaces, i.e., shield door and rail mating surfaces, are coated with either Carboline 890 or Keeler & Long E-Series epoxy enamel. Both coating systems are tested and approved for use in Nuclear Service Level 2 conditions, which include immersion in spent fuel pools. Uncoated exposed wear surfaces are protected from corrosion and adverse interactions with spent fuel pool water by the application of approved nuclear grade lubricants during use and storage of the transfer cask. Proper lubrication is confirmed or augmented prior to each TSC loading sequence. The enamel coating system and lubricated wear surfaces ensure that interactions with the spent fuel pool water will not generate excessive hydrogen gas, corrosion of the carbon steel, or loss of the coating materials in the spent fuel pool. Nitronic 30 wear strips are incorporated on the transfer cask inner surface and the top of the shield doors to provide protection of the coating system from excessive wear caused by TSC handling operations.

The exposed carbon steel surfaces of the transfer adapter, other than the shield door rail surfaces, are coated with an approved two-coat painting system designed to minimize corrosion under long-term exposure in air. The transfer adapter is only used for the dry loading and transfer of a TSC into a concrete cask, or retrieval. Therefore, a special nuclear-grade coating system is not required. Wear surfaces are lubricated with a nuclear-grade lubricant. There are no potential adverse interactions of the transfer adapter surfaces with the operating environment.

The carbon steel components of the concrete cask that are not covered by installed concrete are coated with a Keeler & Long heat-resistant silicone enamel coating system. The coating system is designed to provide protection against corrosion when exposed to an external environment, while being capable of withstanding long-term exposure to the elevated temperatures of the concrete cask components during the storage operations.

The exposed concrete surfaces of the concrete cask are coated with a commercial-grade sealant to provide protection to the cask surfaces during curing and long-term storage operations.

As with the nickel plating, no positive characteristics of the coating systems are considered in the applicable analyses and, therefore, minor scratches and wear of the coatings is not a concern. The coating systems of the accessible exposed carbon steel surfaces of MAGNASTOR components are inspected annually. Required repairs to coating systems are completed as part of the maintenance program in accordance with the manufacturer's recommendations.

8.7 Gamma and Neutron Shielding Materials

MAGNASTOR uses lead, concrete, steel, and NS-4-FR as the principal shielding materials.

8.7.1 Gamma Shielding Material

Lead and steel are the primary gamma radiation shielding materials in the transfer cask. The lead gamma shield is constructed of solid Chemical Copper grade lead bricks. The lead conforms to ASTM Specification B29 (Section 8.13.6) [33]. The specification provides essentially elemental lead, with some trace elements such as copper, which improve the machining characteristics of the material. The bricks are designed to "nest" such that both horizontal gaps (between adjacent bricks) and vertical gaps (between stacked bricks) are precluded. The lead bricks are installed around the inner carbon steel shield, and enclosed by the upper and lower forgings and the outer steel shell. The gap between the lead bricks and the outer shell is filled with neutron shield material. During fabrication assembly, visual inspection is used to verify uniform brick installation for the lead shielding. The transfer cask gamma shielding details are shown in the licensing drawings.

The carbon steel liner provides the primary gamma radiation shielding for the concrete cask. The installed concrete and rebar of the cask also provide measurable gamma radiation shielding capabilities. The steel shell of the TSC is also accounted for in the shielding analysis of the transfer cask and concrete cask.

8.7.2 Neutron Shielding Material

Concrete provides neutron radiation shielding for the concrete cask based on the silicon and water content of the concrete. Silicon, hydrogen and oxygen are low atomic number materials that are effective in thermalizing and capturing energetic neutrons. Since the density of these materials is a relatively fixed function of the concrete mix, the thickness of the concrete shell is designed to establish the required neutron shielding. The concrete is poured and cured in place around reinforcing bar that provides structural rigidity.

The transfer cask incorporates NS-4-FR neutron shielding material containing $\geq$ 0.6 weight percent boron. NS-4-FR is a proprietary commercial product of NAC International that consists primarily of aluminum, carbon, oxygen, and hydrogen.

The low-density NS-4-FR components interact and thermalize the neutrons emitted from the TSC. The boron is effective in absorbing the resultant thermal neutrons. The material is installed in the transfer cask by pouring it into the annulus formed by the outer shell and the lead gamma shield of the transfer cask. The arrangement of the NS-4-FR is shown in the license drawings. Installation of the material is by a proprietary pouring process that ensures the absence of gaps and voids in the installed material. Consequently, no shop testing of the transfer cask for neutron shielding is required or performed.

The acceptable performance of NS-4-FR has been demonstrated by more than 15 years of use in licensed storage casks in the United States, Japan, Spain, and the United Kingdom. There are no reports that the shielding effectiveness of the materials has degraded in these applications, thereby demonstrating the long-term reliability for the purpose of shielding neutrons from personnel and the environment. There are no potential reactions associated with the polymer structure of the NS-4-FR materials and the stainless steel, carbon steel or lead that are contacted during use.

The thermal performance of NS-4-FR has been demonstrated by long-term functional stability tests of the material at temperatures from -40°F to 338°F. These tests included specimens open to the atmosphere and enclosed in a cavity at both constant and cyclic thermal loads. The tests evaluated material loss though off-gassing and material degradation. The results of the tests demonstrate that, in the temperature range of interest, the NS-4-FR does not exhibit loss of material by off-gassing, does not generate any significant gases, and does not suffer degradation or embrittlement. Consequently, the formation of flammable gases is not a concern. Further, the tests demonstrated that encased material, as it is used in MAGNASTOR, performed significantly better than exposed material.

Radiation exposure testing of NS-4-FR in reactor pool water has demonstrated no physical deterioration of the material and no significant loss of hydrogen (less than 1%). The tests also demonstrated that the NS-4-FR retains its neutron shield capability over the cask's 50-year design life with substantial margin. The radiation testing has shown that detrimental embrittlement and loss of hydrogen from the material do not occur at dose rates (9×10^{14} n/cm^2) that exceed those that would occur assuming the continuous storage of design basis fuel for a 50-year life (estimated to be 1.7×10^{12} cm^2/yr). Consequently, detrimental deterioration or embrittlement due to radiation flux does not occur.

Since the NS-4-FR in the transfer cask is sandwiched between the outer shell and the lead, and enclosed within a welded steel shell where the shell seams are welded to top and bottom plates with full-penetration or fillet welds, it will maintain its form over the expected lifetime of the transfer cask. Additionally, the material's placement between the lead shield and the outer shell does not allow the material to redistribute within the annulus.

8.8 Neutron Absorber Material

Neutron absorber materials containing the element boron, specifically the isotope ^{10}B, are widely used in the nuclear industry because of their high cross-section for absorbing thermal neutrons, commonly to ensure subcriticality inside spent nuclear fuel storage and/or transport casks during normal handling and off-normal/accident service conditions. Criticality safety is dependent upon the neutron absorber material remaining fixed in position on the fuel tubes and containing the required amount of boron uniformly distributed throughout the sheet. A neutron absorber (criticality control) material can be a composite of fine particles in a metal matrix or an alloy of boron compounds with aluminum. Fine particles of boron-carbide that are uniformly distributed are required to obtain the best neutron absorption. The specified areal density of ^{10}B in a neutron absorber is determined based on fuel assembly type and reactivity. Three types of neutron absorber materials are commonly used in spent fuel storage and transport cask fuel baskets – borated aluminum alloy, borated metal matrix composites (MMC), and Boral (registered trademark of AAR Advanced Structures).

Applicable terminology definitions for the neutron absorber materials:

acceptance –	tests conducted to determine whether a specific production lot meets selected specified material properties and characteristics, or both, so that the lot can be accepted for commercial use.
areal density –	for sheets with flat parallel surfaces, the density of the neutron absorber times the thickness of the material.
designer –	the organization responsible for the design or the license holder for the dry cask storage system or transport packaging. The designer is usually the purchaser of the neutron absorber material, either directly or indirectly (through a fabrication subcontractor).
lot –	a quantity of a product or material accumulated under conditions that are considered uniform for sampling purposes.
neutron absorber –	a nuclide that has a large thermal or epithermal neutron absorption cross section, or both.
neutron absorber material –	a compound, alloy, composite or other material that contains a neutron absorber.

neutron transmission test –	a process in which a material is placed in a thermal neutron beam, and the number of neutrons transmitted through the material in a specified period of time is counted. The observed neutron counting rate may be converted to areal density by performing the same test on a series of calibration standards. The maximum beam area for the transmission test is 1 in^2 (6.45 cm^2).
neutron cross section –	a measure of the probability that a neutron will interact with a nucleus; a function of the neutron energy and the structure of the interacting nucleus.
packaging –	in transport of radioactive material, the assembly of components necessary to enclose the radioactive contents completely.
qualification –	the process of evaluating, testing, or both, a material produced by a specific manufacturing process to demonstrate uniformity and durability for a specific application.

The MAGNASTOR storage system utilizes sheets of neutron absorber material that are attached to the sides of the spent fuel storage locations in the fuel baskets. The materials and dimensions of the neutron absorber sheets are defined on NAC drawing numbers 71160-571 and 71160-572. The material in the Bill of Materials is identified as a metallic composite (includes borated aluminum alloy, borated metal matrix composites (MMC), and Boral), which is available under various commercial trade names. Incorporating alternative neutron absorber materials in the design provides fabrication flexibility for the use of the most economical and available neutron absorber material that meets the characteristics necessary to assure criticality safety. The critical design characteristics of the neutron absorber material are:

- A minimum "effective" areal density of 0.036 g/cm^2 ^{10}B for the PWR basket and 0.027 g/cm^2 ^{10}B for the BWR basket; and
- A uniform distribution of boron carbide; and
- A strength at least equivalent to that of 1100 series aluminum at 700°F, which is sufficient to maintain its form; and
- An effective thermal conductivity greater than, or equal to, that used in the thermal analyses (Chapter 4).

The required minimum as-fabricated ^{10}B loading in a neutron absorber sheet is determined based on the effectiveness of the material, i.e., 75% for Boral and 90% for borated aluminum alloys and for borated metal matrix composites. Neutron transmission testing, as described in Section 10.1.6, will be used to verify the ^{10}B areal density for the neutron absorber materials. Table 8.8-1 presents a tabulation of the types of neutron absorber materials, the required minimum effective areal density of ^{10}B, and the required minimum as-fabricated areal density of ^{10}B. Since an oxide layer forms on the surfaces of the metallic composite neutron absorber material shortly after fabrication, interaction with the stainless steel as well as the electroless nickel coating is inhibited and the material is protected against degradation. Consequently, no potential reactions associated with the aluminum-based criticality control materials are expected. The positions and attachments of the neutron absorber sheets and the retainers to the fuel tubes are shown on drawings NAC drawing numbers 71160-551 and 71160-591.

Standard industrial inspections will be performed on the neutron absorber products to verify the acceptability of physical characteristics such as dimensions, flatness, straightness, thermal conductivity, tensile properties (if structural considerations are applicable), other mechanical properties as appropriate, surface quality and finish in accordance with the design drawings and fabrication specifications. Specific acceptance criteria and the associated industry standard/code are described in Section 10.1.6.

Qualification of the neutron absorber material will be specified to demonstrate that the material will perform its design functions under the defined environmental conditions during the licensed period. Material qualification and validation specifications are defined in Section 10.1.6 for a range of environmental conditions, including short-term transfer operations, normal conditions, and off-normal and accident events.

Acceptance testing of the neutron absorber material, as described in Section 10.1.6, will be performed to validate that the production materials comply with the specified requirements, including absorber content and uniformity of distribution, mechanical properties, thermal conductivity, surface finish and dimensions.

All qualification and acceptance validation will be conducted in accordance with the NAC International quality assurance program.

Table 8.8-1 Neutron Absorber Material Minimum ^{10}B Loading

Neutron Absorber Type	Required Minimum Effective Areal Density (^{10}B g/cm^2)		% Credit Used in Criticality Analyses	Required Minimum As-Fabricated Areal Density (^{10}B g/cm^2)	
	PWR Fuel	BWR Fuel		PWR Fuel	BWR Fuel
Borated Aluminum Alloy	0.036	0.027	90	0.04	0.03
Borated MMC	0.036	0.027	90	0.04	0.03
Boral	0.036	0.027	75	0.048	0.036

8.9 Concrete and Reinforcing Steel

The concrete cask is fabricated of 28-day, 4000 psi, Type II Portland cement that is reinforced with vertical and circumferential carbon steel reinforcing bar. The cask is fabricated in accordance with American Concrete Institute, "Building Code Requirements for Structural Concrete," (ACI 318) [2].

Quality control of the proportioning, mixing, and placing of the concrete, in accordance with the NAC fabrication/construction specification, will make the concrete highly resistant to water. The concrete shell is not expected to experience corrosion or significant degradation from the storage environment through the life of the cask. The design and analysis considers the maximum temperatures that the concrete could reach to avoid any significant loss of concrete hydration.

The reinforcing bar used is ASTM A615/A615M, Grade 60 material of various diameters and lengths, depending on its position in the cask. The reinforcing bar is completely within the concrete matrix so that degradation of the bar during the storage life is unlikely. The reinforcing bar is installed in accordance with the requirements of ACI 318.

8.10 Chemical and Galvanic Reactions

The materials used in the fabrication and operation of MAGNASTOR are evaluated to determine whether chemical, galvanic or other reactions among the materials, contents, and environments can occur. All phases of operation — loading, unloading, handling, and storage — are considered for the environments that may be encountered under normal conditions and off-normal or accident events. Based on the evaluation, no potential reactions that could adversely affect the overall integrity of the concrete cask, the fuel basket, the TSC, or the structural integrity and retrievability of the fuel from the TSC have been identified. The evaluation conforms to the guidelines of ISG-15 [10].

No potential chemical, galvanic, or other reactions have been identified for MAGNASTOR. Therefore, the overall integrity of the TSC and the structural integrity and retrievability of the spent fuel are not adversely affected for any operations throughout the design basis life of the TSC. Based on the evaluation, no change in the TSC or fuel cladding thermal properties is expected, and no corrosion of mechanical surfaces is anticipated. No change in basket clearances or degradation of any safety components, either directly or indirectly, is likely to occur since no potential reactions have been identified.

8.10.1 Component Operating Environment

Most of the component materials of MAGNASTOR are exposed to two typical operating environments: 1) an open TSC containing fuel pool water or borated water with a pH of 4.5 and spent fuel or other radioactive material; or 2) a sealed TSC containing helium, but with external environments that include air, rain water/snow/ice and marine (salty) water/air. Each category of TSC component materials is evaluated for potential reactions in each of the operating environments to which those materials are exposed. These environments may occur during fuel loading or unloading, handling or storage, and include normal conditions or off-normal and accident events.

The long-term environment to which the TSC's internal components are exposed is dry helium. Both moisture and oxygen are removed prior to sealing the TSC. The helium displaces the oxygen in the TSC, effectively precluding chemical corrosion. The dry environment inside the sealed TSC also inhibits galvanic corrosion between dissimilar metals in electrical contact.

In addition to the spent fuel, the fuel assemblies in the basket may hold control element assemblies, thimble plugs or other nonfuel components that are nonreactive with the fuel assembly. By design, the control components and nonfuel components are inserted in the guide tubes of a fuel assembly. During reactor operation, the control and nonfuel components are immersed in acidic water having a high flow rate and are exposed to significantly higher neutron flux, radiation and pressure than will exist in dry storage. The control and nonfuel components are physically placed in storage in a dry, inert atmosphere in the same configuration as when used in the reactor. Therefore, there are no adverse reactions, such as gas generation, galvanic or chemical reactions or corrosion, since these components are nonreactive with the zirconium-alloy guide tubes and fuel rods. There are no aluminum or carbon steel fuel assembly parts, and no gas generation or corrosion occurs during prolonged water immersion (20 – 40 years). Thus, no adverse reactions occur with the control and nonfuel components over prolonged periods of dry storage.

8.10.2 Component Material Categories

The component materials are categorized in this section for their chemical and galvanic corrosion potential on the basis of similarity of physical and chemical properties and component functions. The categories are stainless steels, nonferrous metals, carbon steel, coatings, concrete, and criticality control materials. The evaluation is based on the environment to which these categories could be exposed during operation or use.

The TSC component materials are not reactive among themselves with the TSC's contents, or with the TSC's operating environments during any phase of normal conditions, off-normal or accident events, loading, unloading, handling or storage operations. Since no reactions will occur, no gases or other corrosion by-products will be generated.

The control component and nonfuel component materials are those that are typically used in the fabrication of fuel assemblies, i.e., stainless steels, Inconel 625, and zirconium-based alloy, so no adverse reactions occur in the inert atmosphere that exists in storage. The control element assembly, thimble plugs and nonfuel components—including start-up sources or instrument segments to be inserted into a fuel assembly—are nonreactive among themselves with the fuel assembly or with the TSC's operating environment for any storage condition.

8.10.2.1 Stainless Steels

No reaction of the TSC component stainless steels is expected in any environment, except for the marine environment where chloride-containing salt spray could potentially initiate pitting of the steels if the chlorides are allowed to concentrate and stay wet for extended periods of time (weeks). Only the external TSC surface could be so exposed. The corrosion rate will, however, be so low that no detectable corrosion products or gases will be generated. MAGNASTOR has smooth external surfaces to minimize the collection of such materials as salts.

The TSC confinement boundary uses Type 304/304L dual-certified stainless steel for all components except the closure lid. No coatings are applied to the stainless steels. Type 304/304L stainless steel resists chromium-carbide precipitation at the grain boundaries during welding and assures that degradation from intergranular stress corrosion will not be a concern over the life of the TSC. Fabrication specifications control the maximum interpass temperature for austenitic steel welds to less than 350°F. The material will not be heated to a temperature above 800°F, other than by welding or thermal cutting. Minor sensitization of Type 304/304L stainless steel that may occur during welding will not affect the material performance over the design life.

8.10.2.2 Carbon Steel

Carbon steel is used to fabricate all of the structural components of the PWR and BWR baskets. There is a small electrochemical potential difference between carbon steel and the stainless steel of the TSC shell and the stainless steel sheet used to protect the neutron absorber in the fuel tubes. However, the carbon steel basket components are coated with electroless nickel using an immersion process. The immersion process ensures that the carbon steel is appropriately coated, reducing the possibility of corrosion due to exposure to air or pool water. When in contact with stainless steel in water, the carbon steel exhibits a limited electrochemically driven corrosion. Typically, BWR pool water is demineralized, and is not sufficiently conductive to promote detectable corrosion for these metal couples. Once the TSC is loaded, the water is drained from the cavity, the air is removed, and the TSC is backfilled with helium and sealed. Removal of the water and the moisture eliminates the catalyst for galvanic corrosion between the carbon and stainless steels. In addition, the displacement of oxygen by helium effectively inhibits oxidation.

The transfer cask structural components are fabricated primarily from ASTM A588 and A36 carbon steel. The exposed carbon steel components are coated with either Keeler & Long E-Series Epoxy Enamel or Carboline 890 to protect the components during in-pool use and to provide a smooth surface to facilitate decontamination.

The concrete shell of the concrete cask contains an ASTM A36 carbon steel liner, as well as other carbon steel components. The exposed surfaces of the carbon steel liner and air inlets and outlets are coated with Keeler & Long Silicone Enamel to provide protection from weather-related moisture. The silicone enamel coating is formulated for use in continuous high-temperature environments.

No potential reactions associated with basket supports and fuel tubes, the transfer cask components or concrete cask components are expected to occur.

8.10.2.3 Nonferrous Metals

Aluminum is used in the neutron absorber material. The aluminum material in electrical contact with the stainless steel cover and carbon steel fuel tube could experience corrosion driven by an electrochemically induced electromotive force when immersed in water, where the conductivity of the water is the dominant factor. Typically, BWR fuel pool water is demineralized and is not sufficiently conductive to promote detectable corrosion for these metal couples. PWR pool water, however, does provide a conductive medium.

Shortly after fabrication, aluminum produces a thin surface film of oxidation that effectively inhibits further oxidation of the surface. This oxide layer adheres tightly to the base metal and does not react readily with the materials or environments to which the fuel basket will be exposed. The volume of the aluminum oxide does not increase significantly over time. Thus, binding due to corrosion product build-up during future removal of spent fuel assemblies is not a concern. The borated water in a PWR fuel pool is an oxidizing-type acid with a pH on the order of 4.5. However, aluminum is generally passive in pH ranges down to about 4 [11]. Data provided by the Aluminum Association [12] shows that aluminum alloys are resistant to aqueous solutions (1-15%) of boric acid (at 140°F). Based on these considerations and the very short exposure of the aluminum in the fuel basket to the borated water, oxidation of the aluminum is not likely to occur beyond the formation of a thin surface film. No observable degradation of aluminum is expected as a result of exposure to BWR or PWR pool water at temperatures up to 200°F, which is higher than the normal condition permissible fuel pool water temperature.

Aluminum is high on the electromotive potential table, and it becomes anodic when in electrical contact with stainless or carbon steel in the presence of water. BWR pool water is demineralized and is not sufficiently conductive to promote detectable corrosion for these metal couples. PWR pool water is sufficiently conductive to allow galvanic activity to begin. However, exposure time of the aluminum to the PWR pool environment is short. The long-term storage environment is sufficiently dry to inhibit galvanic corrosion.

From the foregoing discussion, it is concluded that the initial surface oxidation of the aluminum component surfaces and the conditions of long-term storage effectively inhibit any potential galvanic reactions.

Vendor and Nuclear Regulatory Commission evaluations have concluded that combustible gases, primarily hydrogen, may be produced by a chemical reaction and/or radiolysis when aluminum components are immersed in spent fuel pool water. The evaluations further concluded that it is possible, at higher temperatures (above 150 - 160°F), for the aluminum/water reaction to produce a hydrogen concentration in the TSC that approaches or exceeds the Lower Flammability Limit (LFL) for hydrogen of four percent.

Thus, it is reasonable to conclude that small amounts of combustible gases, primarily hydrogen, may be produced during TSC loading or unloading operations as a result of a chemical reaction between the aluminum neutron absorber in the fuel basket and the spent fuel pool water. The generation of combustible gases stops when the water is removed from the TSC and the aluminum surfaces are dry.

8.10.3 Evaluation of the Operating Procedures

This section evaluates the operating procedures to identify the potential for galvanic reactions, corrosion or flammable gas formation to occur during planned operations. As described in this section, no potential chemical, galvanic, or other reactions have been identified for MAGNASTOR. The use of a dry inert helium atmosphere in storage inhibits galvanic and corrosion events and flammable gas formation. Monitoring for levels of hydrogen approaching the Lower Flammability Limit (LFL) is performed during TSC closure lid root pass welding, and during closure lid weld removal operations in preparation for TSC unloading. If hydrogen levels exceed 60% of LFL (i.e., 2.4%H_2), these operations are stopped and corrective actions are taken until the H_2 levels are reduced to acceptable levels. Therefore, no adverse conditions, such as the ignition of flammable or explosive quantities of combustible gases, can result during any phase of TSC operations.

8.10.3.1 Evaluation of Loading Operations

After the TSC is removed from the pool and during TSC closure operations, the cavity water level is lowered (approximately 70 gallons are removed) to ensure that the closure lid-to-TSC shell weld area is dry during welding. The lowering of the cavity water level will not expose fuel rod cladding to an air environment. As there is limited clearance between the inside diameter of the TSC shell and the outside diameter of the closure lid, it is possible that gases released from a chemical reaction inside the TSC could accumulate beneath the lid.

The aluminum surfaces of the neutron absorber panels oxidize when exposed to air, react chemically in an aqueous solution, and may react galvanically when in contact with stainless steel or carbon steel. The reaction of aluminum in water, which results in hydrogen generation, proceeds as follows.

$$2\ Al + 3\ H_20 \Rightarrow Al_2O_3 + 3\ H_2$$

The aluminum oxide (Al_2O_3) produces the dull, light gray film that is present on the surface of bare aluminum when it reacts with the oxygen in air or water. The formation of the thin oxide film is a self-limiting reaction as the film isolates the aluminum metal from the oxygen source, acting as a barrier to further oxidation. The oxide film is stable in pH neutral (passive) solutions, but is soluble in borated PWR spent fuel pool water. The oxide film dissolves at a rate dependent upon the pH of the water, the exposure time of the aluminum in the water, and the temperatures of the aluminum and water.

PWR spent fuel pool water is a boric acid and demineralized water solution. BWR spent fuel pool water does not contain boron and typically has a neutral pH (approximately 7.0). The pH, water chemistry and water temperature vary from pool to pool. Since the reaction rate is largely dependent upon these variables, it may vary considerably from pool to pool. Thus, the generation rate of combustible gas (hydrogen) that could be considered representative of spent fuel pools in general is very difficult to accurately calculate, but the reaction rate would be less in the neutral pH BWR pool.

The MAGNASTOR basket configurations incorporate carbon steel fuel tubes and support components that are coated with electroless nickel. The coating protects the carbon steel during the comparatively short time that the TSC is immersed in, or contains, water. The coating is nonreactive with the pool water and does not off-gas or generate gases as a result of contact with the pool water. Consequently, there are no flammable gases generated by the coating and no flammable gases generated by the materials of the coated components.

To ensure safe loading of the TSC, the loading procedure described in Chapter 9 provides for the monitoring of hydrogen gas before and during the root pass welding operations that join the closure lid to the TSC shell. The monitoring system is capable of detecting hydrogen at 60% of the Lower Flammability Limit (LFL) for hydrogen (i.e., 2.4% H_2). The hydrogen detector is connected to the cavity volume so as to detect hydrogen prior to initiation of welding. The hydrogen concentration is monitored during the root pass welding operation. The welding operation is stopped upon the detection of hydrogen in a concentration exceeding 2.4%. Hydrogen gas concentrations exceeding 2.4% are removed by flushing air, nitrogen, argon or helium into the region below the closure lid or by evacuating the hydrogen using a vacuum pump.

The vacuum pump exhausts to a system or area where hydrogen flammability is not an issue. Once the root pass weld is completed, there is no further likelihood of a combustible gas burn because the ignition source is isolated from the potential source of combustible gases, and hydrogen gas monitoring is stopped.

Hydrogen is not expected to be detected prior to, or during, the welding operations. During the completion of the closure lid to TSC shell root pass, the hydrogen gas detector accesses the vent port and is used to monitor the hydrogen gas levels. Following closure lid welding and TSC hydostatic testing, the TSC is drained. Once the TSC is dry, no combustible gases form within the TSC.

8.10.3.2 Evaluation of Unloading Operations

The TSC is dried and backfilled with helium immediately prior to final closure welding operations, thereby eliminating all oxidizing gases and water. Therefore, it is not expected that the TSC will contain any combustible gases during the time period of storage. To ensure the safe, wet unloading of the TSC, the unloading procedure described in Chapter 9 provides for monitoring for hydrogen gas during closure lid weld cutting/removal operations.

The principal steps in opening the TSC are the removal of the vent and drain port cover welds, and the removal of the closure lid weld. The welds are expected to be removed by cutting or grinding. Following removal of the vent and drain port covers, the TSC is sampled for radioactive gases, vented, flushed with nitrogen gas, and cooled down with water using the vent and drain ports. Prior to cutting the closure lid weld, the cavity water level is lowered to permit removal of the closure lid weld in a dry environment, and the cavity gas volume is sampled for hydrogen gas levels $\geq$2.4% using a hydrogen gas detector connected to the vent port. If unacceptable hydrogen levels are detected during closure lid weld removal operations, weld removal operations are terminated and the cavity is flushed with air, nitrogen, argon or helium, or the cavity is evacuated with a vacuum pump.

8.10.3.3 Conclusions

The steps taken to monitor for the presence of hydrogen will ensure that combustion of any hydrogen gas does not occur due to either closure lid welding or lid removal operations. Based on this evaluation, which results in no identified reactions, it is concluded that MAGNASTOR operating controls and procedures for loading and unloading the TSC presented in Chapter 9 are adequate to minimize the occurrence of hazardous conditions.

8.11 Cladding Integrity

The MAGNASTOR system and processes minimize spent fuel cladding deterioration during transfer and storage conditions by controlling the spent fuel rod environment, in particular clad temperature and the atmosphere contacting the clad.

Fuel cladding is maintained in storage by providing a high purity helium atmosphere at a positive pressure, limiting the amount of oxidants in the canister and controlling clad temperature. Oxidants are limited to less than one mole. Maximum fuel clad temperature is limited to less than 400°C for normal and transfer conditions and to less than 570°C for off-normal and accident events. Thermal cycles during system drying operations that exceed 65°C are restricted to no more than 10 cycles for fuel having burnup greater than 45 GWd/MTU [35] [38].

Oxidants are removed from the canister by the vacuum drying process. During vacuum drying, the residual moisture and free water in the cavity are vaporized as the internal pressure is reduced. The resultant vapor and residual gasses are removed from the canister through the vent and drain ports by the vacuum pump. The internal decay heat of the fuel contents assists in the vaporization process as the canister internals and fuel temperatures increase during the drying process. The vacuum pumping operation is continued until the cavity pressure is reduced to below 10 torr, which corresponds to one-half the vapor pressure of water at 72°F. Under normal loading conditions, the actual temperatures of the canister internals will exceed this temperature. The canister is then isolated from the vacuum pump and the pump is turned off. If free water exists in the canister, the water will vaporize and increase the canister pressure to above the 10 torr acceptance criterion during the dryness verification minimum hold period of 10 minutes. Upon successful completion of the dryness verification, the vacuum pump is restarted and the canister continues to be evacuated until the NUREG-1536 [39] recommended pressure of less than 3 torr is reached. The continued reduction in cavity pressure from 10 torr to less than 3 torr removes any residual noncondensing and oxidizing gases to a level of less than 1 mole. The canister is then backfilled with high purity helium ($\geq$ 99.995%) to a positive pressure. Implementation of the defined vacuum drying procedures provides assurance that the final canister internal atmosphere is a positive pressure of high purity helium that contains less than 1 mole of oxidizing gases, and that the residual oxidizing gas concentration is less than 0.25 vol%, as recommended in PNL-6365 [40].

To prevent oxidation of the uranium oxide (UO_2) fuel pellets in breached rods, classified as undamaged, provided the breach is no greater than a hairline crack or pinhole, operational steps in Section 9.1.1 specify that fuel rods shall not be exposed to air during canister draining operations in accordance with the guidance in Interim Staff Guidance (ISG)-22 [37].

The MAGNASTOR system operating procedures and specific operational completion times have been determined and defined to preclude thermally induced fuel rod cladding deterioration by limiting fuel rod cladding hoop stress and reducing the potential for the reorientation of hydrides. The thermal analyses presented in Chapter 4 provide the system temperatures for loading operations, normal conditions, and off-normal and accident events. The temperature control criteria applicable to the MAGNASTOR system are as follows:

1. Maximum calculated fuel cladding temperatures are limited to 400°C (752°F) for normal conditions of storage and short-term loading operations.
2. During loading operations, repeated thermal cycling (repeated heat-up/cool-down cycles) is limited to a total of 10 cycles for fuel with burnup greater than 45 GWd/MTU. A thermal cycle is defined as a clad temperature change greater than 65°C [35].
3. For off-normal and accident conditions, the maximum cladding temperature should not exceed 570°C.

Normal and accident condition thermal transients experienced by the MAGNASTOR canister, basket and contained fuel are controlled and introduce insignificant thermal loading and material stress to fuel rod cladding. Normal condition cooldown transients during cask operations may be introduced during vacuum drying when the canister dryness criteria are not met within the prescribed heat load-dependent time limit. If the dryness criteria are not met, the canister is backfilled to 7 bar gauge with helium, and the canister is cooled by the annulus cooling water system or by returning the canister to the pool as stated in Section 1.3.1.4. This backfill with helium may be performed when the temperatures in the mid to upper regions of the fuel basket are in the range of 700°F and the fuel local to the bottom plate is in the range of 250°F. Noting the significant difference in mass between helium and fuel, i.e., approximately five orders of magnitude, helium is heated with little temperature change to the fuel – the basket, canister bottom plate and shell mass add heat to the helium in combination with the fuel – reducing the thermal influence of the initial helium fill on the fuel cladding. Following the helium backfill, the canister is cooled by the annulus cooling water system or returned to the pool. Water in contact with the canister wall provides more effective heat transfer than the air boundary when the transfer cask is sitting in a cask processing area outside the pool. Although this water boundary provides a more effective heat transfer path, the influence of the canister cooling does not produce a thermal shock or significant through-wall gradient to the fuel rod cladding.

Investigation of the canister unloading sequence presented in Section 9.3 leads to similar conclusions as those for the introduction of helium gas discussed above. When the canister is first prepared for unloading and the port covers are removed, nitrogen gas is initially cycled through the canister for a minimum of 10 minutes to flush the radioactive gases from the canister. This gas cycling is similar to the helium backfill. Although nitrogen has a higher thermal capacitance than helium (about a factor of 10), when compared to the mass of the metal canister, basket and fuel, the influence of the nitrogen gas on the thermal gradient response in the fuel cladding remains insignificant. Following the nitrogen flush, water is introduced into the canister at a maximum rate of 8 gpm. The maximum flow rate is based on reflood thermal hydraulic analyses of a bounding canister configuration. The bounding maximum flow rate, water temperature and pressure are defined in step 14 of Section 9.3, "Wet Unloading a TSC." The water initially introduced into the canister flashes to steam in the drain tube and on contact with the bottom plate. Steam in the cavity permits additional heat to be removed from the basket and fuel in a smooth transition without introducing thermal shock through wall stresses. Once water is permitted to form on the canister bottom plate, the canister starts to fill at a maximum rate of 8 gpm. Addition of water at 8 gpm permits the water to rise in the canister at a maximum rate of 0.8 inch per minute. The RELAP thermal hydraulic analyses used to evaluate the TSC reflood operation show thermal cladding temperature radial gradients are less than 1°F during the reflooding of the canister. Such a small increase is consistent with the gradual cooling process created by the initial steam condition followed by water. The axial temperature gradient along the fuel assembly is actually larger than the radial gradient. However, in the fuel axial direction, thermal stresses are not developed since the fuel cladding is free to expand in the axial direction. The combination of initial nitrogen purge, followed by the cooling transition of the steam created in the canister cavity, provides a relatively smooth transition to water cooling and insignificant thermal stress in the fuel rod cladding.

There are no evaluated normal conditions, transfer conditions, off-normal events or accident conditions that result in deterioration of, or damage to, the fuel cladding or the TSC that preclude retrieval of the fuel from the TSC or retrieval of the TSC from the concrete cask for transport and ultimate disposal.

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8.13 Vendor Supplied Documentation

This section provides copies of technical data sheets for the coatings described in Section 8.6.

8.13.1 Electroless Nickel Coating

Nonelectrolytic Nickel Plating

*By the ASM Committee on Nickel Plating**

THREE METHODS may be employed for depositing nickel coatings without the use of electric current:

1 Immersion plating
2 Chemical reduction of nickelous oxide at 1600 to 2000 F
3 Autocatalytic chemical reduction of nickel salts by hypophosphite anions in an aqueous bath at 190 to 205 F ("electroless" nickel plating).

All three methods are, under certain limited conditions, useful substitutes for nickel electroplating; they are particularly useful in applications in which electroplating is impracticable or impossible because of cost or technical difficulties. Of the three methods, electroless nickel plating is in widest use, and is the method to which the most attention is devoted in this article.

Immersion Plating

The composition and operating conditions of an aqueous immersion plating bath are as follows:

Nickel chloride ($NiCl_2 \cdot 6H_2O$)	80 oz per gal
Boric acid (H_3BO_3)	4 oz per gal
pH	3.5 to 4.5
Temperature	160 F

When using this bath, it is desirable, but not mandatory, to move the work at a rate of about 16 ft per min.

This solution is capable of depositing a very thin (about 0.025 mil) and uniform coating of nickel on steel in periods of up to 30 min. The coating is porous and possesses only moderate adhesion, but these conditions can be improved by heating the coated part at 1200 F for 45 min in a nonoxidizing atmosphere. (Higher temperatures will promote diffusion of the coating.)

High-Temperature Chemical-Reduction Coating

By the reduction of a mixture of nickelous oxide and dibasic ammonium phosphate in hydrogen or other reducing atmosphere at 1600 to 2000 F, a nickel coating can be deposited without the use of electric current. This method (U. S. Patent 2,633,631) consists of applying a slurry of the two chemicals to all or selected surfaces of the workpiece, drying the slurry in air, and performing the chemical reduction at elevated temperature. No special tanks or other plating facilities are required. Some diffusion of nickel and phosphorus into the basis metal occurs at elevated temperature; when the coating is applied to steel, it will consist of nickel, iron, and about 3% phosphorus. The slurry may be used for brazing.

Electroless Nickel Plating

The electroless nickel plating process employs a chemical reducing agent (sodium hypophosphite) to reduce a nickel salt (such as nickel chloride) in hot aqueous solution and to deposit nickel on a catalytic surface. The deposit obtained from an electroless nickel solution is an alloy containing from 4 to 12% phosphorus and is quite hard. (As indicated later in this article, the hardness of the as-plated deposit can be increased by heat treatment.) Because the deposit is not dependent on current distribution, it is uniform in thickness, regardless of the shape or size of the plated surface.

Electroless nickel deposits may be applied to provide the basis metal with resistance to corrosion or wear, or for the buildup of worn areas. Typical applications of electroless nickel for these purposes are given in Table 1, which also indicates plate thicknesses and postplating heat treatments.

Surface Cleaning. In general, the methods employed for cleaning and preparing metal surfaces for electroless nickel plating are the same as those used for conventional electroplating. Heavy oxides are removed mechanically, and oils and grease are removed by vapor degreasing. A typical precleaning cycle might consist of alkaline cleaning (either agitated soak or anodic) and acid pickling, both followed by water rinsing.

Prior to electroless plating, the surfaces of all stainless steel parts must be chemically activated in order to obtain satisfactory adhesion of the plate. One activating treatment consists of immersing the work for about 3 min in a hot (200 F) solution containing equal volumes of water and concentrated sulfuric acid. Another treatment consists of immersing the work for 2 to 3 min in the following solution at 160 F:

Sulfuric acid (66° Bé)	25% by volume
Hydrochloric acid (18° Bé)	5% by volume
Ferric chloride hexahydrate	0.53 oz per gal

Pretreatments that are unique to electroless nickel plating include:

1 A strike copper plate must be applied to parts made of or containing lead, tin, cadmium or zinc, to insure adequate coverage and to prevent contamination of the electroless solution.
2 Massive parts are preheated to bath temperature to avoid delay in the deposition of nickel from the hot electroless bath.

Bath Characteristics. A simplified equation that describes the formation of electroless nickel deposits is:

$$NiSO_4 + NaH_2PO_2 + H_2O \xrightarrow[\text{catalyst}]{\text{heat}} Ni + NaH_2PO_3 + H_2SO_4$$

The essential requirements for any electroless nickel solution are:

1 A salt to supply the nickel
2 A hypophosphite salt to provide chemical reduction
3 Water
4 A complexing agent
5 A buffer to control pH
6 Heat
7 A catalytic surface to be plated.

Detailed discussions of the chemical characteristics of electroless baths, and of the critical concentration limits of the various reactants, can be found in several of the references listed at the end of this article.

Both alkaline (pH, 7.5 to 10) and acid (pH, 4.5 to 6) electroless nickel baths are used in industrial production. Although the acid baths are easier to maintain and are more widely used, the alkaline baths are reported to have greater compatibility with sensitive substrates (such as magnesium, silicon and aluminum).

Catalysis. Nickel and hypophosphite ions can exist together in a dilute solution without interaction, but will react on a catalytic surface to form a deposit. Furthermore, the surface of the deposit is also catalytic to the reaction, so that the catalytic process continues until any reasonable plate thickness is applied. This autocatalytic effect is the principle upon which all electroless nickel solutions are based.

Metals that catalyze the plating reaction are members of group VIII in the periodic table, which group includes nickel, cobalt and palladium. A deposit will begin to form on surfaces of these metals by simple contact with the solution. Other metals, such as aluminum or low-alloy steel, first form an

* See page 432 for committee list.

Table 1. Typical Applications of Electroless Nickel Plating

Part and basis metal	Typical plate thickness, mils	Postplating heat treatment(a)
Plate Applied for Corrosion Resistance		
Valve body, cast iron	5.0	None
Printing rolls, cast iron	1.0	None
Electronic chassis, 1010 steel	1.0	None
Railroad tank cars, 1020 steel	3.5	1 hr at 1150 F
Reactor vessels, 1020 steel	4.0	1 hr at 1150 F
Pressure vessel, 4130 steel	1.5	3 hr at 350 F
Tubular shaft, 4340 steel	1.5	3 hr at 375 F
Plate Applied for Wear Resistance		
Centrifugal pump, steel	1.0	2 hr at 400 F
Plastic extrusion dies, steel	2.0	2 hr at 375 F
Printing-press bed, steel	1.0	None
Valve inserts, steel	0.5	2 hr at 1150 F
Hydraulic pistons, 4340 steel	1.0	1 hr at 750 F
Screws, 410 stainless	0.2	None
Stator and rotor blades, 410 stainless	0.8 to 1.0	1 hr at 750 F
Spray nozzles, brass	0.5	None
Plate Applied for Buildup of Worn Areas		
Carburized gear (bearing journal)	0.8 to 1.0	5 hr at 275 F
Splined shaft (ID spline), 16-25-6 stainless	0.5	1 hr at 750 F
Connecting arm (dowel-pin holes), type 410	5.0	1 hr at 750 F

(a) Heat treatments above 450 F should be carried out in an inert or reducing atmosphere.

immersion deposit of nickel on their surfaces, which then catalyzes the reaction; still others, such as copper, require a galvanic nickel deposit in order to be plated. Such a galvanic nickel deposit can be formed by the plating solution itself, if the copper is in contact with steel or aluminum.

Plastics, glass, ceramics and other nonmetallics also can be plated, if their surfaces can be made catalytic. This usually is done by the application of traces of a strongly catalytic metal to the nonmetallic surface by chemical or mechanical means.

There is, however, a group of metals that not only do not display any catalytic action, but also interfere with all plating activity. The salts of these metals, if dissolved in a solution even in comparatively small amounts, are poisons and stop the plating reaction on all metals, thus necessitating the discarding of the solution and the formulation of a new one. Examples of these anticatalysts are Pb, Sn, Zn, Cd, Sb, As and Mo.

Paradoxically, the deliberate introduction of extremely minute traces of poisons has been practiced by a number of users of electroless nickel, with the intent of stabilizing the solution. Being an inherently metastable mixture, electroless nickel solutions are likely to decompose spontaneously, with the nickel and hypophosphite reacting on trace amounts of solid impurities present in any plating bath. In order to minimize this problem, a poisoning element is added in trace concentrations of parts per million (or per trillion) to the original make-up of the solution. The poison is adsorbed on the solid impurities in quantities large enough to destroy their catalytic nature. This selective adsorption on catalytic centers decreases the concentration of the catalytic poison to a level below the critical threshold, so that normal deposition of nickel is not impeded, although the rate of deposition is somewhat reduced. The deliberate introduction of catalytic poisons for the purpose of stabilization is covered by several patents, including U. S. Patents 2,762,723 and 2,847,327.

Table 2. Alkaline Electroless Nickel Baths

Constituent or condition	Bath 1	Bath 2	Bath 3
Composition, Grams per Liter			
Nickel chloride	30	45	30
Sodium hypophosphite	10	11	10
Ammonium chloride	50	50	50
Sodium citrate	..	100	..
Ammonium citrate	..	..	65
Ammonium hydroxide	to pH	to pH	to pH
Operating Conditions			
pH	8 to 10	8.5 to 10	8 to 10
Temperature, F	195 to 205	195 to 205	195 to 205
Plating rate (approx), mil per hr	0.3	0.4	0.3

Alkaline Baths. Most alkaline baths in commercial use today are based on the original formulations developed by Brenner and Riddell. They contain a nickel salt, sodium hypophosphite, ammonium hydroxide, and an ammonium salt; they may also contain sodium citrate or ammonium citrate. The ammonium salt serves to complex the nickel and buffer the solution. Ammonium hydroxide is used to maintain the pH between 7.5 and 10. Table 2 gives the compositions and operating conditions of three alkaline electroless baths.

At the operating temperatures of these baths (about 200 F), ammonia losses are considerable. Thorough ventilation and frequent adjustment of pH are required. The alkaline solutions are inherently unstable and are particularly sensitive to the poisoning effects of anticatalysts such as lead, tin, zinc, cadmium, antimony, arsenic and molybdenum — even when these elements are present in only trace quantities. However, when depletion occurs, these solutions undergo a definite color change from blue to green, indicating the need for addition of ammonium hydroxide.

Acid baths are more widely used in commercial installations than alkaline baths. Essentially, acid baths contain a nickel salt, a hypophosphite salt, and a buffer; some solutions also contain a chelating agent. Frequently, wetting agents and stabilizers also are added.

These baths are more stable than alkaline solutions, are easier to control, and usually provide a higher plating rate. Except for the evaporation of water, there is no loss of chemicals when acid baths are heated to their operating range. Table 3 gives the compositions and operating conditions of several acid electroless baths.

Table 3. Acid Electroless Nickel Plating Baths(a)

Constituent or condition	Bath 4	Bath 5	Bath 6	Bath 7	Bath 8	Bath 9
Composition, Grams per Liter						
Nickel chloride	30	..	..	30	..	30
Nickel sulfate	..	21	20	..	15	..
Sodium hypophosphite	10	24	27	10	14	12
Sodium acetate	..	..	..	..	13	..
Sodium hydroxyacetate	50	..	..	10	..	..
Sodium succinate	..	..	16	..	..	..
Lactic acid (80%)	..	34 ml	..	..	..	..
Propionic acid (100%)	..	2.2 ml	..	..	..	10
Operating Conditions						
pH	4 to 6	4.3 to 4.6	4.5 to 5.5	4 to 6	5 to 6	4.5 to 5.5
Temperature, F	190 to 210	203	200 to 210	190 to 210	190 to 210	190 to 210
Plating rate (approx), mil per hr	0.5	1.0	1.0	0.4	0.7	0.6

(a) Baths 4 and 7 are covered by U. S. Patent 2,532,283 (a public patent assigned to the National Bureau of Standards); bath 5, by U. S. Patents 2,822,293 and 2,822,294, and bath 6 by U. S. Patents 2,658,841 and 2,658,842.

Solution Control. In order to assure optimum results and consistent plating rates, the composition of the plating solution should be kept relatively constant; this requires periodic analyses for the determination of pH, nickel content, and phosphite and hypophosphite concentrations. The rate at which these analyses should be made depends on the quantity of work being plated and the volume and type of solution being used. The following methods have been employed:

pH — Standard electrometric method

Nickel — Any one of the colorimetric, gravimetric or volumetric methods is satisfactory; the cyanide method is probably the most popular.

Phosphite — A 10-ml sample of the plating solution is combined with 20 ml of a 5% solution of sodium bicarbonate and cooled in an ice bath. Next, 50 ml of 0.1*N* iodine solution is added and the flask containing this mixture is stoppered and permitted to stand for 2 hr at room temperature. Then the flask is cooled for 15 min in ice water, after which it is unstoppered, the mixture is acidified with acetic acid, and the excess iodine is titrated with 0.1*N* sodium thiosulfate, with starch as an indicator. Determination is then made as follows:

$$NaH_2PO_3 \text{ per liter} = \frac{\text{net ml of 0.1N iodine} \times 6.3}{\text{ml of plating solution}}$$

Hypophosphite (U. S. Patent 2,697,651) — A 25-ml sample of the plating solution is diluted to 1 liter. A 5-ml aliquot of the

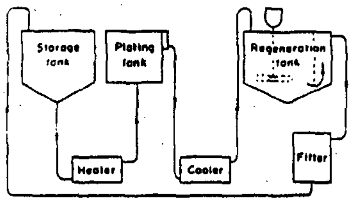


Fig. 1. Schematic of continuous-type system for electroless nickel plating. See text.

dilution is combined with 10 ml of a 10% solution of ammonium molybdate and 10 ml of fresh 6% sulfurous acid. The sample is covered and heated to boiling, and a deep blue color develops. The sample is cooled and diluted to 100 ml, and transmittance at a wave length of 440 microns is determined. The calibration curve on semilog paper is linear.

Hypophosphite (alternative method) — A 5-ml sample of the plating solution is mixed in a beaker with 5 ml of methyl orange solution made up of 1 gram of methyl orange in 1 liter of water. In another beaker is placed 15 ml of an acid solution made up by (*a*) dissolving 40 grams of sodium metabisulfate in 200 ml of water, (*b*) slowly adding the sodium metabisulfate solution to a cold solution of 82 ml of sulfuric acid in 650 ml of water, and then (*c*) diluting this mixture with water to 1 liter. When the acid solution and the solution containing the sample and methyl orange reach a temperature of 77 F in a thermostat, the two solutions are mixed. The time between mixing and the disappearance of the red color is recorded. The hypophosphite concentration is a function of this time and is read from a concentration-time curve made from known standards.

Equipment Requirements. The precleaning and post-treating equipment for an electroless nickel line is comparable to that employed in conventional electrodeposition. The plating tank itself, however, is unique.

The preferred plating tank for batch operations is constructed of stainless steel or aluminum and is lined with a coating of an inert material, such as tetrafluoroethylene or a phenolic-base organic. The size and shape of the tank are usually dictated by the parts to be plated, but the surface area of the plating solution should not be so large that excessive heat loss occurs as a result of evaporation.

A large heat-transfer area and a low temperature gradient are necessary between the heating medium and the plating solution. This combination provides for a reasonable heat-up time without local hot spots that could decompose the solution. It is accepted practice to surround the plating tank with a hot-water jacket or to immerse it in a tank containing hot water. Heating jackets using low-pressure steam also have been used successfully. The use of immersed steam coils is not favored, however, because it entails the sacrifice of a large amount of working area in the tank.

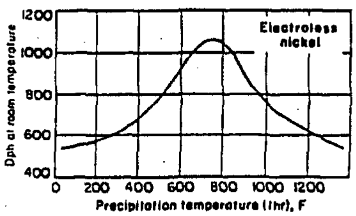
Accessory equipment required or recommended for the tank includes:

1 An accurate temperature controller
2 A filter to remove any suspended solids
3 A pH meter
4 An agitator to prevent gas streaking
5 On small tanks, a cover, to minimize heat loss and exclude foreign particles.
6 On large tanks, a separate small tank to dissolve and filter additives before they are put into the plating tank.

Considerably more equipment is required for a continuous-type system, such as that shown in Fig. 1. The bath is prepared and stored in a separate tank and flows through a heater (which raises its temperature to 205 F) into the plating tank. From the plating tank, the solution is pumped through a cooler, which decreases its temperature to 175 F or below, and then to an agitated regeneration tank, where reagents are added in controlled amounts to restore the solution to its original composition. The solution is then directed past a vertical underflow baffle and out of the regeneration tank to a filter, and then returned to storage.

In externally heated continuous-type systems such as the one shown in Fig. 1, the plating tank and other components of the system that come in contact with the plating solution are constructed of type 304 stainless steel and are not lined or coated; these components are periodically deactivated by chemical treatment. Details of this type of system are covered by several patents, including U. S. Patents 2,941,902; 2,658,839 and 2,874,073.

Properties of the Deposit. Electroless nickel is a hard, lamellar, brittle, uniform deposit. As plated, the hardness



Effect of temperature of 1-hr precipitation heat treatment on room-temperature hardness of a typical electroless nickel deposit (Eberbach tester, 100-gram load). Above 450 F, heat treatment was in an inert atmosphere.

Fig. 2. Heat treatment of coating

varies over a considerable range (425 to 575 dph), depending primarily on phosphorus content, which ranges from 4 to 12%. This hardness can be increased by a precipitation heat treatment. As indicated in Fig. 2, which shows temperature-hardness relationships for a typical deposit, by heating at 750 F for ½ to 1 hr, hardness can be increased to about 1000 dph.

The corrosion resistance of electroless nickel deposits is superior to that of electrodeposited nickel of comparable thickness, but this superiority varies with exposure conditions. Outdoor exposure and salt spray corrosion data indicate that about 25% more resistance is given a steel panel by electroless nickel than by electrolytic.

Table 4. Physical Properties of Electroless Nickel Deposits

Property	Value
Specific gravity	7.8 to 8.5
Melting point	1635 to 1850 F
Electrical resistivity	60 microhm-cm
Thermal expansion	13×10^{-6} per °C
Thermal conductivity	0.0105 to 0.0135 cal/cm sec/°C

Table 5. Costs for Electroless Nickel Plating (Example 2) (a)

Cost factor		Cost per year(b)
Original investment	$18,000	
Fixed costs:		
Depreciation (10 years)		$ 1,800
Insurance		450
Floor space (200 sq ft)		192
Repairs and maintenance		450
Variable costs:		
Raw material		6,100
Utilities		740
Labor costs:		
Direct		10,400
Indirect		2,630
Total		$22,762
Total cost per hr		$9.48
Total cost per sq ft coated to 1 mil		$1.00

(a) Exclusive of costs for: overhead and administration; racking, cleaning and unracking; and preplating and postplating processes. (b) Based on deposition of 1 mil on 0.1-sq-ft parts at rate of 0.8 mil per hr (capacity: 117 pieces, or 9.4 sq-ft/mil, per hr), on a schedule of 10 hr per day, 20 days per month, 2400 hr per year.

Some of the physical properties of electroless nickel are listed in Table 4.

Advantages and Limitations. Some advantages of electroless nickel are:

1 Good resistance to corrosion and wear
2 Excellent uniformity
3 Solderability and brazability
4 Good oxidation resistance.

Limitations of electroless nickel are:

1 High cost
2 Brittleness
3 Poor welding characteristics
4 Lead, tin, cadmium and zinc must be copper strike plated before electroless nickel can be applied
5 Slower plating rate (in general), as compared to electrolytic methods
6 Full brightness in deposit cannot be obtained without extreme brittleness.

Cost. Electroless nickel is considerably more expensive than electrodeposited nickel. Actual costs for electroless nickel plating, as reported by two users, are given in the following examples.

Example 1. Based on the experience of one manufacturing plant, it costs $1.20 to deposit an electroless nickel coating 1 mil thick on a square foot of surface area: 37¢ for chemicals, 59¢ for labor, and 24¢ for equipment and maintenance.

Example 2. Another manufacturing plant reports that it costs $1 per sq ft to plate a 1-mil thickness of electroless nickel on specific parts with a surface area of 0.1 sq ft, on the basis of data obtained over a one-year period (2400 working hours). An analysis of their costs is given in Table 5.

Selected References

A. Brenner, Electroless Plating Comes of Age, *Metal Finishing*, November 1954, p 68-76; December 1954, p 61-68

A. Brenner and G. Riddell, Nickel Plating on Steel by Chemical Reduction, *J Res Nat Bur Stds*, July 1946, p 31-34, and *Proc Am Electroplaters' Soc*, 1946, p 23-29; Deposition of Nickel and Cobalt by Chemical Reduction, *J Res Nat Bur Stds*, Nov 1947, p 385-395, and *Proc Am Electroplaters' Soc*, 1948, p 156-169

G. Gutzeit, Industrial Nickel Coating by Chemical Catalytic Reduction, *Trans Inst Metal Finishing*, 33, 383-423 (1955-1956), and *Corrosion Technol*, 3, 208 (1956)

G. Gutzeit, An Outline of the Chemistry Involved in the Process of Catalytic Nickel Deposition from Aqueous Solution, *Plating*, Oct 1959, p 1158-1164; Nov 1959, p 1275-1278; Dec 1959, p 1377-1378; Jan 1960, p 63-70

C. H. de Minjer and A. Brenner, Studies on Electroless Nickel Plating, *Plating*, December 1957, p 1297-1305

Symposium on Electroless Nickel Plating (Catalytic Deposition of Nickel-Phosphorus Alloys by Chemical Reduction in Aqueous Solution), ASTM STP No. 265 (1959)

8.13.2 Keeler & Long Kolor-Poxy Primer (typical)

E.140

KEELER & LONG INC.

HEADQUARTERS:
P. O. Box 460
856 Echo Lake Road
Watertown, CT 06795
Tel (860) 274-6701
Fax (860) 274-5857

KOLOR-POXY PRIMER
No. 3200

GENERIC TYPE: POLYAMIDE EPOXY

PRODUCT DESCRIPTION: A two component, high solids, polyamide epoxy primer/topcoat formulated to provide a high-build, abrasion, impact and chemical resistant coating.

RECOMMENDED USES: As a high-build primer for steel and concrete surfaces exposed to a wide range of conditions. No. 3200 is certified by the National Sanitation Foundation (NSF) and Ministry of Environment (Ontario and Saskatchewan, CN)** for application to the interior of potable water tanks.* No. 3200 is also accepted by the USDA for application to incidental food contact surfaces.

NOT RECOMMENDED FOR: Immersion in strong acids.

COMPATIBLE TOPCOATS:

- Kolor-Poxy Primers and Enamels
- Kolor-Poxy Hi-Solids Primer
- Kolor-Poxy Hi-Build Enamels
- Poly-Silicone Enamels
- Hydro-Poxy Enamels
- Kolor-Sil Enamels
- Acrythane Enamels
- Kolorane Enamels
- Tri-Polar Silicone Enamels

PRODUCT CHARACTERISTICS:

Solids by Volume:	66% ± 3%
Solids by Weight:	82% ± 3%
Recommended Dry Film Thickness:	2.5 - 6.0 mils
Theoretical Coverage:	350 Sq. Ft./Gallon @ 3.0 mils DFT
Finish:	Flat
Available Colors:	White and tints
Drying Time @ 72°F	
To Touch:	4 Hours
To Handle:	8 Hours
To Recoat:	24 Hours
To Immersion:	10 Days
VOC Content:	2.52 Pounds/Gallon
	302 Grams/Liter

*
White or light grey only
5000 gallon tanks or larger
Up to four coats - Total DFT 24 mils maximum
Use No. 3700 Thinner up to 25% by volume

** Substrate temperature; 45°F (70°C) minimum during cure. Thorough rinse required after final cure.

June, 1994

TECHNICAL BULLETIN

No. 3200 E-140

TECHNICAL DATA

PHYSICAL DATA:	Weight per gallon:	13.6 ± 0.5 (pounds)
	Flash Point (Pensky-Martens):	85°F
	Shelf Life:	2 Years
	Pot Life @ 72°F:	8 Hours
	Temperature Resistance:	350°F
	Viscosity @ 77°F:	87 ± 5 (Krebs Units)
	Gloss (60° meter):	6 ± 5
	Storage Temperature:	50 - 95°F
	Mixing Ratio (Approx. by Volume):	4:1
APPLICATION DATA:	Application Procedure Guide:	APG-3
	Wet Film Thickness Range:	3.8 - 9.1 mils
	Dry Film Thickness Range:	2.5 - 6.0 mils
	Temperature Range:	50 - 120°F
	Relative Humidity:	80% Maximum
	Substrate Temperature:	Dew Point + 5°F
	Minimum Surface Preparation:	SSPC-SP6, SP10, SP5
	Induction Time @ 72°F:	45 Minutes
	Recommended Solvent	
	@ 50 - 85°F:	No. 3700
	@ 86 - 120°F:	No. 2200
	Application Methods	
	Air Spray	
	Tip Size:	.055" - .073"
	Pressure:	30 - 60 PSIG
	Thin:	1.0 - 2.0 Pts/Gal
	Airless Spray	
	Tip Size:	.015" - .019"
	Pressure:	2500 PSIG
	Thin:	0.5 - 1.5 Pts/Gal
	Brush or Roller	
	Thin:	0.5 - 1.5 Pts/Gal

KEELER & LONG INC.

KOLORS

P. O. Box 460, 856 Echo Lake Road
Watertown, CT 06795
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SSPC SUSTAINING MEMBER

8.13.3 Keeler & Long Heat-Proof Silicone Enamel, No. 1447 (typical)

H.100

KEELER & LONG INC

HEADQUARTERS:
P. O. Box 460
856 Echo Lake Road
Watertown, CT 06795
Tel (860) 274-6701
Fax (860) 274-5857

HEAT-PROOF SILICONE BLACK ENAMEL
No. 1447

GENERIC TYPE:	SILICONE
PRODUCT DESCRIPTION:	A single component, silicone enamel formulated as a primer/finish coat for high temperature surfaces up to 750°F.
RECOMMENDED USES:	As a primer/finish coat for exterior surfaces of high temperature piping, stacks, equipment, etc. where the continuous temperature does not exceed 750°F.
NOT RECOMMENDED FOR:	Immersion service or splash and spillage of strong chemicals.
COMPATIBLE UNDERCOATS:	Heat-Proof Silicone Gray Primer Heat-Proof Silicone Black Enamel

PRODUCT CHARACTERISTICS:

Solids by Volume:	41% ± 3%
Solids by Weight:	51% ± 3%
Recommended Dry Film Thickness:	1.0-1.5 mils
Theoretical Coverage:	655 Sq. Ft./Gallon @ 1.0 mil DFT
Finish:	Full Gloss
Available Colors:	Black
Drying Time @ 72°F	
To Touch:	2 Hours
To Handle:	4 Hours
To Recoat:	24 Hours
VOC Content:	3.8 Pounds/Gallon 455 Grams/Liter

December, 1994

TECHNICAL BULLETIN

No. 1447 H 100

TECHNICAL DATA

PHYSICAL DATA:	Weight per gallon:	7.8 ± 0.3 (pounds)
	Flash Point (Pensky-Martens):	104°F ± 2°
	Shelf Life:	2 Years
	Temperature Resistance:	750°F
	Viscosity @ 77°F:	60 ± 3 (Krebs Units)
	Gloss (60° meter):	90 ± 5
	Storage Temperature:	45 - 90°F
APPLICATION DATA:	Application Procedure Guide:	APG-1
	Wet Film Thickness Range:	2.5 - 3.5 mils
	Dry Film Thickness Range:	1.0 - 1.5 mils
	Temperature Range:	45 - 90°F
	Relative Humidity:	85% Maximum
	Substrate Temperature:	Dew Point + 5°F
	Minimum Surface Preparation:	SSPC-SP10
	Recommended Solvent:	No. 1638

Application Methods

Air Spray	
Tip Size:	.055"
Pressure:	30 - 60 PSIG
Thin:	1.0 - 2.0 Pts/Gal
Airless Spray	
Tip Size:	.013" - .017"
Pressure:	2000 PSIG
Thin:	0.0 - 1.0 Pt/Gal
Flow Coat	
Viscosity:	19 - 21 SEC. (Sears Cup)
Brush or Roller	
Thin:	0.0 - 1.0 Pt/Gal

KEELER & LONG INC.

KOLORS

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SSPC SUSTAINING MEMBER

8.13.4 Keeler & Long E-Series Epoxy Enamel

March, 1995

SSU-1

KEELER & LONG INC.

HEADQUARTERS:
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PROTECTIVE COATING SYSTEMS FOR NUCLEAR POWER PLANTS

INTRODUCTION

In the 1960's Keeler & Long made the commitment to develop Protective Coating Systems for Nuclear Power Plants. Coating Systems were developed and qualified in accordance with accepted standards, with emphasis upon their usage and specification for NEW construction projects. These systems were applied directly to either concrete or carbon steel substrates utilizing ideal surface preparation.

Presently, there is a necessity to apply these same coating systems or newly formulated systems over the original systems or over substrates which cannot be ideally prepared. Several years ago, Keeler & Long initiated a test program in order to test and qualify systems in conjunction with competitors products and/or with methods of preparation which are considered less than ideal. This test program provides OPERATING Nuclear Plants with qualified methods of preparation and a variety of qualified mixed coating systems.

HISTORY

In 1967, we embarked upon a testing program in order to comply with standards being prepared by the experts in the field and under the jurisdiction of The American National Standards Institute (ANSI). Earlier testing had involved research in order to determine the radiation tolerance and the decontamination properties of a variety of generic coating types including zinc rich, alkyds, chlorinated rubbers, vinyls, latex emulsions, and epoxies. This testing was conducted by various independent laboratories, such as Oak Ridge National Laboratory, Idaho Nuclear, and The Western New York Nuclear Research Center. It was concluded from these tests that almost any generic coating type would produce satisfactory radiation resistance and decontaminability.

Upon completion of the first ANSI Standards, however, it became evident that only Epoxy Coatings would meet the specific minimum acceptance criteria set forth in these standards. The single most important change from the earlier testing was the inclusion of a test which simulates the operation of the emergency core cooling system. This test is referred to as the Loss of Coolant Accident (LOCA) or the Design Basis Accident Condition (DBA). The test involves a high pressure, high temperature, alkaline, immersion environment.

Simultaneous with the preparation of these standards, we prepared to test Epoxy Systems in order to comply with the requirements. First hand knowledge of these standards was available since our personnel assisted in the development of these documents. Equipment was designed and built by our laboratory in order to conduct in-house DBA tests. The required physical and chemical tests were either conducted by us or by universities through research grants.

In 1972, the testing program was taken a step further in order to establish more credibility. The Franklin Institute of Philadelphia constructed an apparatus in order to simulate various Design Basis Accident Conditions and we prepared blocks and panels for an independent evaluation. The test results were among the "First" from an independent source, and these tests substantiated more than two years of in-house testing.

The Franklin Institute tests, along with our in-house testing program, were used as a basis for qualification until 1976. During this period also the following ANSI standards were revised and/or developed:

> <u>ANSI N5.9-1967</u> "Protective Coatings (Paints) for the Nuclear Industry" (Rev. ANSI N512-1974)
>
> <u>ANSI N101.2-1972</u> "Protective Coatings (Paints) for Light Water Nuclear Reactor Containment Facilities"
>
> <u>ANSI N101.4-1972</u> "Quality Assurance for Protective Coatings Applied to Nuclear Facilities"

Simultaneously, we developed a written Quality Assurance Program in compliance with ANSI N101.4 - 1972, Appendix B 10CFR50 of the Federal Register, and ANSI N45.2-1971 "Quality Assurance Program Requirements For Nuclear Power Plants".

In 1976, Oak Ridge national Laboratory (ORNL) established a testing program in order to conduct Radiation, Decontamination, and DBA tests under one roof. Keeler & Long, under contract with ORNL, conducted a series of tests in compliance with the parameters established by a major engineering firm and the ANSI standards. These tests, and similar series of tests conducted two years later in 1978, became the basis for the qualification of several of our concrete and carbon steel coating systems. From 1978 to the present day we have continued to qualify through ORNL and several other independent testing agencies any modifications to existing formulas and any changes in surface preparation or application requirements. We have also maintained an in-house testing program used to screen new products as well as modifications of existing systems. Furthermore, progress has continued in the revision of the ANSI standards during this time frame. Revision of these documents is presently under the jurisdiction of the American Society for Testing and Materials (ASTM) as outlined in D3842-80 "Standard Guide for Selection of Test Methods for Coatings Used in Light-Water Nuclear Power Plants".

The future dictates significantly less construction of new Nuclear Plants and much more emphasis upon the repair and maintenance of existing facilities. Our commitment remains the same as it was in 1965; that is, to meet the coating requirements of Nuclear Power Plants.

NUCLEAR COATINGS

SSU-1

Level One Coating Systems

The following Coating Systems are qualified for Coating Service Level One of a Nuclear Power Plant. "Coating Service Level One pertains to those systems applied to structures, systems and other safety related components which are essential to the prevention of, or the mitigation of the consequences of postulated accidents that could cause undue risk to the health and safety of the public."

SYSTEM IDENTIFICATION	COATING SYSTEMS	DRY FILM THICKNESS RANGE
CARBON STEEL COATING SYSTEMS		
System S-1		
Primer	No. 6548/7107 EPOXY WHITE PRIMER	3.0 - 14.0 mils DFT
Finish	No. E-1 SERIES EPOXY ENAMEL	2.5 - 6.0 mils DFT
System S-10		
Primer	No. 6548/7107 EPOXY WHITE PRIMER	5.0 - 12.0 mils DFT
Finish	No. D-1 SERIES EPOXY HI-BUILD ENAMEL	3.0 - 6.0 mils DFT
System S-11		
Primer/Finish	No. 6548/7107 EPOXY WHITE PRIMER	8.0 - 18.0 mils DFT
System S-12		
Primer/Finish	No. 4500 EPOXY SELF-PRIMING SURFACING ENAMEL	5.0 - 18.0 mils DFT
System S-14 (FLOORS ONLY)		
Finish	No. 5000 EPOXY SELF-LEVELING FLOOR COATING	10.0 - 25.0 mils DFT
System S-15		
Primer	No. 6548/7107 EPOXY WHITE PRIMER	2.5 - 6.0 mils DFT
Finish	No. 9600 N KEELOCK	5.0 - 8.0 mils DFT
CONCRETE COATING SYSTEMS		
System KL-2		
Curing Compound/Sealer	No. 4129 EPOXY CLEAR CURING COMPOUND	0.5 - 1.75 mils DFT
Surfacer	No. 6548-S EPOXY SURFACER	Flush - 50.0 mils DFT
Finish	No. E-1 SERIES EPOXY ENAMEL	2.5 - 6.0 mils DFT
System KL-8		
Curing Compound/Sealer	No. 4129 EPOXY CLEAR CURING COMPOUND	0.5 - 1.75 mils DFT
Surfacer	No. 6548-S EPOXY SURFACER	Flush - 50.0 mils DFT
Finish	No. D-1 SERIES EPOXY HI-BUILD ENAMEL	4.0 - 8.0 mils DFT
System KL-9		
Curing Compound/Sealer	No. 4129 EPOXY CLEAR CURING COMPOUND	0.5 - 1.75 mils DFT
Surfacer	No. 6548/7107 EPOXY WHITE PRIMER	5.0 - 10.0 mils DFT
Finish	No. D-1 SERIES EPOXY HI-BUILD ENAMEL	3.0 - 8.0 mils DFT
System KL-10		
Curing Compound/Sealer	No. 4129 EPOXY CLEAR CURING COMPOUND	0.5 - 1.75 mils DFT
Surfacer	No. 4000 EPOXY SURFACER	Flush - 50.0 mils DFT
Finish	No. D-1 SERIES EPOXY HI-BUILD ENAMEL	3.0 - 6.0 mils DFT
System KL-12		
Curing Compound/Sealer	No. 4129 EPOXY CLEAR CURING COMPOUND	0.5 - 1.75 mils DFT
Surfacer/Finish	No. 4500 EPOXY SELF-PRIMING SURFACING ENAMEL	10.0 - 50.0 mils DFT
System KL-14 (FLOORS ONLY)		
Primer/Sealer	No. 6129 EPOXY CLEAR PRIMER/SEALER	1.5 - 2.5 mils DFT
Finish	No. 5000 EPOXY SELF-LEVELING FLOOR COATING	35.0 - 50.0 mils DFT

SUMMARY OF QUALIFICATION TEST RESULTS

KEELER & LONG *maintains a complete file of Nuclear Test Reports which substantiate the specification of the carbon steel and* concrete coating systems listed in this bulletin. This file was initiated in the early 1970's and provides complete qualification in accordance with ANSI Standards N512 and N101.2. Results for radiation tolerance, decontamination, and the Design Basis Accident Condition are reported as performed by independent Laboratories. Also reported are the chemical and physical tests which were conducted by the Keeler & Long Laboratory in compliance with the ANSI Standards.

TEST REPORT REFERENCE

K&L COATING SYSTEM	SUBSTRATE	KEELER & LONG TEST REPORT NO. 78-0728-1	78-0810-1	85-0404	85-0524	90-0227	93-0818	93-0601
S-1	Steel	*	*					
S-10	Steel		*					
S-11	Steel		*					
S-12	Steel			*				
S-14	Steel					*		
S-15	Steel						*	
KL-2	Concrete	*	*					
KL-8	Concrete	*						
KL-9	Concrete	*	*					
KL-10	Concrete		*					
KL-12	Concrete				*			
KL-14	Concrete					*		*

This information is presented as accurate and correct, in good faith, to assist the user in application. No warranty is expressed or implied. No liability is assumed.

KOLORS   KEELER & LONG INC.   SSPC SUSTAINING MEMBER

E.340

KEELER & LONG INC.

HEADQUARTERS:
P. O. Box 460
856 Echo Lake Road
Watertown, CT 06795
Tel (860) 274-6701
Fax (860) 274-5857

EPOXY ENAMEL
E-SERIES

GENERIC TYPE: POLYAMIDE EPOXY

PRODUCT DESCRIPTION: A two component, polyamide epoxy enamel formulated to provide excellent chemical resistance, as well as being extremely resistant to abrasion and direct impact, for interior exposures.

RECOMMENDED USES: As a topcoat for concrete and steel surfaces subject to radiation, decontamination, and loss-of-coolant accidents in Coating Service Level I Areas of nuclear power plants.

NOT RECOMMENDED FOR: Areas other than the above, as the J-SERIES can be utilized in Coating Service Level II and III Areas, as well as Balance of Plant, of nuclear power plants, with attendant cost savings.

COMPATIBLE UNDERCOATS: Epoxy White Primer
Epoxy Surfacer

PRODUCT CHARACTERISTICS:

Solids by Volume:	53% ± 3%
Solids by Weight:	66% ± 3%
Recommended Dry Film Thickness:	2.0 - 2.5 mils
Theoretical Coverage:	425 Sq. Ft./Gallon @ 2.0 mils DFT
Finish:	Full Gloss (E-1), Semi-Gloss (E-2)
Available Colors:	White, light tints, and dark red
Drying Time @ 72°F	
To Touch:	4 Hours
To Handle:	8 Hours
To Recoat:	48 Hours
VOC Content:	3.4 Pounds/Gallon 407 Grams/Liter

June, 1994

TECHNICAL BULLETIN

E-SERIES

E-340

TECHNICAL DATA

PHYSICAL DATA:	Weight per gallon:	10.2 ± 0.5 (pounds)
	Flash Point (Pensky-Martens):	85°F± 2°
	Shelf Life:	1 Year
	Pot Life @ 72°F:	8 Hours
	Temperature Resistance:	350°F
	Viscosity @ 77°F:	85 ± 5 (Krebs Units)
	Gloss (60° meter):	95 ± 5 (E-1)
	Storage Temperature:	55 - 95°F
	Mixing Ratio (Approx. by Volume):	4:1
APPLICATION DATA:	Application Procedure Guide:	APG-2
	Wet Film Thickness Range:	4.0 - 5.0 mils
	Dry Film Thickness Range:	2.0 - 2.5 mils
	Temperature Range:	55 - 120°F
	Relative Humidity:	80% Maximum
	Substrate Temperature:	Dew Point + 5°F
	Minimum Surface Preparation:	Primed
	Induction Time @ 72°F:	1 Hour
	Recommended Solvent	
	@ 50 - 85°F:	No. 4093
	@ 86 - 120°F:	No. 2200

Application Methods

Air Spray	
Tip Size:	.055"
Pressure:	30 - 60 PSIG
Thin:	1.0 - 2.0 Pts/Gal
Airless Spray	
Tip Size:	.011" - .017"
Pressure:	2500 - 3000 PSIG
Thin:	0.5 - 1.5 Pts/Gal
Brush or Roller	
Thin:	1.0 - 2.0 Pts/Gal

KEELER & LONG INC.

KOLORS

P. O. Box 460, 856 Echo Lake Road
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SSPC SUSTAINING MEMBER

8.13.5 Carboline 890

product data sheet

carboline®

CARBOLINE® 890

VOC

9860

SELECTION DATA

GENERIC TYPE: Two component, cross-linked epoxy.

GENERAL PROPERTIES: CARBOLINE 890 is a high solids, high gloss, high build epoxy topcoat that can be applied by spray, brush, or roller. The cured film provides a tough, cleanable and esthetically pleasing surface. Available in a wide variety of clean, bright colors. Features include:

- Good flexibility and lower stress upon curing than most epoxy coatings.
- Very good weathering resistance for a high gloss epoxy.
- Very good abrasion resistance.
- Excellent performance in wet exposures.
- Meets the most stringent VOC (Volatile Organic Content) regulations.

RECOMMENDED USES: Recommended where a high performance, attractive, chemically resistant epoxy topcoat is desired. Offers outstanding protection for interior floors, walls, piping, equipment and structural steel or as an exterior coating for tank farms, railcars, structural steel and equipment in various corrosive environments. Recommended industrial environments include Chemical Processing, Offshore Oil and Gas, Food Processing and Pharmaceutical, Water and Waste Water Treatment, Pulp and Paper, Power Generation among others. May be used as a two coat system direct to metal or concrete for Water and Municipal Waste Water immersion. CARBOLINE 890 has been accepted for use in areas controlled by USDA regulations for incidental food contact. Consult Carboline Technical Service Department for other specific uses.

NOT RECOMMENDED FOR: Strong acid or solvent exposures, or immersion service other than recommended.

TYPICAL CHEMICAL RESISTANCE:

Exposure	Immersion	Splash and Spillage	Fumes
Acids	NR	Very Good	Very Good
Alkalies	NR	Excellent	Excellent
Solvents	NR	Very Good	Excellent
Salt Solutions	Excellent	Excellent	Excellent
Water	Excellent	Excellent	Excellent

*NR = Not recommended

TEMPERATURE RESISTANCE:
Continuous: 200° F (93° C)
Non-continuous: 250° F (121° C)

At 300° F, coating discoloration and loss of gloss is observed, without loss of film integrity.

SUBSTRATES: Apply over suitably prepared metal, concrete, or other surfaces as recommended.

COMPATIBLE COATINGS: May be applied directly over inorganic zincs, weathered galvanizing, catalyzed epoxies, phenolics or other coatings as instructed. A test patch is recommended before use over existing coatings. May be used as a tiecoat over inorganic zincs. A mist coat of CARBOLINE 890 is required when applied over inorganic zincs to minimize bubbling. May be topcoated to upgrade weathering resistance. Not recommended over chlorinated rubber or latex coatings. Consult Carboline Technical Service Department for specific recommendations.

April 91 Replaces Oct. 90

SPECIFICATION DATA

THEORETICAL SOLIDS CONTENT OF MIXED MATERIAL:*

	By Volume
CARBOLINE 890	75%±2%

VOLATILE ORGANIC CONTENT:*
As Supplied: 1.78 lbs./gal.(214 gm/liter)
Thinned: The following are nominal values utilizing:
CARBOLINE Thinner # 2 (spray application)

% Thinned	Fluid Ounces/Gal.	Pounds/ Gallon	Grams/ Liter
10%	12.8	2.26	271
CARBOLINE Thinner #33 (brush & roller application)			
12%	16	2.38	285

*Varies with color

RECOMMENDED DRY FILM THICKNESS PER COAT:
4-6 mils(100-150 microns).
5-7 mils (125-175 microns) DFT for a more uniform gloss over inorganic zincs.
Dry film thicknesses in excess of 10 mils(250 microns) per coat are not recommended. Excessive film thickness over inorganic zinc may increase damage during shipping or erection.

THEORETICAL COVERAGE PER MIXED GALLON:
1203 mil sq. ft. (30 sq. m/l at 25 microns)
241 sq. ft. at 5 mils(6.0 sq. m/l at 125 microns)
Mixing and application losses will vary and must be taken into consideration when estimating job requirements.

STORAGE CONDITIONS: Store Indoors
Temperature: 40-110° F (4-43° C)
Humidity: 0-100%

SHELF LIFE: Twenty-four months minimum when stored at 75° F (24° C).

COLORS: Available in Carboline Color Chart colors. Some colors may require two coats for adequate hiding. Colors containing lead or chrome pigments are not USDA acceptable. Consult your local Carboline representative or Carboline Customer Service for availability.

* See notice under DRYING TIMES.

GLOSS: High gloss (Epoxies lose gloss and eventually chalk in sunlight exposure).

ORDERING INFORMATION

Prices may be obtained from your local Carboline Sales Representative or Carboline Customer Service Department.

APPROXIMATE SHIPPING WEIGHT:

	2 Gal. Kit	10 Gal. Kit
CARBOLINE 890	29 lbs. (13 kg)	145 lbs. (66 kg)
THINNER #2	8 lbs. in 1's (4 kg)	39 lbs. in 5's (18 kg)
THINNER #33	9 lbs. in 1's (4 kg)	45 lbs. in 5's (20 kg)

FLASHPOINT: (Pensky-Martens Closed Cup)

CARBOLINE 890 Part A	73° F (23° C)
CARBOLINE 890 Part B	71° F (22° C)
THINNER #2	24° F (−5° C)
THINNER #33	98° F (37° C)

APPLICATION INSTRUCTIONS
CARBOLINE® 890

These instructions are not intended to show product recommendations for specific service. They are issued as an aid in determining correct surface preparation, mixing instructions and application procedure. It is assumed that the proper product recommendations have been made. These instructions should be followed closely to obtain the maximum service from the materials.

0386

SURFACE PREPARATION: Remove oil or grease from surface to be coated with clean rags soaked in CARBOLINE Thinner #2 or Surface Cleaner #3 (refer to Surface Cleaner #3 instructions) in accordance with SSPC-SP 1.

Steel: Normally applied over clean, dry recommended primers. May be applied directly to metal. For immersion service, abrasive blast to a minimum Near White Metal Finish in accordance with SSPC-SP10, to a degree of cleanliness in accordance with NACE #2 to obtain a 1.5-3 mil (40-75 micron) blast profile. For non-immersion, abrasive blast to a Commercial Grade Finish in accordance with SSPC-SP6, to a degree of cleanliness in accordance with NACE #3 to obtain a 1.5-3 mil (40-75 micron) blast profile.

Concrete: Apply over clean, dry recommended surfacer or primer. Can be applied directly to damp(not visibly wet) or dry concrete where an uneven surface can be tolerated. Remove laitance by abrasive blasting or other means.

Do not coat concrete treated with hardening solutions unless test patches indicate satisfactory adhesion. Do not apply coating unless concrete has cured at least 28 days at 70° F (21° C) and 50% RH or equivalent time.

MIXING: Mix separately, then combine and mix in the following proportions:

	2 Gal. Kit	10 Gal. Kit
CARBOLINE 890 Part A	1 gallon	5 gallons
CARBOLINE 890 Part B	1 gallon	5 gallons

THINNING: For spray applications, may be thinned up to 10% (12.8 fl. oz./gal.) by volume with CARBOLINE Thinner #2.

For brush and roller application may be thinned up to 12 % (16 fl. oz./gal.) by volume with CARBOLINE Thinner #33.

Refer to Specification Data for VOC information.

Use of thinners other than those supplied or approved by Carboline may adversely affect product performance and void product warranty, whether express or implied.

POT LIFE: Three hours at 75° F (24° C) and less at higher temperatures. Pot life ends when material loses film build.

APPLICATION CONDITIONS:

	Material	Surfaces	Ambient	Humidity
Normal	60-85° F (16-29° C)	60-85° F (16-29° C)	60-90° F (16-32° C)	0-80%
Minimum	50° F (10° C)	50° F (10° C)	50° F (10° C)	0%
Maximum	90° F (32° C)	125° F (52° C)	110° F (43° C)	80%

Do not apply when the surface temperature is less than 5° F (or 3° C) above the dew point.

Special thinning and application techniques may be required above or below normal conditions.

SPRAY: This is a high solids coating and may require slight adjustments in spray techniques. Wet film thicknesses are easily and quickly achieved. The following spray equipment has been found suitable and is available from manufacturers such as Binks, DeVilbiss and Graco.

Conventional: Pressure pot equipped with dual regulators, 3/8" I.D. minimum material hose, .070" I.D. fluid tip and appropriate air cap.

Airless:
Pump Ratio: 30:1 (min.)*
GPM Output: 3.0 (min.)
Material Hose: 3/8"I.D.(min.)
Tip Size: .017-.021"
Output psi: 2100-2300
Filter Size: 60 mesh

*Teflon packings are recommended and are available from the pump manufacturer.

BRUSH OR ROLLER: Use medium bristle brush, or good quality short nap roller, avoid excessive rebrushing and rerolling. Two coats may be required to obtain desired appearance, hiding and recommended DFT. For best results, tie-in within 10 minutes at 75° F (24° C).

DRYING TIMES: These times are at 5 mils (125 microns) dry film thickness. Higher film thicknesses will lengthen cure times.

Dry to Touch 2 1/2 hours at 75° F (24° C)
Dry to Handle 6 1/2 hours at 75° F (24° C)

Temperature	Dry to Topcoat**	Final Cure
50° F (10° C)	24 hours	3 days
60° F (16° C)	16 hours	2 days
75° F (24° C)	8 hours	1 day
90° F (32° C)	4 hours	16 hours

**When recoating with CARBOLINE 890, recoat times will be drastically reduced. Contact Carboline Technical Service for specific recommendation.

Recommended minimum cure before immersion service is 5 days at 75° F (24° C).

EXCESSIVE HUMIDITY OR CONDENSATION ON THE SURFACE DURING CURING MAY RESULT IN SURFACE HAZE OR BLUSH; ANY HAZE OR BLUSH MUST BE REMOVED BY WATER WASHING BEFORE RECOATING.

CLEANUP: Use CARBOLINE Thinner #2.

CAUTION: READ AND FOLLOW ALL CAUTION STATEMENTS ON THIS PRODUCT DATA SHEET AND ON THE MATERIAL SAFETY DATA SHEET FOR THIS PRODUCT.

CAUTION: CONTAINS FLAMMABLE SOLVENTS. KEEP AWAY FROM SPARKS AND OPEN FLAMES. IN CONFINED AREAS WORKMEN MUST WEAR FRESH AIRLINE RESPIRATORS. HYPERSENSITIVE PERSONS SHOULD WEAR GLOVES OR USE PROTECTIVE CREAM. ALL ELECTRIC EQUIPMENT AND INSTALLATIONS SHOULD BE MADE AND GROUNDED IN ACCORDANCE WITH THE NATIONAL ELECTRICAL CODE. IN AREAS WHERE EXPLOSION HAZARDS EXIST, WORKMEN SHOULD BE REQUIRED TO USE NONFERROUS TOOLS AND TO WEAR CONDUCTIVE AND NONSPARKING SHOES.

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8.13.6 ASTM Specification B29 – Standard Specification for Refined Lead

Designation: B 29 – 03

Standard Specification for Refined Lead[1]

This standard is issued under the fixed designation B 29; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers refined lead in pig, block, or hog form.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to become familiar with all hazards including those identified in the appropriate Material Safety Data Sheet for this product/material as provided by the manufacturer, to establish appropriate safety and health practices, and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 The following documents of the issue in effect on the date of material purchase form a part of this specification to the extent referenced herein.

2.2 *ASTM Standards:*

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[2]

E 37 Test Methods for Chemical Analysis of Pig Lead[3]

E 88 Practice for Sampling Nonferrous Metals and Alloys in Cast Form for Determination of Chemical Composition[3]

3. Ordering Information

3.1 Orders for refined lead under this specification shall include the following information:

3.1.1 ASTM designation and year of issue,

3.1.2 Quantity (weight),

3.1.3 Name of material (for example, pure lead),

3.1.4 Size and shape (see Section 6),

3.1.5 Grade (see Table 1 and accompanying notes), and

3.1.6 Certification or test report if specified (Section 13).

TABLE 1 Chemical Requirements[A,B]

Grade	Composition (Weight Percent)			
	Low Bismuth Low Silver Pure Lead, max[C]	Refined Pure Lead, max[D]	Pure Lead, max	Chemical-Copper Lead[E]
Sb	0.0005	0.0005	0.001	0.001 max
As	0.0005	0.0005	0.001	0.001 max
Sn	0.0005	0.0005	0.001	0.001 max
Sb As and Sn	...	...	0.002	0.002 max
Cu	0.0010	0.0010	0.0015	0.040–0.080
Ag	0.0010	0.0075	0.010	0.020 max
Bi	0.0015	0.025	0.05	0.025 max
Zn	0.0005	0.001	0.001	0.001 max
Te	0.0001	0.0001	...	...
Ni	0.0002	0.0002	0.0005	0.002 max
Fe	0.0002	0.001	0.001	0.002 max
Lead (min) by difference	99.995	99.97	99.94	99.90
UNS Number	L50006	L50021	L50049	L51121

[A] The following applies to all specified limits in Table 1: For the purpose of determining conformance with this specification, an observed value obtained from the analysis shall be rounded off "to the nearest unit" in the last right hand place of figures used in expressing the limiting value, in accordance with the rounding method of Practice E 29.

[B] By agreement between the purchaser and the supplier, analyses may be required and limits established for elements or compounds not specified in Table 1.

[C] This grade is intended for chemical applications where low silver and low bismuth contents are required.

[D] This grade is intended for lead acid battery applications.

[E] This grade is intended for applications requiring corrosion protection and formability.

4. Materials and Manufacture

4.1 Lead shall be supplied in commercial standard forms or shapes requested by the purchaser in the following grades:

4.1.1 Low bismuth low silver pure lead,

4.1.2 Refined pure lead,

4.1.3 Pure lead, and

4.1.4 Chemical copper lead.

4.2 The grades of lead listed in 4.1.1-4.1.4 shall be produced by any smelting and refining process from ore or recycled materials to meet the chemical requirements of this specification.

[1] This specification is under the jurisdiction of ASTM Committee B02 on Nonferrous Metals and Alloys and is the direct responsibility of Subcommittee B02.02 on Refined Lead, Tin, Antimony, and Their Alloys.

Current edition approved June 10, 2003. Published July 2003. Originally approved in 1919. Last previous edition approved in 1997 as B 29 - 92 (1997).

[2] *Annual Book of ASTM Standards*, Vol 14.02.

[3] *Annual Book of ASTM Standards*, Vol 03.05.

5. Composition

5.1 The lead shall conform to the requirements prescribed in Table 1 and accompanying notes.

6. Sizes and Shapes

6.1 Pigs shall weigh up to a nominal 110 lb (50 kg).

6.2 Blocks or hogs shall be square or oblong and weigh up to 2530 lb (1150 kg).

7. Appearance

7.1 The lead shall be reasonably free from surface corrosion and adhering foreign material.

8. Lot

8.1 All lead of the same type produced and cast at one time shall constitute a lot for chemical analysis. Each pig or block of the lot shall bear a single identifying number that can be related to the manufacturing lot.

9. Sampling for Chemical Analysis

9.1 The sample for chemical analysis shall be selected by one of the following methods:

9.1.1 Test samples taken from the lot during casting, or

9.1.2 Test samples taken from the final solidified cast product.

9.2 *Sampling for Lot Analysis*—The supplier may obtain samples from the lot of molten metal during casting. All or part of these samples may be cast into shapes suitable for use in spectrographic analytical methods.

9.3 *Sampling of Cast Product:*

9.3.1 If the lead is in the form of standard pigs (Fig. 1), the sample for chemical analysis shall be taken in accordance with 9.3.3.1, 9.3.3.2, or 9.3.3.3.

9.3.1.1 If the pigs differ in shape from those shown in Fig. 1 or the product is cast into blocks or hogs, the supplier and the purchaser shall agree mutually as to the method to be followed in sampling such shapes.

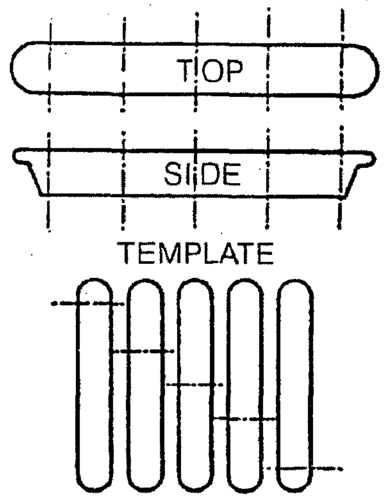
9.3.2 *Sampling Pig Lead*—A portion representative of the total shipment shall be selected at random for the final sample. For lots containing at least 100 000 lb (45 400 kg) of pig lead, one pig shall be taken from every 20 000 lb (9080 kg). For smaller lots, a total of five pigs shall be taken.

9.3.3 *Sample Preparation*—Each pig shall be cleaned thoroughly to rid the surface of dirt or adhering foreign material prior to sampling by one of the following methods: sawing, drilling, or melting.

9.3.3.1 *Sawing*—The pigs selected shall be sawed completely through as illustrated in Fig. 1. The sawings from the pigs shall be mixed thoroughly and quartered, and the samples for analysis taken from the mixed material. The sawings must be free of extraneous material introduced from the saw blade. All sawings shall be treated with a strong magnet in order to remove iron introduced by sawing.

9.3.3.2 *Drilling*—The pigs shall be drilled at least halfway through from two opposite sides as illustrated in Fig. 2. A drill of about ½ in. (12.7 mm) in diameter shall be used. In drilling, the holes shall be spaced along a diagonal line from one corner of the pig to the other. Holes may be made in a single pig or in each of several pigs placed as illustrated in Fig. 2. The drillings shall be clipped into pieces not over ½ in. (12.7 mm) in length, mixed thoroughly, and treated with a strong magnet to remove iron introduced by drilling.

9.3.3.3 *Melting*—Whole pigs, portions of pigs produced by sawing, drillings, or sawings shall be melted in a clean vessel.



Pigs sampled in sets of five according to template as shown above.

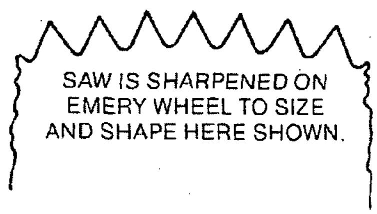
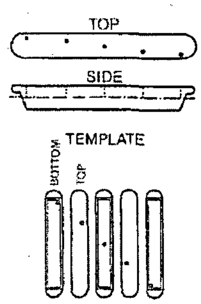


FIG. 1 Method of Sampling Lead by Sawing



NOTE 1—Pigs selected for sampling shall be placed side by side, every other pig bottom side up, and sampled according to template in sets of five pigs each as indicated above. The pigs shall be drilled at least halfway through: when a larger sample is desired, the pigs shall be turned over and sampled on the other diagonal.

FIG. 2 Method of Sampling Lead by Drilling

The melting temperature must not exceed 685°F (363°C) to prevent excessive drossing. The lead must be stirred immediately prior to sampling. The molten lead shall be cast into shapes suitable for use in spectrographic analysis, cast into thin sample bars not to exceed ⅜ in. (9.5 mm) thick for sawing, or granulated by pouring into distilled water and drying the material thoroughly. For sample bars, saw cuts shall be made halfway across the bar from each side and staggered so that they are about ½ in. (12.7 mm) apart. The sawings so produced are treated in accordance with 9.3.3.1.

9.3.4 *Sample Size*:

9.3.4.1 For spectrographic analysis, three samples shall be prepared of a size and shape satisfactory for use by the laboratory at which the analysis is to be made.

9.3.4.2 For wet chemical analysis, each prepared sample (sawings, drillings, or granules) shall weigh at least 600 g.[4]

9.3.5 Aspects of sampling and sample preparation not specifically covered in this specification shall be carried out in accordance with Practice E 88.

10. Methods of Chemical Analyses

10.1 The chemical compositions enumerated in Table 1 of this specification shall, in case of disagreement, be determined by wet chemical or spectrographic methods mutually agreed upon by the supplier and the purchaser.

10.2 By agreement between the purchaser and the supplier, analyses may be required and limits established for elements or compounds not specified in Table 1.

11. Inspection

11.1 Inspection of the material shall be agreed upon between the purchaser and the supplier as part of the purchase contract.

12. Rejection and Rehearing

12.1 Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the supplier promptly and in writing. In case of dissatisfaction with the results of the test, the supplier may make claim for a rehearing.

12.2 Rejection shall be considered as follows:

12.2.1 Variation of weight, quantity, dimensions, or workmanship.

12.2.2 Chemical composition.

12.2.2.1 In case of dispute, the material shall be sampled in the presence of both parties in accordance with 9.3.

12.2.2.2 The resulting sample (at least 1800 g) shall be mixed and separated into three equal parts, each of which shall be placed in a sealed package, one for the supplier, one for the purchaser, and one for the umpire if necessary, and analyzed in accordance with Test Methods E 37.

12.3 When the lead metal satisfies the chemical and physical requirements of this specification, it shall not be condemned for defects in manufacturing or for defects of alloys or products in which it is used.

13. Certification

13.1 When specified in the purchase order or contract, the purchaser shall be furnished certification that samples representing each lot have been tested as directed in this specification and the requirements have been met. When specified in the purchase order or contract, a certified report of the test results shall be furnished.

14. Marking and Special Requirements

14.1 A brand, by which the supplier can be identified, shall be cast or marked legibly upon each pig, block, or hog. In addition, other markings shall identify the material by type and lot number.

14.2 (Any) special marking, color code, and other quality requirements not covered by this specification shall be agreed upon between the supplier and the purchaser.

15. Keywords

15.1 chemical-copper lead; lead; lead metal; pure lead; refined pure lead

[4] "Determination of As, Sb, and Te in Lead and Lead Alloys Using Hydride Generation Atomic Absorption Spectrometry," G.J. Fox, *Atomic Spectroscopy*, Vol 11, No.1, January 1990, p. 13.

Chapter 9
Operating Procedures

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9 OPERATING PROCEDURES

This chapter provides general procedural guidance for the loading, unloading, and recovery of MAGNASTOR. System user personnel shall use this information to prepare the detailed, site-specific procedures for loading, handling, storing, and unloading MAGNASTOR. Users may add, delete, or change the sequence of specific steps of the procedures to accommodate site-specific requirements provided that the general order of the tasks associated with TSC closure and storage is preserved and that the specific requirements for fastener torque values, temperature limits for operations, and other defined values in the procedure are also met.

All facility-specific procedures prepared by users must fully comply with the MAGNASTOR Certificate of Compliance (CoC) and Technical Specifications, including the approved contents and design features.

Equipment and operating requirements will be established by the user prior to implementation. Refer to Table 9.1-1 for a listing of the major auxiliary equipment generally required by the user to load and close or to open and unload the system. MAGNASTOR provides effective shielding for operations personnel; however, the licensee/user may utilize supplemental shielding to further reduce operator radiation exposure. The planned location, type, and possible interactions of the temporary supplemental shielding with MAGNASTOR shall be appropriately evaluated by the licensee/user. MAGNASTOR, when operated by properly trained personnel in accordance with the generic procedures provided herein, will meet As Low As Reasonably Achievable (ALARA) guidance for personnel exposure control.

MAGNASTOR's design features minimize the potential for contamination of the TSC during fuel loading, canister preparation, and transfer. The TSC is loaded in the spent fuel pool, but the external surfaces of the canister are protected from contact with the contaminated pool water by clean water maintained in the annulus between the transfer cask and the TSC. For purposes of the operating procedures, clean water is defined as demineralized, processed, or filtered pool water, or any water external to the spent fuel pool that has water chemistry compatible for use in the spent fuel pool. During loading operations, only the TSC closure lid is exposed to the spent fuel pool water. The smooth top surface of the closure lid can be readily decontaminated. Therefore, the TSC external surfaces are expected to be essentially free of removable contamination during long-term storage operations.

Tables in Chapter 3 provide the handling weights for the major components of MAGNASTOR and the loads to be lifted during various phases of the loading and unloading operations. Licensees/users must perform appropriate reviews and evaluations to ensure that the lifted loads do not exceed rated load limits of user-supplied lifting equipment and comply with the facility's heavy-load program.

9.1 Loading MAGNASTOR

MAGNASTOR is used to load, transfer, and store spent fuel. The three principal components of the system are: the transportable storage canister (TSC), the transfer cask, and the concrete cask. The transfer cask contains and supports the TSC during fuel loading, lid welding and closure operations. The transfer cask, with the transfer adapter, is also used to move the TSC into position for placement in the concrete cask.

These loading procedures are based on three initial conditions.

- the transfer cask is located in a facility's designated workstation for cask preparation
- an empty TSC (properly receipt inspected and accepted) is located in the transfer cask cavity
- an accepted concrete cask is available to receive the TSC when loading and preparation activities are complete

The TSC is filled with clean or pool water and the transfer cask containing the TSC is lowered into the spent fuel pool for fuel assembly loading and verification. The user must identify and select the fuel assemblies to be loaded and ensure that all loaded fuel assemblies comply with the Approved Content provisions of the CoC.

Following fuel loading, the closure lid is installed and the transfer cask containing the loaded TSC is lifted from the bottom of the spent fuel pool. The TSC is partially drained and the closure lid is welded to the TSC shell. The closure lid-to-shell weld is visual and progressive dye penetrant examined. The cavity is refilled and the TSC is subjected to a hydrostatic pressure test with no loss in pressure or observable leakage allowed. Following hydrostatic pressure test acceptance, the closure ring, which provides the redundant confinement closure barrier, is installed, welded and inspected. The TSC cavity water is then drained and volumetrically measured.

The residual moisture in the TSC is then removed by vacuum drying techniques and the TSC dryness is verified. The TSC is then evacuated to ≤ 3 torr and backfilled with a known quantity of pressurized high-purity helium to provide an inert atmosphere and to establish the convective heat transfer flow for the safe long-term storage of the spent fuel contents. System connections to the vent and drain openings are removed and the inner port covers are installed, welded, dye penetrant examined and helium leakage rate tested. The outer port covers, which provide the redundant sealing of the confinement boundary, are installed, welded and dye penetrant examined. Installation and welding of the closure lid, closure ring and port covers complete the assembly of the confinement boundary.

The concrete cask is positioned for the transfer of the TSC and the transfer adapter is installed. The transfer cask containing the loaded TSC is positioned on the transfer adapter on the top of the concrete cask. The TSC is lowered into the concrete cask and the transfer cask and transfer adapter are removed. The concrete lid assembly is installed and secured to complete the loading process.

The loaded concrete cask is moved to the ISFSI storage pad using the site-specific transporter and placed in its long-term storage location. Final radiation surveys are completed and the temperature monitoring system is installed, if used, which completes the MAGNASTOR loading and transfer sequence.

9.1.1 Loading and Closing the TSC

This section describes the sequence of operations to load and close the TSC in preparation for transferring the TSC to the concrete cask. The empty TSC is assumed to be positioned inside the transfer cask located at the designated workstation.

1. Visually inspect the TSC and basket internals for foreign materials or debris.

   Note: When BWR enrichments require the use of the 82-assembly basket configuration, verify the presence of the center cell weldment and upper weldments with blocking strap to assure that assemblies cannot physically be loaded in the five designated nonfuel locations.
2. Visually inspect the top of the TSC shell and closure lid weld preps.
3. Inflate the upper transfer cask annulus seal with air or nitrogen gas. Disconnect the gas supply.

   Note: Either the top or bottom upper annulus seal is used based on the length of the TSC to be loaded.
4. Verify the three TSC retaining blocks are pinned in the retracted position.
5. Verify that at least one lock pin is installed on each transfer cask shield door.
6. Fill the TSC with clean or pool water. For PWR spent fuel contents, the soluble boron concentration in the TSC shall be verified and monitored in accordance with the LCO 3.2.1.
7. Attach the lift yoke to a crane suitable for handling the loaded TSC, transfer cask and yoke. Position the lift yoke over the transfer cask and engage the lift yoke to the two transfer cask trunnions.

   Note: The temperature of the transfer cask (surrounding ambient air temperature) must be verified to be at or above the minimum operating temperature of 0°F, per Section 4.3.1.f. of the Technical Specifications.

8. Lift the transfer cask containing the empty TSC and move it to the spent fuel pool following the prescribed load path.

   Note: A protective cover, attached to the bottom of the transfer cask, may be used to prevent imbedding contaminated particles in the shield doors and door rails.

9. Connect the clean water lines to the lower annulus fill ports of the transfer cask. Ensure that the unused ports are closed or capped to prevent pool water in-leakage.
10. Lower the transfer cask to the pool surface and turn on the clean water supply lines to the lower annulus fill ports to fill the transfer cask/TSC annulus.
11. Spray the transfer cask and lift yoke with clean water to wet the exposed surfaces.

    Note: Wetting the components that enter the spent fuel pool and spraying the components leaving the pool will reduce the effort required to decontaminate the components.

12. Lower the transfer cask as the annulus fills with clean water until the upper annulus fill ports are accessible. Hold this position and connect the clean water annulus fill lines to the upper fill ports. Ensure the unused ports are closed or capped to prevent pool water in-leakage.
13. Lower the transfer cask to the bottom of the pool in the cask loading area.
14. Disengage the lift yoke and visually verify that the lift yoke is fully disengaged. Remove the lift yoke from the spent fuel pool while spraying the yoke and crane cables with clean water.
15. Load the previously selected fuel assemblies into the TSC basket.

    Note: The fuel assemblies shall be selected in compliance with the requirements of the approved contents specified in Appendix B of the Technical Specifications and the boron concentration limits of the Technical Specifications, including limitations on fuel assembly positions within the basket. Assembly selection and placement within the basket shall be independently verified.

16. Visually verify the fuel assembly identification to confirm the serial numbers match the approved fuel-loading pattern.
17. Install three swivel hoist rings hand tight in three of the six closure lid lift holes. Install a three-legged sling set to the hoist rings and connect the sling set to the crane hook or the attachment point on the lift yoke.

    Note: At the discretion of the user, the closure lid can be attached to the lift yoke and the lid installed during the lowering of the lift yoke.

18. Raise the closure lid. Adjust closure lid rigging to level the closure lid.
19. Move the closure lid over the spent fuel pool and align the lift yoke (if used) to the transfer cask trunnions and align the closure lid to the match marks of the TSC.

20. Lower the closure lid until it enters the TSC and seats in the top of the TSC. Visually verify closure lid alignment using the match marks.
21. Allow sling cables to go slack and move the lift yoke into position to engage the transfer cask trunnions. Engage the lift yoke to the trunnions, apply a slight tension, and visually verify engagement.
22. Raise the transfer cask until its top clears the pool surface. Visually verify that the closure lid is properly seated. If necessary, lower the transfer cask and reinstall the closure lid. Rinse the lift yoke and transfer cask with clean water as the equipment is removed from the pool.
23. Rinse and flush the top of the transfer cask and TSC with clean water as necessary to remove any radioactive particles. Survey the top of the TSC closure lid and the top of the transfer cask to check for radioactive particles.
24. As the transfer cask is removed from the spent fuel pool, terminate the annulus fill water supply, remove the annulus fill system hoses and allow annulus water to drain into the spent fuel pool.
25. Following the prescribed load path, move the transfer cask to the designated workstation for TSC closure operations.

    Note: At the option of the user, the TSC closure operations may be performed with the transfer cask partially submerged in the spent fuel pool, cask loading pit or an equivalent structure. This operational alternative provides additional shielding for the cask operators.
26. Disengage the three-legged sling set from the closure lid and the lift yoke from the transfer cask trunnions. Place lift yoke and sling set in storage/lay-down area.
27. Inflate the transfer cask lower annulus seal with air or nitrogen. Disconnect the gas supply from the transfer cask.
28. At the option of the user, based on TSC decay heat load, install the annulus circulating water cooling system to the lower and upper annulus fill lines. Unused fill lines are to be closed or capped.

    Note: Annulus circulating water cooling system operation allows the vacuum drying and TSC transfer times in LCO 3.1.1 to be utilized.

29. Initiate clean water flow into the transfer cask lower fill lines with annulus water discharging through the upper fill lines. Ensure water flow is maintained to keep the outlet water temperature ≤113°F.

    Note: With the annulus circulating water cooling system operating, there is no time limit through completion of the draining of the TSC. However, if the circulating water cooling system is not utilized or becomes nonoperational, measure the cavity water temperature every 2 hours. If TSC preparation operations through draining are not completed prior to the cavity water temperature reaching 200°F, a cooling water flow will be established through the cavity to maintain the water temperature at < 200°F, or the TSC shall be returned to the spent fuel pool within 2 hours and maintained with the TSC submerged for a minimum cooling period of 12 hours, or the annulus circulating water cooling system operation is initiated.

30. Detorque and remove the lifting hoist rings from the closure lid.
31. Using a portable suction pump, remove any standing water from the closure lid weld groove, and the vent and drain ports.
32. Decontaminate the top of the transfer cask and TSC closure lid to allow installation of the welding equipment. Decontaminate external surfaces of the transfer cask and remove the bottom protective cover, if installed.
33. Insert the drain line with a female quick-connector attached through the drain port opening and into the basket drain port sleeve. Remove the female quick-disconnect and any contaminated water displaced from the cavity.
34. Torque the drain tube connector to the drain opening to the value specified in Table 9.1-2. Verify quick-disconnect is installed and properly torqued in the vent port opening.
35. Install a venting device to the vent port quick-disconnect to prevent combustible gas or pressure buildup below the closure lid.
36. Verify that the top of the closure lid is level (flush) with, or slightly above, the top of the TSC shell.
37. At the discretion of the user, establish foreign material exclusion controls to prevent objects from being dropped into the annulus or TSC.
38. Install the welding system, including supplemental shielding, to the top of the closure lid.

    Note: At the discretion of the user, supplemental shielding may be installed around the transfer cask to reduce operator dose. Use of supplemental shielding shall be evaluated to ensure its use does not adversely affect the safety performance of MAGNASTOR.
39. Connect a suction pump to the drain port quick-disconnect and verify venting through the vent port quick-disconnect.
40. Operate the suction pump to remove approximately 70 gallons of water from the TSC. Disconnect the suction pump.

    Note: The radiation level will increase as water is removed from the TSC cavity, as shielding material is being removed.

Note: Fuel rods shall not be exposed to air during the 70-gallon pump-down.

41. Attach a hydrogen detector to the vent line. Ensure that the vent line does not interfere with the operation of the weld machine.
42. Sample the gas volume below the closure lid and observe hydrogen detector for H_2 concentration prior to commencing closure lid welding operations. Monitor H_2 concentration in the TSC until the root pass of the closure lid-to-shell weld is completed.

    Note: If H_2 concentration exceeds 2.4% prior to or during root pass welding operations, immediately stop welding operations. Evacuate the TSC gas volume or purge the gas volume with helium. Verify H_2 levels are <2.4% prior to restarting welding operations.
43. Install shims into the closure lid-to-TSC shell gap, as necessary, to establish a uniform gap for welding. Tack weld the closure lid and shims, as required.
44. Operate the welding equipment to complete the closure lid-to-TSC shell root pass weld in accordance with the approved weld procedure.
45. Remove the H_2 detector from the vent line while ensuring the vent line remains installed.
46. Perform visual and liquid penetrant (PT) examinations of the root pass and record the results.
47. Operate the welding equipment to perform the closure lid-to-shell weld to the midplane between the root and final weld surfaces. Perform visual and PT examinations for the midplane weld pass, and record the results.
48. Complete welding through the completion of the final pass of the closure lid weld, perform final visual and PT examinations, and record the results.
49. Perform the hydrostatic test of the TSC as follows:
    a. Connect a drain line to the vent port and a pressure test system to the drain port.
    b. Refill the TSC with clean water until water is observed flowing from the vent port drain line. Close the vent line isolation valve. Ensure continuing compliance with the boron concentration requirements of LCO 3.2.1.
    c. Pressurize the TSC to 130 (+5, -0) psig and isolate the TSC.
    d. Monitor the TSC pressure for a minimum of 10 minutes and visually examine the closure lid-to-TSC shell weld for leakage of water.
    e. The hydrostatic test is acceptable if there is no observed pressure drop or visible water leakage from the closure lid weld during the test.
    f. Vent the TSC cavity and remove the pressure test system from the drain port and the drain line from the vent line. Reinstall a vent line to the vent port to prevent pressurization of the TSC.
50. Install and tack the closure ring in position in the closure lid-to-TSC shell weld groove.

51. Weld the closure ring to the TSC shell and to the closure lid. Perform visual and PT examinations of the final surfaces of the welds and record the results.
52. Remove the water from the TSC using one of the following methods: drain down using a suction pump with a pressurized helium cover gas; or blow down using pressurized helium gas. Ensure the totalizer in the drain line is reset to zero prior to the start of draining.
    Note: Fuel rods shall not be exposed to air during canister draining operations.
53. Connect a drain line with or without suction pump to the drain port connector.
54. Connect a regulated helium gas supply to the vent port connector.
55. Open gas supply valve and start suction pump, if used, and drain water from the TSC until water ceases to flow out of the drain line. Close gas supply valve and stop suction pump.
56. Record the time at the completion of the draining of the TSC. Record the volume of water drained from the TSC (V_{TSC}) as measured by the totalizer.
57. At the option of the user, disconnect suction pump, close discharge line isolation valve, and open helium gas supply line. Pressurize TSC to approximately 25 psig and open discharge line isolation valve to blow down the TSC. Repeat blow down operations until no significant water flows out of the drain line. Note that time used for system draining and blow down is considered part of the vacuum drying time.
58. Disconnect the drain line and gas supply line from the drain and vent port quick-disconnects.
59. Dry the TSC cavity using vacuum drying methods as follows.
    Note: Ensure heat load dependent vacuum drying time limits are not exceeded so that fuel cladding temperatures are maintained below 752°F. Vacuum drying cycle time limits in LCO 3.1.1 are based on utilizing the annulus circulating water cooling system.
    Note: At the option of the user, the drain and/or vent port quick-disconnects can be removed and replaced temporarily with suitable straight-through fittings to increase flow area cross-section and to reduce resistance to gas flow. The quick-disconnect fittings must be reinstalled and torqued prior to final helium backfill.
    a. Connect the vacuum drying system to the vent and drain port openings.
    b. Operate the vacuum pump until a vapor pressure of ≤ 10 torr is achieved in the TSC. The time durations of the first vacuum drying cycle shall be in accordance with the time limits of LCO 3.1.1.

c. Isolate the vacuum pump from the TSC and turn off the vacuum pump. Observe the vacuum gauge connected to the TSC for an increase in pressure for a minimum period of 10 minutes. If the TSC pressure is ≤ 10 torr at the end of 10 minutes, the TSC is dry of free water in accordance with LCO 3.1.1.

Note: If the dryness verification is not met within the first vacuum drying cycle time as defined in LCO 3.1.1, the TSC shall be backfilled with helium to 7 bar, gauge, and cooled by the annulus circulating water cooling system or by placement in the spent fuel pool for a 24-hour (+1, -0) period. After the cooling period, subsequent drying cycle operations can continue for the times indicated in LCO 3.1.1. Drying cycles and cooling periods may be continued until the TSC cavity passes the dryness verification of Step 59.c per LCO 3.1.1. For fuel burnup greater than 45 GWd/MTU, the number of cooling cycles is limited to ten.

60. Upon satisfactory completion of the dryness verification, evacuate the TSC cavity to a pressure of ≤ 3 torr. Isolate the vacuum pump, and backfill and pressurize the TSC cavity with 99.995% (minimum) pure helium as follows:
    a. Determine the free volume of the TSC (V_{TSC}) per Step 56.
    b. Multiply the V_{TSC} free volume by the helium loading value per unit volume (L_{helium}) to determine required helium mass (M_{helium}) to be backfilled into the cavity.
    c. Set the helium bottle regulator to 100 (+5,-0) psig.
    d. Connect the helium backfill system to the vent port and reset the mass-flow meter to zero.
    e. Slowly open the helium supply valve and backfill the TSC with the required helium mass (M_{helium}) in accordance with LCO 3.1.1.
61. Disconnect the vacuum drying helium backfill system from the vent and drain openings. Note the time the helium backfill is completed.
62. Install and weld the inner port cover on the drain port opening.
63. Install and weld the inner port cover on the vent port opening.
64. Perform visual and PT examinations of the final surface of the port cover welds and record the results.
65. Perform helium leak test on each of the inner port cover welds to verify the absence of helium leakage past the inner port cover welds.
66. Install and weld the outer port cover on the drain port opening. Perform visual and PT examinations of the final weld surface and record the results.

67. Install and weld the outer port cover on the vent port opening. Perform visual and PT examinations of the final weld surface and record the results.
68. Using an appropriate crane, remove the weld machine and supplemental shield.
69. If the annulus circulating water cooling system is utilized and the helium backfill time is satisfied (see LCO 3.1.1), drain the TSC/transfer cask annulus by stopping annulus circulating water flow to the annulus and connecting one or more drain lines to the lower annulus fill ports. Once the annulus is drained, deflate the top and bottom annulus seals. Note the time the annulus circulating water cooling system flow is terminated.

    Note: The time duration of the sequence of operations from stopping the annulus circulating water cooling system, or completing the helium backfill if the annulus circulating water cooling system is not used, through completion of TSC transfer into the concrete cask shall not exceed the transfer time limits in LCO 3.1.1. If the TSC transfer to the concrete cask cannot be completed in the defined time period, the transfer operation will be suspended and the TSC shall be cooled by the annulus circulating water cooling system for a minimum of 24 hours prior to restarting TSC transfer operations. The second, and subsequent, TSC transfer evolution times are limited to LCO 3.1.1 heat load specific transfer times.
70. Remove the lock pins and move the transfer cask retaining blocks inward into their functional position. Reinstall the lock pins.
71. Install the six swivel hoist rings into the six threaded holes in the closure lid if TSC transfer is to be performed by two sets of redundant slings. Torque the hoist rings to the manufacturer's recommended value.

    Note: Alternative site-specific TSC lifting systems and equipment may be used for lowering and lifting the TSC in the transfer cask. The lifting system design must comply with the user's heavy load program and the applicable requirements of ANSI N14.6, NUREG-0612, and/or ASME/ANSI B30.1, as appropriate.
72. Complete final decontamination of the transfer cask exterior surfaces. Final TSC contamination surveys may be performed after TSC transfer following Step 21 in Section 9.1.2 when TSC surfaces are more accessible.
73. Proceed to Section 9.1.2.

9.1.2 Transferring the TSC to the Concrete Cask

This section describes the sequence of operations required to complete the transfer of a loaded TSC from the transfer cask into a concrete cask, and preparation of the concrete cask for movement to the ISFSI pad.

1. Position an empty concrete cask with the lid assembly removed in the designated TSC transfer location.

   Note: The concrete cask can be positioned on the ground, or on a deenergized air pad set, roller skid, heavy-haul trailer, rail car, or transfer cart. The transfer location can be in a truck/rail bay inside the loading facility or an external area accessed by the facility cask handling crane.

   Note: The minimum ambient air temperature (either in the facility or external air temperature, as applicable for the handling sequence) must be $\geq$ 0°F for the use of the concrete cask, per Section 4.3.1.g. of the Technical Specifications.
2. Inspect all concrete cask openings for foreign objects and remove if present; install supplemental shielding in four outlets.
3. Install a four-legged sling set to the lifting points on the transfer adapter.
4. Using the crane, lift the transfer adapter and place it on top of the concrete cask ensuring that the guide ring sits inside the concrete cask lid flange. Remove the sling set from the crane and move the slings out of the operational area.
5. Connect a hydraulic supply system to the hydraulic cylinders of the transfer adapter.
6. Verify the movement of the connectors and move the connector tees to the fully extended position.
7. Connect the lift yoke to the crane and engage the lift yoke to the transfer cask trunnions. Ensure all lines, temporary shielding and work platforms are removed to allow for the vertical lift of the transfer cask.

   Note: The minimum ambient air temperature (either in the facility or external air temperature, as applicable for the handling sequence) must be $\geq$ 0°F for the use of the transfer cask, per Section 4.3.1.f. of the Technical Specifications.
8. Raise the transfer cask and move it into position over the empty concrete cask.
9. Slowly lower the transfer cask into the engagement position on top of the transfer adapter to align with the door rails and engage the connector tees.
10. Following set down, remove the lock pins from the shield door lock tabs.
11. Install a stabilization system for the transfer cask, if required by the facility heavy load handling or seismic analysis programs.

12. Disengage the lift yoke from the transfer cask trunnions and move the lift yoke from the area.
13. As appropriate to the TSC lifting system being used, move the lifting system to a position above the transfer cask. If redundant sling sets are being used, connect the sling sets to the crane hook.
14. Using the TSC lifting system, lift the TSC slightly (approximately ½-1 inch) to remove the TSC weight from the shield doors.

    Note: The lifting system operator must take care to ensure that the TSC is not lifted such that the retaining blocks are engaged by the top of the TSC.
15. Open the transfer cask shield doors with the hydraulic system to provide access to the concrete cask cavity.
16. Using the cask handling crane in slow speed (or other approved site-specific handling system), slowly lower the TSC into the concrete cask cavity until the TSC is seated on the pedestal.

    Note: The transfer adapter and the standoffs in the concrete cask will ensure the TSC is appropriately centered on the pedestal within the concrete cask.

    Note: The completion of the transfer of the TSC to the concrete cask (i.e., the top of the TSC is in the concrete cask cavity) completes the TSC transfer evolution time from Step 69 in Section 9.1.1.
17. When the TSC is seated, disconnect the slings (or other handling system) from the lifting system, and lower the sling sets through the transfer cask until they rest on top of the TSC.
18. Retrieve the lift yoke and engage the lift yoke to the transfer cask trunnions.
19. Remove the seismic/heavy load restraints from the transfer cask, if installed.
20. Close the shield doors using the hydraulic system and reinstall the lock pins into the shield door lock tabs.
21. Lift the transfer cask from the top of the concrete cask and return it to the cask preparation area for next fuel loading sequence or to its designated storage location.
22. Disconnect hydraulic supply system from the transfer adapter hydraulic cylinders.
23. Remove redundant sling sets, swivel hoist rings, or other lifting system components from the top of the TSC, if installed.
24. Verify all equipment and tools have been removed from the top of the TSC and transfer adapter.
25. Connect the transfer adapter four-legged sling set to the crane hook and lift the transfer adapter off the concrete cask. Place the transfer adapter in its designated storage location and remove the slings from the crane hook. Remove supplemental shielding from outlets.

    Note: If the optional low profile concrete cask is used, proceed to Step 26. If the standard concrete cask is provided, proceed to Step 38.

26. Install three swivel hoist rings and the three-legged sling set on the concrete cask shield ring.
27. Using the crane, lift the shield ring and place it into position inside of the concrete cask top flange.
28. Remove the three-legged sling and swivel hoist rings.
29. Using the designated transport equipment, move the loaded concrete cask out of the low clearance work area or truck/rail bay.
30. Install the three swivel hoist rings into the three threaded holes and attach the three-legged sling set to the shield ring.
31. Using an external or mobile crane, lift and remove the shield ring. Place the shield ring in position for the next loading sequence or return it to its designated storage location.
32. Install four swivel hoist rings in the threaded holes of the concrete cask extension using the manufacturer-specified torque.
33. Install the four-legged sling set and attach to the crane hook.

    Note: A mobile crane of sufficient capacity may be required for concrete cask extension and lid installations performed outside the building.
34. Perform visual inspection of the top of the concrete cask and verify all equipment and tools have been removed.

    Note: Take care to minimize personnel access to the top of the unshielded loaded concrete cask due to shine from the TSC.
35. Lift the concrete cask extension and move it into position over the concrete cask, ensuring alignment of the two anchor cavities with their mating lift anchor embedment.
36. Lower the concrete cask extension into position and remove the sling set from the crane hook.
37. Remove the four swivel hoist rings and cables from the concrete cask extension.

    Note: If concrete cask transport is to be performed by a vertical cask transporter, proceed to Step 38. If transport is to be performed using air pads in conjunction with a flat-bed transporter, proceed to Step 40.
38. Install the lift lugs into the anchor cavities of the concrete cask extension, or directly on top of the lifting embedment for the standard concrete cask, if applicable to the concrete cask design utilized.
39. Install the lift lug bolts through each lift lug and into the threaded holes in the embedment base. Torque each of the lug bolts to the value specified in Table 9.1-2.
40. Install three swivel hoist rings into the concrete cask lid and attach the three-legged sling set. Attach the lifting sling set to the crane hook.
41. At the option of the user, install the weather seal on the concrete cask lid flange. Lift the concrete cask lid and place it in position on the top of the flange.

42. Remove the sling set and swivel hoist rings and install the concrete cask lid bolts. Torque to the value specified in Table 9.1-2.
43. Move the loaded concrete cask into position for access to the site-specific transport equipment.
44. Proceed to Section 9.1.3.

9.1.3 Transporting and Placing the Loaded Concrete Cask

The section describes the general procedures for moving a loaded concrete cask to the ISFSI pad using either a vertical cask transporter (Step 1 through Step 9) or a flat-bed transport vehicle (Steps 10 through 17). Steps following Step 17 are performed for all concrete casks.

Vertical Cask Transporter

1. Using the vertical cask transporter lift fixture or device, engage the two concrete cask lifting lugs.
2. Lift the loaded concrete cask and move it to the ISFSI pad following the approved onsite transport route.

   Note: Ensure vertical cask transporter lifts the concrete cask evenly using the two lifting lugs.

   Note: Do not exceed the maximum lift height for a loaded concrete cask of 24 inches, per Section 4.3.1.h. of the Technical Specifications.
3. Move the concrete cask into position over its intended ISFSI pad storage location. Ensure the surface under the concrete cask is free of foreign objects and debris.

   Note: The spacing between adjacent loaded concrete casks must be at least 15 feet.
4. Using the vertical transporter, slowly lower the concrete cask into position.
5. Disengage the vertical transporter lift connections from the two concrete cask lifting lugs. Move the cask transporter from the area.
6. Detorque and remove the lift lug bolts from each lifting lug, if the lugs are to be reused.

   Note: At the option of the user, the lift lugs may be left installed during storage operations.
7. Lift out and remove the concrete cask lift lugs. Store the lift lugs for the next concrete cask movement.
8. Install the lug bolts through the extension base (or through the cover plate for the standard concrete cask) and into the threaded holes. Torque each bolt to the value specified in Table 9.1-2.
9. For the casks with extensions containing anchor cavities, install the weather seal and cover plates. Install the bolts and washers and torque to the value specified in Table 9.1-2.

Flat-bed Transport Vehicle Loaded with the Closed Concrete Cask

10. Move the transport vehicle with the closed concrete cask to a position adjacent to the ISFSI pad.
11. If required, install a bridging plate to cover the gap between the vehicle and the ISFSI pad.
12. If not already installed, insert four deflated air pads into the four inlets.
13. Attach a restraining device around the concrete cask and connect to a tow vehicle suitable for pushing or pulling the concrete cask off of the transport vehicle.
14. Using an air supply and an air pad controller, inflate the air pads.
15. Verify the ISFSI pad surface in the storage location is free of foreign objects and debris.
16. Using the tow vehicle, move the concrete cask into its position on the storage pad.

    Note: The center-to-center spacing of loaded concrete casks shall be a minimum of 15 feet.
17. Lower the concrete cask into position by deflating and removing the four air pads.

All Concrete Casks

18. If optional temperature monitoring is implemented, install the temperature monitoring devices in each of the four outlets of the concrete cask and connect to the site's temperature monitoring system.
19. Install inlet and outlet screens to prevent access by debris and small animals.

    Note: Screens may be installed on the concrete cask prior to TSC loading to minimize operations personnel exposure.
20. Scribe and/or stamp the concrete cask nameplate to indicate the loading date. If not already done, scribe or stamp any other required information.
21. Perform a radiological survey of the concrete cask within the ISFSI array to confirm dose rates comply with ISFSI administrative boundary and site boundary dose limits.
22. Initiate a daily temperature monitoring program or daily inspection program of the inlet and outlet screens to verify continuing effectiveness of the heat removal system.

Table 9.1-1 Major Auxiliary Equipment

Item	Description
Air Pad Rig Set	A device consisting of four air pads, a controller, and an air supply source that lifts the concrete cask using air supplied at a high volume.
Annulus Fill System	System that supplies clean/filtered spent fuel pool water through the transfer cask/TSC annulus using the lower and upper transfer cask fill lines. The system maintains a positive clean water flow to minimize the exposure of the TSC external surfaces to contaminated spent fuel pool water.
Annulus Circulating Water Cooling System	The system provides a circulating water flow through the annulus to maintain the TSC shell temperature during TSC preparation and drying evolutions. The system includes appropriate circulating pump, pressure gauges, and inlet and outlet water thermometer.
Annulus Seals	Inflatable seals provided at the top and bottom of the transfer cask/TSC annulus for use with the annulus fill and annulus circulating water cooling systems.
Bottom Protective Cover	Optional plate temporarily attached to the base of the transfer cask to prevent particulate contamination of the transfer cask shield doors and rails.
Canister Upender	Lifting device used to upright a TSC from the horizontal position to a vertical orientation to allow vertical handling for placing the TSC in the transfer cask.
Cask Transporter	A heavy-haul trailer, a rail car, a vertical cask transporter, or other specially designed equipment used onsite to move the concrete cask. The loaded concrete cask is transported vertically resting on its base (requiring a flat-bed transporter) or it is transported vertically suspended from its lifting lugs (requiring a vertical cask transporter).
Closure Lid Lifting Sling System	Sling system used to install the closure lid into the TSC in the spent fuel pool. At the user's option, the sling system can be suspended from the lift yoke and used to install the lid and engage the yoke with one crane sequence.
Cooldown System (CDS)	Introduces nitrogen, helium and cooling water to the TSC cavity to cooldown the TSC internals and stored spent fuel to allow the return of the TSC to the spent fuel pool for the unloading of the fuel assemblies. This system would only be required in the highly unlikely event that a loaded TSC had to be unloaded.

Table 9.1-1 Major Auxiliary Equipment (continued)

Drain and Blow Down System (DBS)	System used to pump out and/or blow down the water from the TSC cavity prior to the start of drying operations, and to refill the cavity and hydrostatic test the closure lid weld. The system includes the appropriate suction pump, piping/hoses, flow meter/totalizer, helium cover gas supply, pressure gauges, and valves to connect to the TSC vent and drain port connections to complete the draining and hydrostatic testing of the cavity.
Hydrogen Detection System	System that detects increased concentration of H_2 in the cavity resulting from material reactions during closure lid root pass welding operations and for closure lid weld removal operations.
Helium Mass Spectrometer Leak Detector (MSLD)	A system utilized to perform the helium leakage testing of the inner vent and drain port cover welds.
Lid Retention System	An optional component installed on top of the TSC closure lid to secure the lid during cask handling operations between the spent fuel pool and the workstation used to close the TSC.
Lift Yoke (with Crane Hook Extension, if required)	Device for lifting and moving MAGNASTOR transfer cask by engaging the lifting trunnions.
Loaded TSC Sling System	Redundant sling system (two 3-legged slings) used to transfer a TSC into a concrete cask or a transfer cask and meeting the requirements of ANSI N14.6 and the facility crane. Alternative TSC handling systems that meet site-specific or client requirements and comply with the facility's heavy lift program developed per NUREG-0612 may be utilized.
Remote/Robotic Welding System	System that completes the closure lid and port cover welds with minimal operator assistance. The system may include video cameras and a recording device to remotely observe the welding activities and to videotape the results of the closure lid PT examinations.
Supplemental Weld Shield	Optional steel plate installed on the closure lid to provide additional shielding to the cask operators during TSC welding, preparation, and test activities. The supplemental weld shield may be installed separately or as the base plate for the welding system.
Vacuum Drying and Helium Backfill System	The system used to vaporize and remove residual water, water vapor, and oxidizing gases from the TSC cavity prior to backfilling with helium. The system includes the appropriate vacuum pump(s), vacuum and pressure gauges, helium supply connections and valves, and hoses to connect the system to the vent and drain connections.
Weld Removal System	Semiautomatic mechanical weld and/or TSC shell cutting system used to remove the closure lid and port cover welds in the unlikely event that a TSC needs to be unloaded.

Table 9.1-2 Threaded Component Torque Values

Threaded Component	Torque Value (ft-lb)
Concrete Cask Lid Bolts	Snug + 1 wrench flat
Concrete Cask Body Extension	Snug + 1 wrench flat
Closure Lid Lifting Hoist Rings • Lid Handling Only • Loaded TSC Handling	 Hand Tight Per hoist ring manufacturer's recommendation
Drain Tube Connector • Viton, EDPM, or Elastomer Seal • Metallic Seal	 Per seal manufacturer's specs Per seal manufacturer's specs
Vent Port Connector • Viton, EDPM, or Elastomer Seal • Metallic Seal	 Per seal manufacturer's specs Per seal manufacturer's specs
Cover Plate Bolts	Snug + 1 wrench flat
Concrete Cask Lift Lug Bolts	600 (+60, -60) ft-lb
Concrete Cask Lid Lifting Hoist Rings	Hand Tight

9.2 Removing the Loaded TSC from a Concrete Cask

This procedure assumes the loaded concrete cask is returned to the reactor loading facility for unloading. However, transfer of the TSC to another concrete cask can be performed at the ISFSI without the need to return to the loading facility, provided a cask transfer facility that meets the requirements specified in the Technical Specifications is available.

As the steps to move a loaded concrete cask are essentially the reverse of the procedures in Section 9.1.2 and Section 9.1.3, the procedural steps are only summarized here.

1. Remove inlet and outlet screens and temperature measuring equipment (if installed).
   Note: The minimum ambient air temperature (either in the facility or external air temperature, as applicable for the handling sequence) must be ≥ 0°F for the use of the concrete cask, per Section 4.3.1.g. of the Technical Specifications.
2. For concrete casks to be transported by a vertical cask transporter, remove anchor cavity cover plates, remove the lid assembly bolts, and install the lift lugs. Torque the lift lug bolts for each lift lug to the value specified in Table 9.1-2. Attach the concrete cask to the vertical cask transporter.
3. For concrete casks to be transported on a flat-bed vehicle, install an air pad rig set in the inlets. Inflate the air pads and move concrete cask onto the vehicle deck.
4. Move the loaded concrete cask to the facility.
5. Remove the concrete cask lid. Install concrete cask shield ring, if required.
6. Install the six hoist rings into the canister closure lid threaded holes. Remove shield ring, if installed.
7. Install transfer adapter on top of the concrete cask.
8. Place transfer cask onto the transfer adapter and engage the shield door connectors.
   Note: The minimum ambient air temperature (either in the facility or external air temperature, as applicable for the handling sequence) must be ≥ 0°F for the use of the transfer cask, per Section 4.3.1.f. of the Technical Specifications.
9. Open the shield doors, retrieve the lifting slings, and install the slings on the lifting system.
10. Slowly withdraw the TSC from the concrete cask. The chamfer on the underside of the transfer adapter assists in the alignment into the transfer cask.
11. Bring the TSC up to just below the retaining blocks. Close the transfer cask shield doors and install the shield door lock pins.

12. Lift transfer cask off the concrete cask and move to the designated workstation.

After the transfer cask with the loaded TSC is in, or adjacent to, the facility, the operational sequence to load another concrete cask is performed in accordance with the procedures in Section 9.1.2. Note that the amount of time that a loaded TSC can remain in the transfer cask without cooling will be administratively controlled and is based on the heat load of the TSC. Cooling of the TSC may be required as described in Section 9.1.1.

9.3 Wet Unloading a TSC

This section provides the basic operational sequence to prepare, open, and unload a TSC in a spent fuel pool. Due to the rugged design and fabrication of the TSC, users are not expected to perform this operational sequence. However, in accordance with the Technical Specifications, each user shall have the procedures and required equipment available, and perform a dry run of the unloading process.

The procedure that follows assumes that the TSC is in a transfer cask in the appropriate workstation.

1. Pull the lock pins and retract the retaining blocks in the transfer cask. Reinstall the lock pins.
2. Survey the TSC and transfer cask to establish radiation areas.
3. Install the weld removal system on the closure lid and bolt the system to the closure lid threaded holes.
4. Establish appropriate airborne radiation controls.
5. Using the weld removal system, remove the outer and inner port covers from the vent and drain ports.
6. Remove the weld removal system.
7. Using a vacuum sample bottle, take a gas sample of cavity gas.
8. Determine total gaseous inventory and connect a venting system to the vent connector and route to HEPA filters or to the off-gas system.
9. Determine TSC internal pressure and vent the cavity gas.
10. Once pressure has been reduced to atmospheric, and using appropriate radiological controls, remove the vent and drain quick-disconnects and seals.
11. Replace the quick-connects and seals with approved spares, and torque them to the value specified in Table 9.1-2.
12. Attach the cooldown system to the vent and drain connections.
13. Initiate nitrogen gas flow through the TSC to flush out residual radioactive gases. Continue nitrogen flow for a minimum of 10 minutes.
14. Initiate the controlled filling (5 +3/-0 gpm) of the TSC with clean water through the drain connector under controlled temperature (minimum 70°F) and pressure conditions (25 +10/-0 psig). Borated water shall be used as required for the PWR fuel contents in accordance with LCO 3.2.1.
15. Monitor steam/water temperature of the discharge from the vent connection.
16. Continue cooldown operations until the discharge water temperature is below 180°F.
17. Terminate cooling water flow and disconnect the cooldown system from the drain and vent ports. Install a vent line to the vent port.

Note: Cooling of the TSC using the annulus circulating water system may be required to assure cavity water boiling will not occur during closure lid weld removal operations per Section 9.1.1.

18. Connect a suction pump to the drain connector. Operate the pump and remove approximately 70 gallons of water from the cavity. Disconnect and remove the pump.
19. Remove the drain line from the closure lid.
20. Install the hydrogen detector to the vent line and verify hydrogen gas concentration in the gas volume in the cavity. If the concentration reaches 2.4%, stop all cutting activities and remove cavity gas using a vacuum pump.
21. Install the weld removal system on the closure lid. Operate the weld removal system to remove the closure ring-to-TSC shell and closure ring-to-closure lid welds. Remove the closure ring from the lid area.
22. Operate the weld removal system to remove the closure lid-to-shell weld.
23. Remove shims, if installed, to provide a suitable gap to be able to extract the closure lid under water.
24. Remove the weld removal system. Terminate annulus circulating water flow, if used.
25. Install three swivel hoist rings into the closure lid threaded holes. Attach three-legged sling set to the hoist rings and the lifting system (or, alternately, the transfer cask lifting yoke).
26. Engage the lift yoke to the transfer cask trunnions and bring the transfer cask over the spent fuel pool.
27. Install lower annulus fill lines and fill the annulus with clean water while lowering the transfer cask.
28. When the trunnions are near the pool surface, install upper annulus fill lines and start clean water flow.
29. Lower the transfer cask to the bottom of the pool. Disengage the lift yoke.
30. Slowly remove the closure lid and move the lid to an appropriate storage area.
    Note: The closure lid may be contaminated and slightly activated.
31. Following fuel unloading, reengage the lift yoke to the transfer cask trunnions and remove the transfer cask from the pool.
32. While the transfer cask is over the pool, stop the flow of water to the annulus, disconnect the upper and lower fill lines, and allow the water in the annulus to drain back into the pool.
33. Place transfer cask and empty TSC in the cask decontamination area or other workstation.
34. Using a suction pump, remove the water from the TSC and pump to radwaste drains or return the water to the spent fuel pool.
35. Remove and store the contaminated TSC until a determination is made regarding reuse or disposition of the closure lid and TSC.

36. As appropriate, the user may proceed with the loading of the removed fuel assemblies in a new TSC in accordance with the procedures in Section 9.1.

Chapter 10
Acceptance Criteria and Maintenance Program

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10 Acceptance Criteria and Maintenance Program

This chapter specifies the workmanship inspections, the acceptance test program, and the applicable inspection and test acceptance criteria to be implemented for the fabrication, use, and maintenance of the MAGNASTOR system. The inspections and tests described in this chapter provide assurance that MAGNASTOR components are fabricated, inspected, tested, accepted for use, and maintained under the conditions specified in this Safety Analysis Report (SAR) and the Certificate of Compliance (CoC).

The controls, inspections, and tests set forth in this chapter ensure that the MAGNASTOR system will maintain the confinement of radioactive material under normal conditions or off-normal or accident events of storage; will maintain subcriticality control; will properly transfer the decay heat of the stored radioactive materials; and that the off-site radiation doses will comply with regulatory requirements.

The MAGNASTOR system is classified as important-to-safety and, therefore, the structures, systems, and components (SSCs) of the system are designed, fabricated, assembled, inspected, tested, accepted, and maintained in accordance with a quality assurance program. The application of the quality assurance program for the system's SSCs shall be commensurate with their defined safety category. The safety classifications of the major SSCs are provided in Chapter 2.

10.1 Acceptance Criteria

This section provides the workmanship and acceptance tests to be performed on the MAGNASTOR components and systems during their fabrication, as well as prior to and during loading of the system. These tests and inspections provide assurance that the components and systems have been procured, fabricated, assembled, inspected, tested, and accepted for use under the conditions and controls specified in this document and the Certificate of Compliance.

10.1.1 Visual Inspection and Nondestructive Examination

Fabrication, inspection, and testing are performed in accordance with the applicable design criteria, codes and standards specified in Chapter 2 and on the license drawings.

The following fabrication controls and inspections shall be performed to assure compliance with this document and the license drawings:

a) Materials of construction for the MAGNASTOR are identified on the license drawings and shall be procured with certification and supporting documentation as required by the ASME Code, Section II [1], when applicable; and the requirements of ASME Code, Section III, Subsection NB [2] and Subsection NG [3], when applicable.

b) Materials and components shall be receipt inspected for visual and dimensional acceptability, material conformance to the applicable Code specification and traceability markings, as applicable. Materials for the TSC confinement boundary (e.g., TSC shell plates, base plate, closure lid, and port covers) shall also be inspected per the requirements of ASME Code, Section III, Subsection NB-2500.

c) The confinement boundary shall be fabricated and inspected in accordance with ASME Code, Section III, Subsection NB, with the code alternatives as listed in Chapter 2, Table 2.1-2. The TSC fuel basket and basket supports shall be fabricated and inspected in accordance with the ASME Code, Section III, Subsection NG, with the alternatives listed in Table 2.1-2.

d) The steel components of the transfer cask shall be in accordance with ASTM specifications and fabricated in accordance with ANSI N14.6 [11]. Inspections and NDE of the transfer cask shall be in accordance with ASME Code, Section III, Subsection NF.

e) The steel components of the concrete cask shall be in accordance with ASTM specifications and fabricated in accordance with ASME Code, Section VIII [6] (or fabrication may be in accordance with ANSI/AWS D1.1). Inspections of the welded steel components of the concrete cask shall be in accordance with ASME Code, Section VIII or ANSI/AWS D1.1.

f) ASME Code welding shall be performed using welders and weld procedures qualified in accordance with ASME Code, Section IX [7] and the ASME Code, Section III subsection applicable to the component (e.g., NB, NG or NF). ANSI/AWS code welding may be performed using welders and procedures qualified in accordance with the applicable AWS requirements or in accordance with ASME Code, Section IX.

g) Construction and inspections of the concrete component of the concrete cask shall be performed in accordance with the applicable sections and requirements of ACI-318 [8].

h) Visual examinations of the welds of the confinement boundary shall be performed in accordance with ASME Code, Section V, Articles 1 and 9 [9], with acceptance per Section III, Subsection NF, Article NF-5360. The final surface of TSC shell welds shall be dye penetrant examined (PT) in accordance with ASME Code, Section V, Articles 1 and 6, with acceptance per Section III, Subsection NB, Article NB-5350. The TSC shell longitudinal and circumferential welds shall be radiographic examined (RT) in accordance with ASME Code, Section V, Articles 1 and 2, with acceptance per Section III, Subsection NB, Article NB-5320. The weld of the TSC baseplate to the TSC shell shall be ultrasonic examined (UT) in accordance with ASME Code, Section V, Articles 1 and 5, with acceptance per Section III, Subsection NB, Article NB-5330. In accordance with ISG-15 [14], the TSC closure lid to shell weld, performed following fuel loading, shall be dye penetrant (PT) examined at the root, mid-plane and final surface in accordance with ASME Code, Section V, Articles 1 and 6, with acceptance per Section III, Subsection NB, Article NB-5350. The closure ring to TSC shell and the closure ring to closure lid welds shall be PT examined in accordance with the same code and acceptance criteria as the closure lid to TSC shell weld, except that only the weld final surface will be examined. The inner and outer (redundant) port covers to closure lid welds shall be PT examined at the final surface in accordance with the same code and acceptance criteria as for the closure lid to shell weld. Repairs to TSC vessel welds shall be performed in accordance with ASME Code, Section III, Subsection NB, Article NB-4450, and the welds reinspected per the original acceptance criteria applicable to the examination method.

i) Visual examinations of the welds of the fuel basket and basket supports shall be performed in accordance with ASME Code, Section V, Articles 1 and 9, with acceptance per Section III, Subsection NG, Article NG-5360. The fuel tube welds shall be magnetic particle examined (MT) in accordance with ASME Code, Section V, Articles 1 and 7, with acceptance criteria per Section III, Subsection NG, Article NG-5340. Repairs to fuel basket welds shall be performed in accordance with ASME Code, Section III, Subsection NG, Article NG-4450, and the welds reinspected per the original acceptance criteria applicable to the examination method.

j) Visual examinations of the concrete cask structural steel weldments shall be performed in accordance with the ASME Code, Section V, Articles 1 and 9, or ANS/AWS D1.1, Section 6.9, with acceptance per Section VIII, Division 1, Part UW, Articles UW-35 and UW-36, or Table 6.1 of ANSI/AWS D1.1, respectively. Repairs to concrete cask structural weldment welds shall be performed in accordance with ANSI/AWS D1.1, and the welds reinspected per the original acceptance criteria.

k) Visual examination of the welds of the transfer cask shall be performed in accordance with ASME Code, Section V, Articles 1 and 9, or ANSI/AWS D1.1, Section 6.9, with acceptance per Section III, Subsection NF, Article NF-5360. Following structural load testing of the transfer cask, the final surface of all critical load-bearing welds shall be either dye penetrant (PT) or magnetic particle (MT) examined in accordance with ASME Code, Section V, Articles 1 and 6 for PT and Articles 1 and 7 for MT. The acceptance criteria for the weld examinations shall be in accordance with Section III, Subsection NF, Article NF-5350 for PT and NF-5340 for MT. Repairs to the transfer cask vertical load-bearing welds shall be performed in accordance with ASME Code, Section III, Subsection NF, Article NF-4450 or ANSI/AWS D1.1. Repaired welds shall be reinspected per the original acceptance criteria applicable to the examination method.

l) Dimensional inspections of components shall be performed in accordance with written and approved procedures to verify compliance to the license drawings and fit-up of individual components. All dimensional inspections and functional fit-up tests shall be documented.

m) All components shall be inspected for cleanliness and proper packaging for shipping in accordance with written and approved procedures. All components will be free of any foreign material, oil, grease, and solvents.

n) Inspection and nondestructive examination personnel shall be qualified in accordance with the requirements of SNT-TC-1A [10].

10.1.2 Structural and Pressure Tests

10.1.2.1 Load Testing of Transfer Casks

The transfer cask is designed, fabricated, and tested to the requirements of ANSI N14.6 [11]. The transfer cask is provided with two lifting trunnions near the top of the cask for lifting and handling. The trunnion pair is designed for a maximum design lift load of 230,000 pounds. The transfer cask shield doors and supporting door rails are designed to retain and support the maximum TSC loaded weight of 118,000 pounds.

Following completion of fabrication, the load-bearing components of the transfer cask, including the lifting trunnions, shield doors, and rails, are load tested to verify their structural integrity to lift and retain the applicable loads.

The lifting and handling of the transfer cask and loaded TSC are defined as critical lifting loads per NUREG-0612 [12] at a number of nuclear facilities. In accordance with ANSI N14.6, special lifting devices for critical loads shall be provided with redundant lifting paths, or be designed and tested to higher safety factors. The transfer cask lifting trunnions, shield doors, and rails are designed to higher safety factors and are load tested to 300% of the maximum service load for each type of component.

The lifting trunnion pair shall have a load equal to three times their maximum service load applied for a minimum of 10 minutes. Likewise, the transfer cask shield doors and rails shall have a load equal to three times their maximum service load applied for a minimum of 10 minutes. After release of the test loads, the accessible portions of the trunnions and the adjacent areas, and the shield doors and rails and adjacent areas shall be visually examined to verify no deformation, distortion, or cracking occurred. The critical load-bearing welds of the transfer cask shall be examined by the methods and acceptance criteria defined in Section 10.1.1, Item k).

Any evidence of deformation, distortion, or cracking of the loaded components, critical load-bearing welds or adjacent areas shall be cause for failure of the load test, and repair and/or replacement of the component. Following repair or replacement, the applicable portions of the load test shall be performed again and the components reexamined in accordance with the original procedure and acceptance criteria.

Load testing of the transfer cask shall be performed in accordance with written and approved procedures, and the test results shall be documented.

10.1.2.2 Load Testing of Concrete Cask Lifting Lugs and Anchors

The concrete cask is designed to be lifted and transported using two lifting anchors imbedded in the reinforced concrete of the shell. Lifting lugs are bolted to the anchors and provide a pin connection to a lifting system. The concrete lifting anchors, lifting lugs and attachment bolting are designed, fabricated, and tested in accordance with the requirements of ANSI N14.6 for lifts not made over safety-related equipment (noncritical lifts).

The concrete cask lifting lug load test shall be performed on the lugs independently of the concrete cask and will consist of applying a vertical load that is equal to 150% of the maximum concrete cask weight, plus a 10% dynamic load factor. The test load shall be applied for a minimum of 10 minutes. After the release of the test load, the accessible portions of the lifting anchors shall be visually examined to verify no deformation, distortion, or cracking occurred. Critical load-bearing welds of the lifting anchors shall be magnetic particle (MT) examined in accordance with ASME Code, Section V, Articles 1 and 7, with acceptance criteria per Section III, Subsection NF, Article NF-5340.

Any evidence of deformation, distortion, or cracking of the loaded components, critical load-bearing welds or adjacent areas shall be cause for failure of the load test, and repair and/or replacement of the affected component(s). Following repair or replacement, the applicable portions of the load test shall be reperformed and the components reexamined in accordance with the original procedure and acceptance criteria.

Load testing of the concrete cask lifting lugs shall be performed in accordance with written and approved procedures, and the test results shall be documented.

10.1.2.3 Pressure Testing of the TSC

Following completion of the closure lid-to-TSC shell weld during the TSC preparation operations after fuel loading, the TSC shall be hydrostatically pressure tested in accordance with ASME Code, Section III, Subsection NB, NB-6000 requirements as described in Section 9.1.1. The minimum test pressure of 130 psig shall be applied to the drain port connection for a minimum of 10 minutes. The minimum test pressure is 125% of the normal operating pressure of 104 psig. There shall be no loss in pressure or visible water leakage from the closure lid weld during the 10-minute test period. The normal operating pressure and minimum test pressure are identical for both PWR and BWR TSCs.

10.1.3 Leakage Tests

The confinement boundary is defined as the TSC shell weldment, closure lid, and vent and drain port covers. As described in Section 10.1.1, the confinement boundary is designed, fabricated, examined, and tested in accordance with the requirements of the ASME Code, Section III, Subsection NB, except for the code alternatives listed in Table 2.1-2.

Following welding, the TSC shell weldment shall be leakage tested using the evacuated envelope method as described in ASME Code, Section V, Article 10, and ANSI N14.5 to confirm the total leakage rate is less than or equal to 1×10^{-7} ref. cm^3/s at an upstream pressure of 1 atmosphere absolute and a downstream pressure of 0.01 atmosphere absolute, or less. Under these test conditions, this corresponds to a test leakage rate of 2×10^{-7} cm^3/s, helium at standard conditions.

The TSC shell weldment will be closed using a test lid installed over the top of the shell and the cavity evacuated with a vacuum pump to a vacuum of two torr or less. A test envelope will be installed around the TSC enclosing all of the TSC shell confinement welds, evacuated and backfilled to approximately 1 atmosphere absolute with 99.995% (minimum) pure helium. The percentage of helium gas in the test envelope will be accounted for in the determination of the test sensitivity. A mass spectrometer leak detector (MSLD) is attached to the test lid and samples the evacuated volume for helium. The minimum sensitivity of the helium MSLD and test system shall be less than or equal to 1×10^{-7} cm^3/s, helium, which is one-half of the allowable leakage criteria for leaktight.

If helium leakage is detected, the area of leakage shall be identified and repaired in accordance with the ASME Code, Section III, Subsection NB, NB-4450. The complete helium leakage test shall be performed again to the original test acceptance criteria.

Leakage testing of the TSC shell weldment shall be performed in accordance with written and approved procedures, and the test results documented.

Based on the confinement system materials, welding requirements and inspection methods, leakage testing of the closure lid is not required. In order to ensure the integrity of the vent and drain inner port cover welds, a helium leakage test of each weld is performed using the evacuated envelope method, as described in ASME Code, Section V, Article 10, and ANSI N14.5. The leakage test is to confirm that the leakage rate for each port cover is $\leq 1\times10^{-7}$ ref. cm^3/s, which corresponds to a helium test leakage rate of $\leq 2\times10^{-7}$ ref. cm^3/s. Following inner port cover welding, a test bell is installed over the top of the port cover and the test bell volume is evacuated to a low pressure by a helium Mass Spectrometer Leak Detector (MSLD) system. The minimum sensitivity of the helium MSLD shall be $\leq 1\times10^{-7}$ ref. cm^3/s, helium, which is one-half of the allowable leakage criteria for leaktight.

If leakage is detected, the area of leakage shall be identified and repaired in accordance with ASME Code, Section III, Subsection NB, NB-4450. The helium leak test shall be reperformed to the original test acceptance criteria.

10.1.4 Component Tests

10.1.4.1 Valves, Rupture Discs, and Fluid Transport Devices

The MAGNASTOR system design does not include any rupture discs or fluid transport devices. The closure lid vent and drain openings are each closed by valved quick-disconnect nipples. These nipples are recessed into the closure lid and are used during TSC preparation activities to drain, dry, and helium fill the TSC cavity. No credit is taken for the ability of the valved nipples to confine radioactive material. After completion of final helium backfill pressure adjustment, the port covers are welded in the vent and drain openings enclosing the valved nipples. The port covers provide the confinement boundary for the vent and drain openings.

10.1.4.2 Gaskets

The confinement boundary provided by the welded TSC has no mechanical seals or gaskets. The concrete cask includes weather seals at the concrete cask lid to cask interface. These gaskets do not provide a safety function and loss of the gaskets during operation would have no effect on the safe operation of the concrete cask. The gaskets are provided to facilitate concrete cask maintenance by minimizing water intrusion into the gasketed area.

10.1.5 Shielding Tests

The MAGNASTOR system design is analyzed based on the materials of fabrication and their thickness, using conservative shielding codes to evaluate system dose rates at the system's surface and at selected distances from the surface. The system shield design does not require performance of a shield test.

Following the loading of each MAGNASTOR and its movement to the ISFSI pad, radiological surveys are performed by the system user to establish area access requirements and to confirm that evaluated offsite doses will meet the applicable regulations. These tests are sufficient to identify any significant defect in the shielding effectiveness of the concrete cask.

10.1.6 Neutron Absorber Tests

NOTE

Sections 10.1.6.4.5, 10.1.6.4.6 and 10.1.6.4.7 are incorporated into the MAGNASTOR CoC Technical Specification by reference, Paragraph 4.1.1, and may not be deleted or altered in any way without a CoC amendment approval from the NRC. The text in these three sections is shown in bold to distinguish it from other sections.

Neutron absorber materials are included in the design and fabrication of the MAGNASTOR fuel basket assemblies to assist in the control of reactivity, as described in Chapter 6. Criticality safety is dependent upon the neutron absorber material remaining fixed in position on the fuel tubes and containing the required amount of uniformly distributed boron. A neutron absorber material can be a composite of fine particles in a metal matrix or an alloy of boron compounds with aluminum. Fine particles of boron or boron-carbide that are uniformly distributed are required to obtain the best neutron absorption. Three types of neutron absorber materials are commonly used in spent fuel storage and transport cask fuel baskets: Boral (registered trademark), borated metal matrix composites (MMC), and borated aluminum alloy. The fabrication of the neutron absorber material is controlled to provide a uniform boron carbide distribution and the specified ^{10}B areal density.

10.1.6.1 Design/Performance Requirements

The MAGNASTOR system utilizes sheets of neutron absorber material that are attached to the sides of the spent fuel storage locations in the fuel baskets. The materials and dimensions of the neutron absorber sheets are defined on license drawings 71160-571 and 71160-572. The material is called out as a metallic composite (includes borated aluminum alloy, borated MMC, and Boral, which are available under various commercial trade names). Incorporating optional neutron absorber materials in the design provides fabrication flexibility for the use of the most economical and available neutron absorber material that meets the critical characteristics necessary to assure criticality safety. The critical design characteristics of the neutron absorber material are:

- A minimum “effective” areal density of 0.036 g/cm^2 ^{10}B for the PWR basket and 0.027 g/cm^2 ^{10}B for the BWR basket; and
- A uniform distribution of boron carbide; and
- A yield strength greater than or equal to that used in Section 10.1.6.4.4; and
- An effective thermal conductivity greater than or equal to that used in Section 10.1.6.4.4.

The required minimum actual ^{10}B loading in a neutron absorber sheet is determined based on the effectiveness of the material, i.e., 75% for Boral and 90% for borated aluminum alloys and for borated metal matrix composites. Neutron attenuation testing will be used to verify the areal density and the uniform distribution of ^{10}B in the neutron absorber materials. Table 8.8-1 presents a tabulation of the types of neutron absorber materials, the required minimum effective areal density of ^{10}B, and the required minimum as-fabricated areal density of ^{10}B.

The positions of the neutron absorber sheets with their attachments and retainers to the fuel tubes are shown on license drawings 71160-551 and 71160-591. The attachments and retainers ensure that the neutron absorber remains in place for all loading conditions for the lifetime of the canister.

10.1.6.2 Terminology

Applicable terminology definitions for the neutron absorber materials:

acceptance –	tests conducted to determine whether a specific production lot meets selected material properties and characteristics, or both, so that the lot can be accepted for commercial use.
areal density –	for sheets with flat parallel surfaces, the density of the neutron absorber times the thickness of the material.
designer –	the organization responsible for the design or the license holder for the dry cask storage system or transport packaging. The designer is usually the purchaser of the neutron absorber material, either directly or indirectly (through a fabrication subcontractor).
lot –	a quantity of a product or material accumulated under conditions that are considered uniform for sampling purposes.
neutron absorber –	a nuclide that has a large thermal or epithermal neutron absorption cross-section, or both.

neutron absorber material –	a compound, alloy, composite or other material that contains a neutron absorber.
neutron attenuation test –	a process in which a material is placed in a thermal neutron beam, and the number of neutrons transmitted through the material in a specified period of time is counted. The observed neutron counting rate may be converted to areal density by performing the same test on a series of calibration standards.
neutron cross-section –	a measure of the probability that a neutron will interact with a nucleus; a function of the neutron energy and the structure of the interacting nucleus.
packaging –	in transport of radioactive material, the assembly of components necessary to enclose the radioactive contents completely.
qualification –	the process of evaluating and testing, or both, a material produced by a specific manufacturing process to demonstrate uniformity and durability for a specific application.

10.1.6.3 Inspections

After manufacturing, each sheet of neutron absorber material will be visually and dimensionally inspected for damage, embedded foreign material, and dimensional compliance. The neutron absorber sheets are intended to be defect/damage free, but limited defects/damages are acceptable. Allowed defects are discussed in each material specification section that follows. Standard industrial inspections will be performed on the neutron absorber sheets to verify the acceptability of physical characteristics such as dimensions, flatness, straightness, tensile properties (if structural considerations are applicable) or other mechanical properties as appropriate, surface quality and finish. Inspection and testing of the neutron absorber materials will be performed in accordance with written procedures, by appropriately certified personnel, and the inspection and test results will be documented.

10.1.6.4 Specification

Three types of neutron absorber materials are permitted to augment criticality control in the MAGNASTOR fuel baskets – (1) Boral, a clad composite of aluminum and boron carbide, as specified in Section 10.1.6.4.1; (2) borated metal matrix composites (MMC), as specified in

Section 10.1.6.4.2; and (3) borated aluminum alloy, as specified in Section 10.1.6.4.3. The required minimum "effective" areal density of ^{10}B in a neutron absorber is defined on license drawings 71160-571 and 71160-572, in Section 1.8, and is based on the fuel basket geometry and on the fuel assembly type and reactivity. The analyses of the fuel baskets do not consider the tensile strength of the neutron absorber material other than that it be sufficient to maintain its form, i.e., at least equivalent to the properties listed in Table 8.3-16. Environmental conditions encountered by the neutron absorber material may include:

- Immersion in water with the associated chemical, temperature and pressure concerns
- Dissimilar materials
- Gamma and neutron radiation fluence
- Dry heat-up rates
- Maximum temperatures

Except for materials for which validation has been completed, the durability of the neutron absorber materials is validated to demonstrate the following results:

- Neutron absorber materials will not incur significant damage due to the pressure, temperature, radiation, or corrosion environments that may be present in the loading and storage of spent fuel;
- Aluminum and boron carbide do not react with each other in the range of the maximum temperatures present in the fuel baskets;
- There are no significant changes in mechanical properties of the neutron absorber materials due to the fast neutron fluences experienced in spent fuel storage;
- General corrosion does not have time to affect the integrity of the neutron absorber material due to the very short time of immersion in spent fuel pool water.

Individual material types and process lots are tested to verify the presence, uniform distribution and minimum areal density (effectiveness) of ^{10}B specific to each type of neutron absorber material.

10.1.6.4.1 Boral

Boral is a composite core of blended boron carbide and aluminum powders between outer layers of aluminum. The core is slightly porous. Sheets of Boral are formed and mechanically bonded by hot-rolling ingots of the core material between aluminum sheets. Boral is credited with an effectiveness of 75% of the specified minimum areal density of ^{10}B in Boral based on acceptance and qualification testing of the material as described in Sections 10.1.6.4.4, 10.1.6.4.5 and 10.1.6.4.6. Visual inspections of the Boral sheets will verify the presence of a full core and will identify any cladding damage, cracks or discontinuities, embedded foreign material, or peeled cladding. Evidence of less than a full core, embedded foreign material, cracks or sharp burrs in the cladding shall be identified as nonconforming. Nonconforming items are segregated and evaluated within the NAC International Quality Assurance Program, and assigned one of the following dispositions: "Use-As-Is," "Rework/Repair" or "Reject." Only material that is determined to meet all applicable conditions of the license will be accepted. Embedded pieces of B_4C matrix material are not considered foreign material, but such material shall be removed from the surface of the Boral. Scratches, creases or other surface indications are acceptable on the cladding of the Boral, but exposure of the core through the cladding surface of the sheet is not acceptable.

10.1.6.4.2 Borated Metal Matrix Composites - MMC

Borated metal matrix composite (MMC) material can be produced by powder metallurgy, casting or thermal spray methods and consists of fine boron carbide particles in a matrix of aluminum. Borated MMC material is a metallurgically bonded matrix, low porosity product. Borated metal matrix composites rely on a fine (average 10-40 micron) boron carbide particle size to achieve a uniform boron distribution. Specifications on the boron carbide particle size in MMCs are included in Section 10.1.6.4.7. MMCs are credited with an effectiveness of 90% of the specified minimum areal density of ^{10}B in the borated MMC material based on acceptance and qualification testing of the material as described in the Sections 10.1.6.4.4, 10.1.6.4.5 and 10.1.6.4.6. Visual inspections of the sheets of borated MMC material will be based on Aluminum Association recommendations, as applicable—i.e., blisters and/or widespread rough surface conditions such as die chatter or porosity shall be identified as nonconforming. Nonconforming items are segregated and evaluated within the NAC International Quality Assurance Program, and assigned one of the following dispositions: "Use-As-Is," "Rework/Repair" or "Reject." Only material that is determined to meet all applicable conditions of the license will be accepted. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores or discoloration are acceptable based on material neutron attenuation and thermal performance not being impacted by minor fabrication anomalies.

10.1.6.4.3 Borated Aluminum

Borated aluminum material is a direct chill cast metallurgy product with a uniform fine dispersion of discrete boron particles in a matrix of aluminum. Borated aluminum material is a metallurgically bonded matrix, low porosity product. Borated aluminum is credited with an effectiveness of 90% of the specified minimum areal density of ^{10}B in the borated aluminum material based on acceptance and qualification testing of the material as described in Sections 10.1.6.4.4, 10.1.6.4.5 and 10.1.6.4.6. Visual inspections of the sheets of borated aluminum material will be based on Aluminum Association recommendations, as applicable—i.e., blisters and/or widespread rough surface conditions such as die chatter or porosity shall be identified as nonconforming. Nonconforming items are segregated and evaluated within the NAC International Quality Assurance Program, and assigned one of the following dispositions: "Use-As-Is," "Rework/Repair" or "Reject." Only material that is determined to meet all applicable conditions of the license will be accepted. Local or cosmetic conditions such as scratches, nicks, die lines, inclusions, abrasion, isolated pores or discoloration are acceptable based on material neutron attenuation and thermal performance not being impacted by minor fabrication anomalies.

10.1.6.4.4 Thermal Conductivity and Yield Strength Testing of Neutron Absorber Material

Thermal Conductivity Testing

Thermal conductivity qualification testing of the neutron absorber materials shall conform to ASTM E1225 [15], ASTM E1461 [16], or an equivalent method. The testing shall be performed at room temperature on test coupons taken from production material. Note that thermal conductivity increases slightly with temperature increases.

- Sampling will initially be one test per lot and may be reduced if the first five tests meet the specified minimum thermal conductivity. Additional tests may be performed on the material from a lot whose test result does not meet the required minimum value, but the lot will be rejected if the mean value of the tests does not meet the required minimum value.
- Upon completion of 25 tests of a single type of neutron absorber material having the same aluminum alloy matrix and boron content (in the same compound), further testing may be terminated if the mean value of all of the test results minus two standard deviations meets the specified minimum thermal conductivity. Similarly, testing may be terminated if the matrix of the material changes to an alloy with a larger coefficient of thermal conductivity, or if the boron compound remains the same, but the boron content is reduced.

In the Chapter 4 thermal analyses, the neutron absorber is conservatively evaluated as a 0.125-in nominal thickness sheet (0.1-in thick boron composite core with 0.0125-in thick aluminum face plates - Boral) for the PWR fuel basket and a 0.10-in nominal thickness sheet (0.075-in thick boron composite core with 0.0125-in thick aluminum face plates - Boral) for the BWR fuel basket. The required minimum thermal conductivities for the MAGNASTOR absorbers are as follows.

Minimum Effective Thermal Conductivity - BTU/(hr-in-°F)

Fuel Basket Type	Radial		Axial	
	100°F	500°F	100°F	500°F
PWR	4.565	4.191	4.870	4.754
BWR	4.687	4.335	5.054	5.017

Neutron absorber sheets of borated MMC material or borated aluminum will have higher effective coefficients of thermal conductivity than the Boral sheets evaluated due to their larger aluminum alloy content. The neutron absorber thermal acceptance criterion will be based on the nominal sheet thickness. Surface anomalies increase radiation heat transfer and have insignificant influence on thermal conductivity, permitting acceptance of minor surface defects without additional material testing.

Additional thermal conductivity qualification testing of neutron absorber material is not required if certified quality-controlled test results (from an NAC approved supplier) that meet the specified minimum thermal conductivity are available as referenced documentation.

Yield Strength Testing

Yield strength qualification testing of the neutron absorber shall conform to ASTM Test Method B 557/B 557M, E 8 or E 21 [17, 18, 19]. For the laminated absorber (i.e., Boral), yield strength credited in the structural analysis was limited to the outer aluminum cover sheets. Therefore, only the cover sheet material must be shown to meet the required strength.

Neutron absorber material yield strength must be equal to or greater than 1.6 ksi at 700°F. Per Table 8.3-16, a yield strength of 1.6 ksi is the material strength of the neutron absorber at 700°F and is applied as a temperature-independent value in the structural evaluations of the absorber. This yield strength assures that the material will maintain its form when subjected to normal, off-normal and accident condition loads.

The neutron absorber yield strength acceptance criterion will be based on the absorber meeting the specified nominal sheet thickness. Control and limitations on the neutron absorber boron content (primary driver to material structural performance) permits acceptance without additional material yield strength acceptance testing.

Additional yield strength qualification testing of neutron absorber material is not required if certified quality-controlled test results (from an NAC approved supplier) that meet the specified minimum yield strength are available as referenced documentation.

10.1.6.4.5 Acceptance Testing of Neutron Absorber Material by Neutron Attenuation

NOTE

Section 10.1.6.4.5 is incorporated into the MAGNASTOR CoC Technical Specification by reference, Paragraph 4.1.1, and may not be deleted or altered in any way without a CoC amendment approval from the NRC. The text in this section is shown in bold to distinguish it from other sections.

Acceptance testing shall be performed to ensure that neutron absorber material properties for sheets in a given production run are in compliance with the materials requirements for the MAGNASTOR fuel baskets and that the process is operating in a satisfactory manner.

Statistical tests will be run to augment findings relating to isotopic content, impurity content or uniformity of the ^{10}B distribution.

- **Determination of neutron absorber material acceptance shall be performed by neutron attenuation testing. Neutron attenuation testing of the final product or the coupons shall compare the results with those for calibrated standards composed of a homogeneous ^{10}B compound. Other calibrated standards may be used, but those standards must be shown to be equivalent to a homogeneous standard. These tests shall include a statistical sample of finished product or test coupons taken from each lot of material to verify the presence, uniform distribution and the minimum areal density of ^{10}B.**
- **Alternative test methods for neutron attenuation may include chemical analysis or radiography, or a combination of these two methods, provided the alternate methods have been benchmarked (validated or calibrated) to neutron attenuation testing results and have adequate precision to confirm absorber efficacy.**
- **The ^{10}B areal density is measured using a collimated thermal neutron beam of up to 1.2 cm diameter. A beam size greater than 1.2 cm diameter, but no larger than 1.7 cm diameter, may be used if computations are performed to demonstrate that the calculated k_{eff} of the system is still below the calculated Upper Subcritical Limit (USL) of the system, assuming defect areas the same area as the beam. Following are the required computations for using a neutron beam size greater than 1.2 cm diameter.**

    1. **Defects of the same area as the proposed neutron beam or larger have an areal density significantly below the specified minimum areal density.**

2. These defects are distributed randomly or systematically over the material, or in a manner that is conservative for the design analysis.

3. The total of such defective areas amounts to (100-x) percent of the neutron absorber material area, where x is the probability level used for determining the lower tolerance limit.

Alternately, apply more rigorous statistical criteria for lot acceptance, i.e., increase the factor K in the following expression.

Lower tolerance limit = average of sample – K * standard deviation of sample ≥ Technical Specification areal density acceptance criterion,

where, K is the one-sided tolerance limit factor for a normal distribution with a specified sample size, probability and confidence.

The value of K should be increased to compensate for the decreased standard deviation that results from using a larger neutron beam to examine a material that has defect areas with a characteristic dimension of 1.2 cm.

- Based on the MAGNASTOR required minimum effective areal density of ^{10}B – 0.036 g/cm^2 for the PWR basket and 0.027 g/cm^2 for the BWR basket – and the credit taken for the ^{10}B for the criticality analyses, i.e., 75% for Boral and 90% for borated aluminum alloys and for borated metal matrix composites, a required minimum areal density for the as-manufactured neutron absorber sheets is established.
- Test locations/coupons shall be well distributed throughout the lot of material, particularly in the areas most likely to contain variances in thickness, and shall not contain unacceptable defects that could inhibit accurate physical and test measurements.
- The sampling plan shall require that each of the first 50 sheets of neutron absorber material from a lot, or a coupon taken therefrom, be tested. Thereafter, coupons shall be taken from 10 randomly selected sheets from each set of 50 sheets. This 1 in 5 sampling plan shall continue until there is a change in lot or batch of constituent materials of the sheet (i.e., boron carbide powder or aluminum powder) or a process change. A measured value less than the required minimum areal density of ^{10}B during the reduced inspection is defined as nonconforming, along with other contiguous sheets, and mandates a return to 100% inspection for the next 50 sheets. The coupons are indelibly marked and recorded for identification. This

identification will be used to document the neutron absorber material test results, which become part of the quality record documentation package.

- The minimum areal density specified shall be verified for each lot at the 95% probability, 95% confidence level (also expressed as 95/95 level) or better. The following illustrates one acceptable method.

  The acceptance criterion for individual plates is determined from a statistical analysis of the test results for that lot. The minimum ^{10}B areal densities determined by neutron attenuation are converted to volume density, i.e., the minimum ^{10}B areal density is divided by the thickness at the location of the neutron attenuation measurement or the maximum thickness of the coupon. The lower tolerance limit of ^{10}B volume density is then determined—defined as the mean value of ^{10}B volume density for the sample, less K times the standard deviation, where K is the one-sided tolerance limit factor for a normal distribution with 95% probability and 95% confidence.

  Finally, the minimum specified value of ^{10}B areal density is divided by the lower tolerance limit of ^{10}B volume density to arrive at the minimum plate thickness that provides the specified ^{10}B areal density.

  Any plate that is thinner than this minimum or the minimum design thickness, whichever is greater, shall be treated as nonconforming, with the following exception. Local depressions are acceptable, as long as they total no more than 0.5% of the area on any given plate and the thickness at their location is not less than 90% of the minimum design thickness.

- All neutron absorber material acceptance verification will be conducted in accordance with the NAC International Quality Assurance Program. The neutron absorber material supplier shall control manufacturing in accordance with the key process controls via a documented quality assurance system (approved by NAC or NAC's approved fabricator), and the designer shall verify conformance by reviewing the manufacturing records.

- Nonconforming material shall be evaluated within the NAC International Quality Assurance Program and shall be assigned one of the following dispositions: "Use-As-Is," "Rework/Repair" or "Reject." Only material that is determined to meet all applicable conditions of the license will be accepted.

10.1.6.4.6 Qualification Testing of Neutron Absorber Material

NOTE

Section 10.1.6.4.6 is incorporated into the MAGNASTOR CoC Technical Specification by reference, Paragraph 4.1.1, and may not be deleted or altered in any way without a CoC amendment approval from the NRC. The text in this section is shown in bold to distinguish it from other sections.

Qualification tests for each MAGNASTOR System neutron absorber material and its set of manufacturing processes shall be performed at least once to demonstrate acceptability and durability based on the critical design characteristics, previously defined in this section.

The licensed service life will include a range of environmental conditions associated with short-term transfer operations, normal storage conditions, as well as off-normal and accident storage events. Additional qualification testing is not required for a neutron absorber material previously qualified, i.e., reference can be provided to prior testing with the same, or similar, materials for similar design functions and service conditions.

- **Qualification testing is required for: (1) neutron absorber material specifications not previously qualified; (2) neutron absorber material specifications previously qualified, but manufactured by a new supplier; and (3) neutron absorber material specifications previously qualified, but with changes in key process controls. Key process controls for producing the neutron absorber material used for qualification testing shall be the same as those to be used for commercial production.**
- **Qualification testing shall demonstrate consistency between lots (2 minimum).**
- **Environmental conditions qualification will be verified by direct testing or by validation by data on the same, or similar, material, i.e., the neutron absorber material is shown to not undergo physical changes that would preclude the performance of its design functions. Conditions encountered by the neutron absorber material may include: short-term immersion in water, exposure to chemical, temperature, pressure, and gamma and neutron radiation environments. Suppliers' testing will document the durability of neutron absorber materials that may be used in the MAGNASTOR system by demonstrating that the neutron absorber materials will not incur significant damage due to the pressure, temperature, radiation, or corrosion environments or the short-term water immersion that may occur in the loading and storage of spent fuel.**

- Thermal conductivity and yield strength qualification testing shall be as previously described in Section 10.1.6.4.4.
- The uniformity of the boron carbide distribution in the material shall be verified by neutron attenuation testing of a statistically significant number of measurements of the areal density at locations distributed throughout the test material production run, i.e., at a minimum from the ends and the middle of the run. The sampling plan must be designed to demonstrate 95/95 compliance with the absorber content requirements. Details on acceptable neutron attenuation testing are previously provided in this section for Acceptance Testing. Alternate test methods may be employed provided they are validated (benchmarked) to neutron attenuation tests.
- One standard deviation of the neutron attenuation test sampling results shall be less than 10% of the sample mean. This requirement provides additional assurance that a consistent product is achieved by the manufacturing process.
- A material qualification report verifying that all design requirements are satisfied shall be prepared.
- Key manufacturing process controls in the form of a complete specification for materials and process controls shall be developed for the neutron absorber material by the supplier and approved by NAC to ensure that the product delivered for use is consistent with the qualified material in all respects that are important to the material's design function.
- Major changes in key manufacturing processes for neutron absorber material shall be controlled by mutually agreed-upon process controls established by the certificate holder/purchaser and the neutron absorber supplier. These process controls will ensure that the neutron absorber delivered will always be consistent with the qualification test material in any and all respects that are important to the neutron absorber's safety characteristics. Changes in the agreed-upon process controls may require requalification of those parts of the qualification that could be affected by the process changes. Typical changes covered by the agreed-upon process controls may include:
  - Changes that could adversely affect mechanical properties (e.g., change in thermal conductivity, porosity, material strength, change of matrix alloy, boron carbide content, increase in the B_4C content above that used in previously qualified material, etc.);
  - Changes that could affect the uniformity of boron (e.g., change to mixing process for aluminum and boron carbide powders, change in stirring of melt, change in boron precipitate phase, etc.).

- **Minor neutron absorber material processing changes may be determined to be acceptable on the basis of engineering review without additional qualification testing, if such changes do not adversely affect the particle bonding microstructure, i.e., the durability or the uniformity of the boron carbide particle distribution, which is the neutron absorber effectiveness.**
- **Nonconforming material shall be evaluated within the NAC International Quality Assurance Program and shall be assigned one of the following dispositions: "Use-As-Is," "Rework/Repair" or "Reject." Only material that is determined to meet all applicable conditions of the license will be accepted.**

10.1.6.4.7 Additional Material Specifications

NOTE

Section 10.1.6.4.7 is incorporated into the MAGNASTOR CoC Technical Specification by reference, Paragraph 4.1.1, and may not be deleted or altered in any way without a CoC amendment approval from the NRC. The text in this section is shown in bold to distinguish it from other sections.

Boron carbide particles for MMCs shall have an average size in the range 10-40 microns and no more than 10% of the particles shall be over 60 microns. The material shall have negligible interconnected porosity exposed at the surface or edges.

10.1.7 Thermal Tests

Thermal acceptance testing of the MAGNASTOR system following fabrication and construction is not required. Continued effectiveness of the heat-rejection capabilities of the system may be monitored during system operation using a remote temperature-monitoring system.

The heat-rejection system consists of convection air cooling where air flow is established and maintained by a chimney effect, with air moving from the lower inlets to the upper outlets. Since this system is passive, and air flow is established by the decay heat of the contents of the TSC, it is sufficient to ensure by inspection that the inlet and outlet screens are clear and free of debris that could impede air flow. Because of the passive design of the heat-rejection system, no thermal testing is required.

10.1.8 Cask Identification

Each TSC and concrete cask shall be marked with a model number and an identification number. Each concrete cask will additionally be marked for empty weight and date of loading. Specific marking instructions are provided on the license drawings for these system components.

10.2 Maintenance Program

A generic maintenance program is defined in an operations manual, which will be provided to system users. The operations manual will provide instructions for the inspection, testing, and component replacements required to ensure continued safe and effective operation and handling of the MAGNASTOR system. System users will develop site-specific maintenance programs and documents.

The MAGNASTOR is totally passive by design. There are no active components or systems required to assure the continued performance of its safety functions during storage operations. This results in a minimal inspection and maintenance program for the lifetime of the system. The routine maintenance requirements and schedule are shown in Table 10.2-1. As shown in the table, the requirements include concrete surface condition inspections and repairs, and reapplication of corrosion-inhibiting coatings on accessible external carbon steel surfaces.

Maintenance activities for the MAGNASTOR shall be performed under the user's approved quality assurance (QA) program. Maintenance activities shall be administratively controlled and the results documented, as required by the QA program.

10.2.1 Structural and Pressure Tests

As described and analyzed in this document, there is no credible event leading to the structural failure of the TSC resulting in the loss of radioactive material confinement. Therefore, periodic structural or pressure tests on the TSC following initial acceptance and loading are not required.

The transfer cask shall be maintained, tested, and inspected in accordance with the routine inspection, maintenance, and annual testing requirements of ANSI N14.6. Prior to each use of the transfer cask, the trunnions and shield door assembly will be inspected for gross damage, adequate lubrication, and proper function. On a maintenance schedule established by the user, the transfer cask corrosion-inhibiting coating will be inspected and repaired in accordance with the coating supplier application procedures. Areas of minor scratching or damage to the coating of the transfer cask found during use may be temporarily repaired using a nuclear grade, pool-compatible grease.

10.2.2 Leakage Tests

The TSC confinement boundary is provided by a welded vessel and, as described in Chapters 3 and 12, no credible normal conditions or off-normal or accident events result in a loss of confinement. Therefore, maintenance leakage testing of the TSC is not required.

10.2.3 Subsystem Maintenance

The MAGNASTOR does not include any active subsystems that provide safety functions during storage operations. Therefore, no subsystem maintenance is required.

Auxiliary systems used during operations, such as equipment, rigging, and instrumentation used to handle, prepare, and weld the TSC or concrete cask, are maintained and calibrated by the users in accordance with their QA program and the safety importance of the auxiliary system, equipment, instrument, or rigging.

10.2.4 Shielding Tests

The shielding materials of the TSC, concrete cask, and transfer cask are designed for long-term use with negligible degradation over time as a result of normal operations. Chipping, spalling, or other defects of the concrete cask surface shall be identified by annual visual inspection. Repairs to defects larger than approximately one-inch deep or square shall be performed using grout repair materials applied in accordance with the manufacturer's instructions. Accessible external carbon steel surfaces are inspected annually to verify the integrity of corrosion-inhibiting coatings. Coatings are reapplied as necessary for the repair of the coating in accordance with manufacturer's instructions.

Table 10.2-1 MAGNASTOR Maintenance Program Schedule

Task	Frequency
Visual inspection and repair or recoating of concrete cask concrete and accessible coated carbon steel surfaces	Annually during storage operations
Visual inspection of concrete cask identification markings	Annually
Load testing and/or visual and dimensional inspection of the transfer cask	Annually while transfer cask is in operation, or prior to returning to service
Visual inspection and repair or recoating of transfer cask exposed carbon steel surfaces, except on sliding surfaces	Annually while transfer cask is in operation, or prior to returning the transfer cask to service
Visual inspection of transfer cask exposed carbon steel surfaces and temporary repair of coating surfaces using site-approved materials	Quarterly
Functional check of transfer cask sliding parts to verify adequate lubrication	Each use
Functional check of transfer cask inflatable seals to confirm operability	Each use

10.3 References

1. ASME Boiler and Pressure Vessel Code, Section II, Part A & Part B, "Materials," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
2. ASME Boiler and Pressure Vessel Code, Section III, Subsection NB, "Class 1 Components," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
3. ASME Boiler and Pressure Vessel Code, Section III, Subsection NG, "Core Support Structures," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
4. ASME Boiler and Pressure Vessel Code, Section III, Subsection NF, "Supports," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
5. ANSI/AWS D1.1, "Structural Welding Code – Steel," American National Standards Institute, Inc., Washington, DC, 1998.
6. ASME Boiler and Pressure Vessel Code, Section VIII, Part UW, "Pressure Vessels Fabricated by Welding," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
7. ASME Boiler and Pressure Vessel Code, Section IX, "Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
8. ACI 318-95 and (ACI 318R-95), "Building Code Requirements for Structural Concrete," and Commentary, American Concrete Institute, Farmington Hills, MI, October 1995.
9. ASME Boiler and Pressure Vessel Code, Section V, "Nondestructive Examination," American Society of Mechanical Engineers, New York, NY, 2001 Edition with 2003 Addenda.
10. Recommended Practice SNT-TC-1A, "Nondestructive Testing", American Society for Nondestructive Testing, Columbus, OH, edition as invoked by the applicable ASME Code.
11. ANSI N14.6-1993, "American National Standard for Radioactive Materials – Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4,500 kg) or More," American National Standards Institute, Inc., Washington, DC, June 1993.
12. NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants," US Nuclear Regulatory Commission, Washington, DC, July 1980.
13. TR-017218-R1, EPRI Guideline for Sampling in the Commercial Grade Item Acceptance Process, Final Report, January 1999.
14. ISG-15, "Materials Evaluation," US Nuclear Regulatory Commission, Washington, DC, Revision 0, January 10, 2001.

15. ASTM Standard E1225[a], "Test Method for Thermal Conductivity of Solids by Means of the Guarded-Comparative-Longitudinal Heat Flow Technique."
16. ASTM Standard E1461[a], "Test Method for Thermal Diffusivity of Solids by the Flash Method."
17. ASTM Standard B 557/B 557M[a], "Test Methods of Tension Testing Wrought and Cast Aluminum and Magnesium Alloy Products."
18. ASTM Standard E8[a], "Test Methods for Tension Testing of Metallic Materials."
19. ASTM Standard E21[a], "Test Methods for Elevated Temperature Tension Tests of Metallic Materials."

[a] Current edition of testing standards at time of testing is to be used.

Chapter 11
Radiation Protection

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11 RADIATION PROTECTION

MAGNASTOR is provided in PWR and BWR fuel assembly configurations. The PWR system is designed to store up to 37 PWR spent fuel assemblies and associated nonfuel hardware. The BWR system is designed to store up to 87 BWR spent fuel assemblies with or without zirconium-based alloy channels. The radiation protection features and analysis presented in this chapter apply to both fuel assembly configurations. The estimated exposures for operations and storage are based on the PWR or BWR contents that result in the highest dose rates. Transfer cask exposures are based on the cask configuration documented in Section 5.1.1 and, as such, rely on a dry canister cavity with a supplemental (weld) shield in place.

11.1 Ensuring that Occupational Radiation Exposures Are As Low As Reasonably Achievable (ALARA)

MAGNASTOR provides appropriate radiation protection features for cask system operations to minimize the exposure of operations personnel to radiation or radioactive materials. The components of the system that require operation, maintenance, and inspection are designed to minimize radiation exposure to personnel.

11.1.1 Policy Considerations

MAGNASTOR is designed so that operation, inspection, repair, and maintenance can be carried out while maintaining occupational exposure As Low As Reasonably Achievable (ALARA) [1,2].

11.1.2 Design Considerations

When used in accordance with its design, MAGNASTOR maintains occupational radiation exposures as low as reasonably achievable while meeting overall system performance objectives. The following specific design features demonstrate the ALARA philosophy.

- Material selection and surface preparation that facilitate decontamination.
- Basket configurations that allow spent fuel loading using accepted standard practices.
- Positive clean water flow in the transfer cask/TSC annulus to minimize the potential for contamination of the TSC surfaces during in-pool loading.
- Passive confinement, thermal, criticality, and shielding systems that require no maintenance.
- Thick steel and concrete shells in the storage system, and a steel/lead/neutron shield/steel configuration in the transfer system.
- Nonplanar cooling air pathways with respect to the spent fuel assembly source regions to minimize radiation streaming at the concrete cask inlets and outlets.
- Provision of shield blocks below the vent and drain openings in the closure lid to minimize streaming.
- Provision of quick-release devices for use on the transfer cask doorstops and retaining blocks.
- Optional use of remote, automated outlet air temperature measurement to reduce surveillance time.

11.1.3 Operational Considerations

The ALARA philosophy has been incorporated into the procedural steps necessary to operate the system in accordance with its design. The following features or actions, which comprise a baseline radiological controls approach, have been incorporated in the design or procedures to minimize occupational radiation exposure.

- Use of a prefabricated weld shield as a base for the welding system during welding equipment setup, removal, welding, and weld inspection of the closure lid, closure ring, and port covers. The weld shield is used during the TSC closing and sealing operations.
- Use of remote manual or automatic equipment for welding the closure lid and closure ring.
- Decontamination of the exterior surface of the transfer cask and welding of the closure lid while the TSC remains filled with water. (Personnel exposures reported in this chapter are based on a conservative dry TSC shielding evaluation.)
- Use of quick-disconnect fittings at vent and drain port penetrations to facilitate auxiliary system connections.
- Use of remote handling equipment, where practicable, to reduce radiation exposure.

The operational procedures and ALARA practices at a particular facility will be determined by the user's operational conditions and facilities.

11.2 Radiation Protection Design Features

The detailed description of the MAGNASTOR radiation shielding design is provided in Chapter 5. The principal radiation protection design features are the shielding necessary to meet the design objectives, the placement of penetrations near the edge of the TSC lid to reduce operator exposure and improve access, and the use of the weld shield for work on and around the closure lid. Use of the weld shield reduces operator exposure during the welding, inspection, draining, drying and helium backfilling operations.

Radiation exposure rates at various work locations were determined with the MCNP5 code within the vicinity of a single transfer and concrete cask and the NAC-CASC (a modified SKYSHINE-III version) code for the concrete cask array. These codes generated bounding dose rate profiles at various distances from the transfer and concrete cask, which are used to estimate the operator exposures for loading and routine operations.

11.3 Estimated Onsite Collective Dose Assessment

Operations personnel exposure estimates are based on identifying the operational cask sequence, estimating the duration and number of personnel required to perform the tasks, determining the location of the personnel in relation to the cask, and multiplying the dose rates at the particular task location by the number of personnel and the task duration. The operational tasks identified are based on the MAGNASTOR operating procedures provided in this document and operational experiences in loading other canister-based systems.

A collective dose estimate is provided for placing a single MAGNASTOR on the ISFSI, and for exposures related to routine storage operations of a 20-cask (2×10 array) ISFSI. Each cask in the array is assumed to be loaded with the contents that produce the maximum dose rate.

The personnel exposure estimates associated with loading and routine operations are presented in Table 11.3-1 through Table 11.3-4. The estimated durations, task sequences, and personnel requirements are based on the MAGNASTOR design features, operational experiences in loading systems of similar design, and operational and equipment improvements based on previous experience. These estimates are provided to allow the user to perform ALARA evaluations on MAGNASTOR implementation and use, and to establish personnel exposure guidelines for operating personnel. For each user, the site-specific design features, location and configuration of work stations, equipment staging, standard practices, operating crew size, use of temporary shielding, etc., will result in personnel exposures that may be higher or lower than those presented.

11.3.1 Estimated Dose Due to Loading Operations

The estimated dose due to loading operations considers the collective dose due to the loading, closure, transfer, and placement of a single TSC containing bounding fuel assembly contents. This analysis assumes that the exposure incurred by the operators is independent of background radiation, as background will vary with site conditions. A two mrem/hr dose rate is assigned to tasks not performed within four meters of the equipment or component surface. An example for these tasks is the monitoring of the operation of the welding system using cameras. This task may be performed at more than four meters from the cask body, and behind significant auxiliary shielding. The number of persons allocated to task completion is generally the minimum number of actual operators required for the task and excludes supervisory, health physics, security, and other nonoperating personnel.

Area dose rates are assigned based on the orientation of the worker(s) with respect to the source for a given operational task or sequence. Exposure estimates for the PWR and BWR systems are shown in Table 11.3-1 and Table 11.3-2. The number of individual tasks required for loading and transfer of the TSCs is collapsed to eight groups for this presentation. Dose rates shown are time-averaged values across the individual subtasks. Activities 7 and 8 of Table 11.3-1 and Table 11.3-2 include a crane operator who is considered to be outside of the radiation zone around the cask. Exposures due to loading operations are based on design basis casks conservatively loaded with 37 kW PWR and 35 kW BWR heat loads.

11.3.2 Estimated Dose Due to Routine Operations

Once the MAGNASTOR is in storage at the ISFSI, limited ongoing maintenance and surveillance will be required. The annual dose evaluations presented herein consider the tasks that are anticipated to be representative of an operational facility. Exposure due to certain events, such as clearing the material blocking the air vents, is taken into account.

Routine operations may include the following.

- An optional daily electronic measurement of ambient air and outlet air temperatures for each TSC in service. Outlet temperature measurements are recorded at a location away from the cask array, and operators are not expected to incur dose as a result of the temperature measurement.
- An optional inspection of the concrete cask inlet and outlet screens to verify that they are unobstructed. The time required to perform the inspection, and the expected dose, will be site-specific due to ISFSI pad dimensions and configurations, the concrete cask array, distance of the inspector, etc.
- A daily inspection of the security fence and equipment surrounding the ISFSI storage area. This surveillance is assumed to require 15 minutes and is performed by one security officer.
- Radiological surveillance. The surveillance consists of a radiological survey comprised of a surface radiation measurement on each cask, the determination and/or verification of general area exposure rates and radiological postings. This surveillance is assumed to require 30 minutes, and be performed quarterly by one health physics technician.
- Annual visual inspection of the general condition of the concrete casks. This inspection is estimated to require 10 minutes per cask and require one technician. For each cask, three minutes of health physics support is also included.
- Corrective maintenance. As the MAGNASTOR is a passively cooled and shielded system, no significant maintenance is expected over the lifetime of the IFSFI. To account for activities such as minor concrete repairs, air inlet and outlet cleaning, or temperature-monitoring equipment replacement, 10% of the array is assumed to require maintenance

each year. Maintenance exposure is evaluated based on two operators for 30 minutes each and one health physics technician for 10 minutes.

- Grounds maintenance performed twice a month by one maintenance technician. Grounds maintenance is assumed to require 60 minutes.

Storage operation exposures for a 2×10 array of either PWR or BWR concrete casks loaded with TSCs containing bounding fuel assembly sources are presented in Table 11.3-3 and Table 11.3-4. ISFSI exposures are based on design basis casks conservatively loaded with 40 kW PWR and 38 kW BWR heat loads.

Table 11.3-1 Estimated Person-mrem Exposure for Loading Operations of the PWR System

	Description	# of Subtasks	Exposure Duration (min)	Average Dose Rate (mrem/hr)	Exposure (mrem)
1	Fuel Assembly Loading and Transfer Cask Removal from Pool	4	908	2.7	83
2	HP Survey and Decon Top of TSC/Transfer Cask	3	30	26.0	13
3	Install Weld Shield/Weld Machine, and Perform Partial Drain of TSC	4	45	20.0	15
4	Perform Closure Lid and Ring Welding and PT Exams, Hydrostatically Test TSC	16	480	24.6	197
5	Drain TSC and Decontaminate Transfer Cask	5	230	32.3	124
6	Dry TSC Cavity, Backfill/Pressure TSC, Install Port Covers, Weld and Inspect Covers, Remove Weld Shield/Weld Machine, and Survey Cask/TSC Surfaces	13	475	7.2	57
7	Install Hoist Rings, Place Transfer Cask on Concrete Cask, Transfer TSC, Install Concrete Cask Lid, and Perform HP Survey	17	220	42.0	154
8	Move Concrete Cask to ISFSI, Position Concrete Cask on ISFSI Pad, and Install/Connect Screens and Temperature Measuring System	11	180	23.0	69
	Total				**712**

Table 11.3-2 Estimated Person-mrem Exposure for Loading Operations of the BWR System

	Description	# of Subtasks	Exposure Duration (min)	Average Dose Rate (mrem/hr)	Exposure (mrem)
1	Fuel Assembly Loading and Transfer Cask Removal from Pool	4	2033	2.3	159
2	HP Survey and Decon Top of TSC/Transfer Cask	3	30	36.0	18
3	Install Weld Shield/Weld Machine, Connect Drain System, and Perform Partial Drain of TSC	4	45	22.7	17
4	Perform Closure Lid and Ring Welding and PT Exam, Hydrostatically Test TSC	16	480	31.3	250
5	Drain TSC and Decontaminate Transfer Cask	5	230	35.0	134
6	Dry TSC Cavity, Backfill/Pressure TSC, Install Port Covers, Weld and Inspect Covers, Remove Weld Shield/Weld Machine, and Survey Cask/TSC Surfaces	13	475	13.5	107
7	Install Hoist Rings, Place Transfer Cask on Concrete Cask, Transfer TSC, Install Concrete Cask Lid and Perform HP Survey	17	220	45.8	168
8	Move Concrete Cask to ISFSI, Position Concrete Cask on ISFSI Pad, and Install/Connect Screens and Temperature Measuring System	11	180	20.0	60
	Total				**913**

Table 11.3-3 Estimate of Annual Exposures Due to Routine Operations for a PWR 20-Cask Array

Activity	Location	# of Casks	Frequency (/year)	Time (min)	Dose Rate (mrem/hr)	# of Personnel	Exposure (mrem)
Security Surveillance	Outside Fence	Array	365	15	< 2	1	183
Radiological Surveillance	4 m	Array	4	30	30.4	1	61
Annual Inspection	1 m	20	1	10	54.8	1	183
Radiological Support	1 m	20	1	3	54.8	1	55
Corrective Maintenance	1 ft	2	1	30	67.0	2	134
Radiological Support	1 m	2	1	10	54.8	1	18
Grounds Maintenance	Outside Fence	Array	26	60	< 2	1	52
Total Person-mrem for the Array							686
Total Person-mrem - Average Dose Per Cask							**34**

Table 11.3-4 Estimate of Annual Exposures Due to Routine Operations for a BWR 20-Cask Array

Activity	Location	# of Casks	Frequency (/year)	Time (min)	Dose Rate (mrem/hr)	# of Personnel	Exposure (mrem)
Security Surveillance	Outside Fence	Array	365	15	< 2	1	183
Radiological Surveillance	4 m	Array	4	30	27.6	1	55
Annual Inspection	1 m	20	1	10	49.4	1	165
Radiological Support	1 m	20	1	3	49.4	1	49
Corrective Maintenance	1 ft	2	1	30	61.9	2	124
Radiological Support	1 m	2	1	10	49.4	1	16
Grounds Maintenance	Outside Fence	Array	26	60	< 2	1	52
Total Person-mrem for the Array							644
Total Person-mrem - Average Dose Per Cask							**32**

11.4 Exposures to the Public

Chapter 5 presents the detailed controlled area boundary evaluations. The MAGNASTOR dose contribution to public exposure at the controlled area boundary is due to direct gamma and neutron radiation emitted from the cask surfaces. When assembled in accordance with the operating procedures, the TSC is leaktight and, therefore, does not release radionuclides from the TSC interior. External surface contamination limits applied to the system assure that no significant public exposure results from particulate release from the system surfaces.

11.5 References

1. 10 CFR 72, "Licensing Requirements for the Storage of Spent Fuel in an Independent Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste," US Nuclear Regulatory Commission, Washington, DC.
2. 10 CFR 20, "Standards for Protection Against Radiation," Code of Federal Regulations, US Nuclear Regulatory Commission, Washington, DC.

Chapter 12
Accident Analyses

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12 ACCIDENT ANALYSES

The results of the analyses of the off-normal and accident events, including those identified by ANSI/ANS 57.9-1992 [1], are presented in this chapter. Section 12.1 describes the off-normal events that could occur during the use of MAGNASTOR, possibly as often as once per calendar year. Section 12.2 addresses very low probability events that might occur once during the lifetime of MAGNASTOR or hypothetical events that are postulated because their consequences may result in the maximum potential effect on the surrounding environment. The detailed analysis of each evaluated event is presented in the appropriate technical chapters – structural, thermal, shielding, criticality, confinement, or radiation protection. In the analyses in those chapters, the bounding parameters (i.e., maximum concrete cask weight and center of gravity) are conservatively used, as appropriate, to determine the capability of MAGNASTOR to withstand the effects of the analyzed events.

The load conditions imposed on the TSCs and the fuel baskets by the design basis normal, off-normal and accident events of storage are less severe than those imposed by the transport conditions–including the 30-foot drop impacts and the fire accident (10 CFR 71) [2]. Consequently, the evaluation of the TSCs and the fuel baskets for transport conditions bounds the storage condition results reported in this chapter.

This chapter demonstrates that MAGNASTOR is in compliance with the requirements of 10 CFR 72.24 and 10 CFR 72.122 [3] for off-normal and accident events. The evaluations provided are based on conservative assumptions and demonstrate that MAGNASTOR will provide safe storage of spent fuel during all analyzed off-normal and accident events.

12.1 Off-Normal Events

This section evaluates postulated off-normal events that might occur once during any calendar year of operations. The actual occurrence of any of these events is, therefore, infrequent.

12.1.1 Severe Ambient Temperature Events (106°F and -40°F)

This section provides the results of the evaluation of MAGNASTOR for the steady-state effects of severe ambient temperature events (106°F and -40°F).

12.1.1.1 Cause of Severe Ambient Temperature Event

Large geographical areas of the United States are subjected to sustained summer temperatures in the 90°F to 100°F range and winter temperatures that are significantly below zero. To bound the expected steady-state temperatures of the TSC and storage cask during severe ambient temperature events, analyses are performed to calculate the steady-state concrete cask, TSC, fuel basket, and fuel cladding temperatures for a 106°F ambient temperature and solar loads. Similarly, winter weather analyses are performed for a -40°F ambient temperature with no solar load. Neither ambient temperature event is expected to last longer than several days.

12.1.1.2 Detection of Severe Ambient Temperature Event

Detection of off-normal ambient temperatures would occur during measurement of ambient temperature.

12.1.1.3 Analysis of Severe Ambient Temperature Event

The analysis for the off-normal temperature events is presented in Chapter 4. Two-dimensional axisymmetric models are used to determine the temperatures of the concrete, the TSC, fuel basket, and fuel cladding. Steady-state conditions are considered in all analyses. Based on the analysis, the calculated principal component temperatures for each of the ambient temperature conditions and the allowable temperatures are summarized as follows.

	106°F Ambient Max Temp. (°F)		-40°F Ambient Max Temp. (°F)		Allowable Temp. (°F)	
Component	PWR	BWR	PWR	BWR	PWR	BWR
Fuel Cladding	752	719	603	569	1,058	1,058
Fuel Basket	752	719	603	569	1,000	1,000
TSC Shell	485	459	336	312	800	800
Concrete	311	282	118	93	350	350

Note that the maximum temperatures of the fuel cladding are conservatively used as the maximum temperatures of the fuel basket.

The thermal stress evaluations for the concrete cask for these off-normal events are bounded by those for the accident event of "Maximum Anticipated Heat Load (133°F Ambient Temperature)" as presented in Section 12.2.7. Thermal stress analyses for the TSC and the basket components are performed using ANSYS finite element models as described in Section 3.6. A bounding thermal gradient is applied to the TSC to bound the severe ambient temperature conditions. The maximum bounding stress intensity in the TSC is 15.4 ksi, which occurs in the closure lid. Similarly, a bounding temperature gradient is also applied to the PWR and BWR fuel baskets. The maximum bounding stress intensity in the fuel baskets is 48.3 ksi, which occurs in the PWR fuel tubes. Factors of safety for off-normal events are presented in Section 3.6.

12.1.1.4 Corrective Actions

No corrective actions are required for these off-normal events.

12.1.1.5 Radiological Impact

There is no radiological impact due to these off-normal events.

12.1.2 Blockage of One-Half of the Air Inlets

This section provides the results of the evaluation of MAGNASTOR for the steady-state effects of a blockage of one-half of the air inlets at the normal ambient temperature (76°F).

12.1.2.1 Cause of Blockage of One-Half of the Air Inlets Event

Although unlikely, blockage of one-half of the air inlets may occur due to blowing debris, snow, intrusion of a burrowing animal, etc. The screens over the inlets are expected to minimize any blockage of the inlet channels and expedite recovery by restricting the blockage to the exterior of the concrete cask.

12.1.2.2 Detection of One-Half of the Air Inlets Blockage Event

The blockage of one-half of the air inlet screens would be detected visually by persons performing a daily surveillance of the ISFSI or observing an increase in the concrete cask outlet temperature if measured, which would result from the reduced airflow caused by the blockage. The air inlet screens blockage event may also be detected by security forces, or other operations personnel, engaged in other routine activities such as fence inspection or grounds maintenance.

12.1.2.3 Analysis of One-Half of the Air Inlets Blockage Event

Using the same methods and the same thermal models for the severe ambient temperature events, thermal evaluations are performed for the concrete cask and the TSC and its contents for the one-half air inlet blockage event. The boundary condition of the two-dimensional axisymmetric concrete cask and TSC model is modified to allow only one-half of the airflow into the air inlet to simulate the one-half of the air inlets blocked condition. The detailed analysis is provided in Section 4.5.

The calculated maximum component temperatures are compared to the allowable component temperatures. As shown, the calculated component temperatures are less than the component allowable temperatures.

Component	One-Half of Air Inlets Blocked Max Temperature (°F)		Allowable Temperature (°F)	
	PWR	BWR	PWR	BWR
Fuel Cladding	717	684	1,058	1,058
Fuel Basket	717	684	1,000	1,000
TSC Shell	459	433	800	800
Concrete	274	246	350	350

Note that the maximum fuel cladding temperatures are conservatively used as the maximum fuel basket temperatures.

The thermal stress evaluation for the concrete cask for the one-half of the air inlets blocked event is bounded by those for the accident event of "Maximum Anticipated Heat Load (133°F Ambient Temperature)" as reported in Section 12.2.7. Thermal stress analyses for the TSC and the basket components are performed using ANSYS finite element models as described in Section 3.6. For the TSC and baskets, bounding temperature gradients are used to bound the one-half of the air inlets blocked condition. A summary of thermal stresses is presented in Section 3.6.

12.1.2.4 Corrective Actions

The debris blocking the air inlet screens will be manually removed. The nature of the debris may indicate that other actions are required to prevent recurrence of the blockage.

12.1.2.5 Radiological Impact

There are no significant radiological consequences for the one-half of the air inlets blocked event. Personnel will be subject to an estimated maximum contact dose rate of 448 mrem/hr when clearing the inlet screens of a concrete cask containing a conservative 37 kW payload of PWR fuel. If it is assumed that a worker kneeling, with his hands at the inlet screens, would require 15 minutes to clear the screens, the estimated maximum extremity dose is 112 mrem. For clearing the inlet screens of a concrete cask containing a conservative 35 kW payload of BWR fuel, the maximum contact dose rate and the maximum extremity dose are estimated to be

364 mrem/hr and 91 mrem, respectively. The whole body dose in both the PWR and the BWR cases will be significantly less than the extremity doses.

12.1.3 Off-Normal TSC Handling Load

This section reports the results of the evaluation of the consequences of off-normal handling loads on the TSC during the installation of the TSC in the concrete cask, or removal of the TSC from the concrete cask or from the transfer cask. The TSC is handled vertically in the transfer cask.

12.1.3.1 Cause of Off-Normal TSC Handling Load Event

Unintended loads could be applied to the TSC due to misalignment or faulty crane operation, or inattention of the operators.

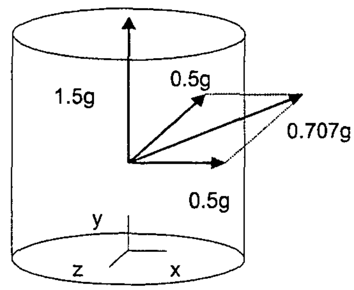
12.1.3.2 Detection of Off-Normal TSC Handling Load Event

The off-normal TSC-handling event can be detected visually during the handling of the TSC, or audibly by hearing a banging or scraping noise associated with TSC movement. The event is expected to be obvious to the operators at the time of occurrence.

12.1.3.3 Analysis of Off-Normal TSC Handling Load Event

The TSC off-normal handling analysis is performed using an ANSYS finite element model described in Chapter 3. The model is used to evaluate the TSCs for both PWR and BWR fuel types by modeling the longest TSC with the heaviest fuel/fuel basket weight. The material stress allowables used in the analysis consider the higher component temperatures that occur during transfer operations.

The off-normal TSC handling loads are defined as 0.5g applied in all directions (i.e., in the global x, y, and z directions) in addition to a 1g lifting load applied in the vertical direction. The resulting off-normal handling accelerations are 0.707g in the lateral direction and 1.5g (0.5g + 1g) in the vertical direction.



The resulting maximum TSC stresses for combined off-normal handling, maximum internal pressure and thermal stress loads are summarized in Section 3.6.

The structural evaluation of the PWR and BWR fuel basket tubes and support weldments for off-normal events is also presented in Section 3.6.

The TSCs and fuel baskets are shown to be structurally adequate for the off-normal handling condition. The minimum factors of safety for the TSC and the fuel basket are 1.28 and 1.07, respectively.

12.1.3.4 Corrective Actions

Operations should be halted until the cause of the misalignment, interference or faulty operation is identified and corrected. Since the radiation level of the TSC sides and bottom is high, extreme caution should be exercised if inspection of these surfaces is required.

12.1.3.5 Radiological Impact

There are no radiological consequences associated with this off-normal TSC handling event.

12.1.4 Failure of Instrumentation

MAGNASTOR may use a temperature-sensing system to measure the outlet air temperature at each of the four air outlets on each concrete cask. The air temperature at the outlets may be recorded and reviewed daily.

12.1.4.1 Cause of Instrumentation Failure Event

The temperature instrumentation failure event could occur as a result of instrumentation component failure, or as a result of any event that interrupted power or altered temperature sensor output.

12.1.4.2 Detection of Instrumentation Failure Event

The temperature instrumentation failure event may be identified by the lack of, or an inappropriate, reading at the temperature reader terminal. The event could also be identified by disparities between outlet temperatures in a cask or between similar casks.

12.1.4.3 Analysis of Instrumentation Failure Event

For concrete casks incorporating daily temperature-monitoring systems, the maximum time period during which an increase in the outlet air temperatures may go undetected is 24 hours. The principal condition that could cause an increase in temperature is the blockage of the air inlets. Section 12.2.13 shows that even if all of the air inlets of a single cask are blocked immediately after a temperature measurement, it would take longer than 24 hours before any component approaches its allowable temperature limit. Therefore, there will be sufficient time to identify and correct temperature instrumentation failure events prior to critical system components reaching the temperature limits. During the period of loss of instrumentation, no significant change in TSC temperature will occur under normal conditions. Therefore, instrument failure would be of no consequence when the affected storage cask continues to operate in a normal storage condition.

Because the TSC and the concrete cask are a large heat sink, and because there are few conditions that could result in an outlet temperature increase, the temporary loss of the optional remote sensing and monitoring of the outlet air temperature is not a major concern. No applicable regulatory criteria are violated by the failure of the temperature instrumentation system.

12.1.4.4 Corrective Actions

This event requires that the temperature-monitoring equipment be either replaced or repaired or otherwise returned to operable, or that the concrete cask air inlet screens be visually inspected daily for blockage.

12.1.4.5 Radiological Impact

There are no radiological consequences for this event.

12.1.5 Small Release of Radioactive Particulate From the TSC Exterior

The procedures for loading the TSC provide for operations and measures to minimize TSC exterior surface contact with contaminated spent fuel pool water, and the TSC external surfaces are surveyed, to the extent practical, to verify removable contamination is within allowable limits. The external surfaces of the TSC are rolled or flat stainless steel plates, and the presence of excessive removable contamination on the external surfaces is unlikely. Therefore, radioactive particulate release from the TSC exterior surface is not expected to occur during normal storage operations.

12.1.5.1 Cause of Radioactive Particulate Release Event

The most likely cause of a radioactive particulate release event is air passing over the external surfaces of a contaminated TSC. In spite of precautions taken to preclude contamination of the external surface of the TSC, it is possible that a portion of the TSC surface may become contaminated during fuel loading by the spent fuel pool water and that the removable contamination in excess of allowable limits may go undetected. Subsequently, surface contamination could become airborne and be released as a result of the airflow over the TSC surfaces.

12.1.5.2 Detection of Radioactive Particulate Release Event

The release of small amounts of radioactive contamination particulates over time is difficult to detect. Any release is likely to be too low to be detected by any of the normally employed long-term radiation dose monitoring methods (such as TLDs) normally located at the ISFSI perimeter fence. It is possible that a suspected release could be verified by a smear survey of the air outlets.

12.1.5.3 Analysis of Radioactive Particulate Release Event

The analysis presented in Section 5.6.5 calculates a total dose of less than 0.1 mrem at 100 meters from a design basis concrete cask based on removable contamination levels of 20,000 dpm/100 cm^2 β-γ and 200 dpm/100 cm^2 α.

The method for determining the dose is based on the plume dispersion calculations presented in U.S. NRC Regulatory Guides 1.109 [4] and 1.145 [5] and is highly conservative. The analysis demonstrates that the offsite radiological consequences from the release of TSC surface contamination is negligible, and all applicable regulatory criteria are met for an ISFSI array. ISFSI-specific allowable dose rates will be calculated on a site-specific basis to conform to 10 CFR 72.

12.1.5.4 Corrective Actions

No corrective action is required since the radiological consequence is negligible.

12.1.5.5 Radiological Impact

As previously shown, the potential offsite radiological impact due to the release of TSC surface contamination is negligible.

12.2 Accidents and Natural Phenomena

This section presents the results of analyses of the design basis and hypothetical accident events evaluated for MAGNASTOR. In addition to design basis accidents, this section addresses very low-probability events, including natural phenomena that might occur once over the lifetime of the ISFSI, or hypothetical events that are postulated to occur because their consequences may result in the maximum potential effect on the immediate environment.

MAGNASTOR includes TSCs of two different lengths to accommodate two lengths of PWR fuel or two lengths of BWR fuel. In the accident analyses of this section, the bounding cask parameters (such as weight and center of gravity) are conservatively used, as appropriate, to determine the cask's capability to withstand the effects of the accidents. The results of these analyses show that any credible potential accident will result in a dose of ≤5 rem beyond the postulated controlled area. Consequently, MAGNASTOR is demonstrated to have a substantial design margin of safety, and will provide protection to the public and to site operations personnel during storage of spent fuel.

12.2.1 Accident Pressurization

Accident pressurization is a hypothetical event that assumes the failure of all of the fuel rods contained within the TSC. No normal storage conditions are expected to lead to the rupture of all of the fuel rods.

The results of analysis of this event demonstrate that the TSC is not significantly affected by the increase in internal pressure that results from the hypothetical rupture of all (PWR or BWR) fuel rods and burnable absorbers contained within the TSC.

12.2.1.1 Cause of Pressurization

The hypothetical failure of all of the fuel rods in a TSC would release the fill and fission gases contained within the fuel and cladding to the TSC cavity, resulting in an increase in internal TSC pressure.

12.2.1.2 Detection of Accident Pressurization

The rupture of fuel rods within the TSC is unlikely to be detected by any measurement or inspection that could normally be undertaken from the exterior of the TSC or the concrete cask.

12.2.1.3 Analysis of Accident Pressurization

Analysis of this accident involves calculation of the maximum TSC internal pressure and the resulting stresses. The maximum TSC pressure is calculated by adding the releasable quantity of fill and fission gas in the fuel assemblies, BPRA gases, and the subsequent calculation of the pressure in the TSC if these gases are added to the helium backfill pressure already present in the TSC (see Section 4.6). The analysis shows that the maximum TSC pressures for the 100 % fuel failure assumption are 201 psig (PWR) and 158 psig (BWR). The pressure for both PWR and BWR configurations is less than the design pressure of 250 psig for the accident event. As presented in Section 3.7.1.1, a structural evaluation is performed for the TSC for the internal pressure of 250 psig using the ANSYS finite element model that envelops both PWR and BWR configurations. The minimum factor of safety for the TSC stresses is calculated to be 1.59.

Consequently, there is no adverse consequence to the TSC as a result of the maximum accident internal pressure.

12.2.1.4 Corrective Actions

No recovery or corrective actions are required for this hypothetical accident.

12.2.1.5 Radiological Impact

There are no dose consequences due to this accident.

12.2.2 Failure of All Fuel Rods With a Ground-level Breach of the TSC

Since no mechanistic failure of the TSC occurs and since the TSC is leaktight, this potential accident condition is not evaluated.

12.2.3 Fresh Fuel Loading in the TSC

This section evaluates the effects of an inadvertent loading of up to 37 fresh, unburned PWR fuel assemblies or up to 87 fresh, unburned BWR fuel assemblies in a TSC. In-plant operational procedures and engineering and quality control programs are expected to preclude occurrence of this event. Nonetheless, it is evaluated here to demonstrate the adequacy of the TSC design for accommodating fresh fuel without a resulting criticality event. There are no adverse effects on the TSC due to this event since the criticality control features of MAGNASTOR ensure that the k_{eff} of the fuel is less than 0.95 for all loading conditions of fresh fuel.

12.2.3.1 Cause of Fresh Fuel Loading

The cause of this event is operator and/or procedural error.

12.2.3.2 Detection of Fresh Fuel Loading

This event is expected to be identified immediately by observation of the identification of the fuel installed in the TSC prior to closure lid installation, or by a review of the fuel handling records.

12.2.3.3 Analysis of Fresh Fuel Loading

The criticality analysis presented in Chapter 6 evaluates the loading of up to 37 PWR or up to 87 BWR fresh fuel assemblies having no burnup. The maximum k_{eff} for the accident events remains below the upper subcritical limit (USL) and the k_{eff} of MAGNASTOR is less than 0.95 for fresh fuel loading conditions. Therefore, there is no adverse impact on MAGNASTOR due to this event.

12.2.3.4 Corrective Actions

This event requires that the TSC be unloaded when the incorrect fuel loading is identified. The root cause for the fuel misloading error should be identified and procedural actions implemented to preclude recurrence.

12.2.3.5 Radiological Impact

There are no dose impacts due to this event, as MAGNASTOR remains subcritical.

12.2.4 24-Inch Drop of the Concrete Cask

This section provides a summary of the results of the structural evaluation of a loaded concrete cask for a 24-inch drop onto a concrete storage pad. The concrete cask may be lifted using lifting lugs in the top of the cask. The concrete cask containing the heaviest TSC is used in the analysis as the bounding case. The evaluation shows that neither the concrete cask nor the TSC experiences significant adverse effects due to the drop accident. Lifting of the concrete cask to a height greater than 24 inches is precluded by the Technical Specifications.

12.2.4.1 Cause of 24-Inch Cask Drop

The concrete cask may be lifted and moved by a transport frame, which may be self-propelled or towed. The transport frame raises the cask using a lifting attachment that connects to the two lifting lugs. The failure of one or more of the lifting lugs, or the failure of the lifting frame, could result in a drop of the cask.

12.2.4.2 Detection of 24-Inch Cask Drop

The operators will visually detect this event as it occurs.

12.2.4.3 Analysis of 24-Inch Cask Drop

The detailed analyses of the cask drop event are provided in Chapter 3. A bottom-end impact is assumed to occur on the concrete cask bottom surface, transmitting the maximum load to the concrete cask and the TSC. The energy absorption is computed as the product of the compressive force acting on the concrete cask and its displacement. Conservatively assuming that the storage pad surface impacted is an infinitely rigid surface, the concrete cask body will crush until the impact energy is absorbed.

The TSC rests upon a base weldment designed to support and facilitate cooling of the TSC. Following the initial impact, the air inlet system will partially collapse, providing an energy-absorption mechanism that somewhat reduces the deceleration force on the TSC.

As described in Section 3.7.3, the accelerations of the concrete cask and TSC and the deformation of the base weldment are determined using a LS-DYNA model. The maximum accelerations of the TSC during the bottom-end impact are 25.2g. The LS-DYNA analyses show that the maximum deformation of the base weldment is about 2.9 inches. This deformation reduces the air inlet to approximately 66% of the original height. This condition is bounded by the consequences of the loss of one-half of the air inlets evaluated in Section 12.1.2.1.

The TSC stress evaluation for the concrete cask 24-inch bottom-end-drop accident is performed using a conservative g-load of 60g. This evaluation bounds the 25.2g load that is calculated for the 24-inch bottom-end-drop event as previously determined. This TSC evaluation is performed using the ANSYS finite element program. The analyses show that the structural components of the TSC (shell, bottom plate, and closure lid) satisfy the allowable stress intensity limits. The results of the bounding TSC analysis for the 60g bottom-end impact loading are presented in tables in Section 3.7.1. The minimum margin of safety for the TSC stresses is calculated to be 3.60.

Classical theory and empirical buckling formula are used to evaluate buckling of the TSC shell for the 60g bottom-end impact. The evaluation requirements of Regulatory Guide 7.6, Paragraph C.5, are satisfied by the results of the buckling interaction equation calculations. The maximum stress components used in the evaluation are provided in Section 3.7.1. The factor of safety against buckling is 4.1; therefore, buckling of the canister shell does not occur during the 24-inch drop.

Stresses in the basket are calculated using classical hand calculations, as described in Section 3.7.2. Conservatively, an inertia load of 60g is applied in the axial direction. The stress evaluation of the basket is performed using the Level D allowable stresses according to ASME Code, Section III, Subsection NG. The stress evaluation results are presented in Section 3.7.2 for both the PWR and BWR baskets. The minimum factors of safety are +1.07 and +1.17 for PWR and BWR basket supports, respectively.

12.2.4.4 Corrective Actions

Although the concrete cask remains functional following this event and no immediate recovery actions are required, the TSC should be inspected and transferred to an undamaged concrete cask as soon as practicable. The damaged cask should be inspected and repaired as required prior to continued use. Prior to transferring the TSC from the damaged concrete cask, temperature-monitoring or inlet and outlet screen inspection frequencies should be evaluated for an increase based on the damaged cask's air flow path restrictions.

12.2.4.5 Radiological Impact

There are no radiological consequences for this accident.

12.2.5 Explosion

The analysis of a design-basis flood presented in Section 12.2.9 shows that the flood exerts a pressure of 22 psig on the TSC, and that MAGNASTOR experiences no adverse effects due to this pressure. The pressure of 22 psig is considered to bound any pressure due to an explosion occurring in the vicinity of the ISFSI.

12.2.5.1 Cause of Explosion

An explosion affecting MAGNASTOR may be caused by industrial accidents or the presence of explosive substances in the vicinity of the ISFSI. However, no flammable or explosive substances are stored or used at the storage facility. In addition, site administrative controls exclude explosive substances in the immediate vicinity of the ISFSI. Therefore, an explosion affecting MAGNASTOR is extremely unlikely. This accident is evaluated in order to provide a bounding pressure that could be used in the event that the potential effects of an explosion require consideration at a given site.

12.2.5.2 Analysis of Explosion

Pressure due to an explosion event is bounded by the pressure effects of a flood having a depth of 50 feet. The TSC shell is evaluated in Chapter 3 for the effects of the flood having a depth of 50 feet, and the results are summarized in Section 12.2.9

There is no adverse consequence to the TSC as a result of the 22 psig pressure exerted by a design basis flood. This pressure conservatively bounds an explosion event.

12.2.5.3 Corrective Actions

In the unlikely event of a nearby explosion, inspection of the concrete casks is required to ensure that the air inlets and outlets are free of debris, and to ensure that any monitoring system and inlet and outlet screens are intact. No further recovery or corrective actions are required for this accident.

12.2.5.4 Radiological Impact

There are no radiological consequences for this accident.

12.2.6 Fire Accident

This section provides the results of the evaluation of the effects of a bounding condition hypothetical fire accident, although a fire accident is a very unlikely occurrence in the storage lifetime of MAGNASTOR. The evaluation demonstrates that for the hypothetical thermal accident (fire) event, the cask meets its storage performance requirements.

12.2.6.1 Cause of Fire

A fire may be caused by flammable material at the ISFSI or by transport equipment fuel. While it is possible that a transport vehicle could cause a fire while transferring a loaded storage cask at the ISFSI, this fire will likely be confined to the vehicle and will be rapidly extinguished by the persons performing the transfer operations or by the site fire crew. The maximum permissible quantity of fuel in the transport vehicle or prime mover is the only means by which fuel (maximum 50 gallons of flammable liquid) would be next to a cask, and potentially at, or above, the elevation of the surface on which the cask is supported.

The fuel carried by other onsite vehicles or by other equipment used for ISFSI operations and maintenance, such as air compressors or electrical generators, is considered not to be within the proximity of a loaded cask on the ISFSI pad. Site-specific analysis of fire hazards will evaluate the specific equipment used at the ISFSI and determine any additional controls required.

12.2.6.2 Detection of Fire

A fire in the vicinity of MAGNASTOR will be detected by observation of the fire or smoke.

12.2.6.3 Analysis of Fire

The detailed analysis of the fire event is provided in Chapter 4. The analysis uses a two-dimensional axisymmetric finite element model to perform a transient analysis for the bounding configuration of PWR fuel. The initial condition of the analysis is based on the steady-state results for the normal condition of storage that correspond to an ambient temperature of 100°F with solar insolation, which envelopes the 76°F ambient used in Chapter 4. The fire condition is implemented by constraining the nodes at the inlet to be 1,475°F for 8 minutes, applied as a stepped boundary condition. At the end of the 8 minutes, the temperature of the node at the inlet is reset to the ambient temperature of 100°F. The maximum fuel cladding temperature for the fire accident is calculated to be 717°F, which is only 3°F higher than that for the normal condition of storage. The maximum temperature of the TSC shell increases to 512°F due to the fire condition—well below the accident condition allowable temperature of 800°F.

The limited duration of the fire and the large thermal capacitance of the concrete cask maintained the cask temperatures above 300°F to a region less than 10 inches above the top surface of the air inlets, which does not adversely affect the safe operation of the cask. Therefore, the operation of the concrete cask is not adversely affected by the fire accident event.

12.2.6.4 Corrective Actions

Immediately upon detection of the fire, appropriate actions should be taken by site personnel to extinguish the fire. The exterior surfaces of the concrete cask should then be visually inspected for general deterioration of the concrete, loss of shielding (spalling of concrete), exposed reinforcing bar, and surface discoloration that could affect heat rejection. This inspection will be the basis for the determination if any repair activities are necessary to maintain or return the concrete cask to its design basis configuration.

12.2.6.5 Radiological Impact

There are no significant radiological consequences for this accident. There may be local spalling of concrete during the fire event, which could lead to some minor reduction in shielding effectiveness and an insignificant increase in radiation dose rates on the cask surface.

12.2.7 Maximum Anticipated Heat Load (133°F Ambient Temperature)

This section evaluates MAGNASTOR response to storage operation at an ambient temperature of 133°F. The event is analyzed in accordance with the requirements of ANSI/ANS 57.9 to evaluate a credible worst-case thermal loading. A steady-state condition is considered in the thermal evaluation of the system for this accident event.

12.2.7.1 Cause of Maximum Anticipated Heat Load

This condition results from a weather event that causes the concrete cask to be subject to a 133°F ambient temperature with full insolation.

12.2.7.2 Detection of Maximum Anticipated Heat Load

Detection of the high ambient temperature condition will be by observation of ambient temperature.

12.2.7.3 Analysis of Maximum Anticipated Heat Load

Using the same methods and thermal models described in Section 12.1.1 for the off-normal events of severe ambient temperatures (106°F and -40°F), thermal evaluations are performed for the concrete cask and the TSC with its contents for this accident condition. The principal PWR and BWR cask component temperatures for this ambient condition and the allowables are:

Component	PWR Maximum Temp. (°F)	BWR Maximum Temp. (°F)	Allowable Temp. (°F)
Fuel Cladding	786	753	1,058
Fuel Basket	786	753	1,000
TSC Shell	510	483	800
Concrete	347	317	350

This evaluation shows that the component temperatures are within the allowable temperatures for the extreme ambient temperature conditions.

Thermal stress evaluations for the concrete cask are presented in Section 12.1.1. The concrete temperature results obtained from the thermal analysis for this accident condition are applied to the structural model for stress calculation. The stresses are used in the loading combination (Table 2.3-1) for the concrete cask evaluation. The maximum stress, 20.2 ksi in the reinforcing steel, occurs in the vertical direction. The factor of safety is 2.67. The maximum compressive stress is 1.2 ksi in the concrete. The factor of safety is 2.21. The maximum tensile stress in the concrete is 0.1 ksi. The factor of safety is 2.1.

12.2.7.4 Corrective Actions

The high ambient temperature event is a natural phenomenon, and no recovery or corrective actions are required.

12.2.7.5 Radiological Impact

There are no radiological consequences for this accident.

12.2.8 Earthquake Event

This section provides the results of the evaluation of the response of the concrete cask to an earthquake imparting horizontal accelerations of 0.37g at the top surface of the concrete storage pad. This evaluation shows that the loaded or empty concrete cask does not tip over in this earthquake event. The vertical acceleration is defined as two-thirds of the horizontal acceleration in accordance with ASCE 4-86 [16].

12.2.8.1 Cause of the Earthquake Event

Earthquakes are natural phenomena to which the storage system might be subjected at any U.S. site. Earthquakes are detected by the ground motion and by seismic instrumentation onsite and offsite.

12.2.8.2 Earthquake Event Analysis

The evaluation of the concrete cask for the earthquake event is presented in Section 3.7.3. In the event of an earthquake, there exists a base shear force or overturning force due to the horizontal acceleration ground motion and a restoring force due to the vertical acceleration ground motion. To maximize the overturning moment, the dimensions for the longer PWR configuration, which has the highest center of gravity, are used in the evaluation. As shown in Section 3.7.3, the natural frequency of the structure is greater than 33 cycles per second (Hz).

The results of the tip-over evaluation show that the minimum ground acceleration that may cause a tip-over of a loaded concrete cask is 0.41g. ANSI/ANS-57.9 requires a factor of safety of 1.1 against tip-over; therefore the maximum allowable ground acceleration for the MAGNASTOR system is 0.37g. Since the 0.25g design basis earthquake ground acceleration for MAGNASTOR is less than 0.37g, the storage cask will not tip over. The analysis conservatively assumes that the TSC is in the maximum off-center position.

The analyses in Section 3.7.3 conservatively apply seismic loads of 0.5g in the horizontal direction and 0.5g in the vertical direction to evaluate concrete cask stress. These accelerations reflect a more rigorous seismic loading and, therefore, bound the design basis earthquake event. The maximum compressive stresses are calculated to be –138 psi at the outer surface and –105 psi at the inner surface, with no credit taken for the steel inner liner. These compressive stresses are used in the load combinations for the concrete cask as also shown in Section 3.7.3, and the combined stress results meet stress criteria for the accident events.

12.2.8.3 Corrective Actions

Visual inspection of the array of concrete casks is required following an earthquake event. The positions of the concrete casks should be verified to ensure they meet the minimum center-to-center spacing requirements. The functions of the temperature-monitoring system, if used, should be verified.

12.2.8.4 Radiological Impact

There are no radiological consequences for this accident.

12.2.9 Flood

This section reports the results of the evaluation of a 50-foot depth of water having a velocity of 15 ft/second. This flood depth would fully submerge MAGNASTOR. Analysis demonstrates that the concrete cask does not overturn when exposed to the design basis rate of water flow. The hydrostatic pressure exerted by the 50-foot depth of water does not produce significant stress in the TSC. The design basis flood, therefore, does not adversely affect MAGNASTOR.

Small floods may lead to a blockage of concrete cask air inlets. Full blockage of air inlets is evaluated in Section 12.2.13.

12.2.9.1 Cause of Flood

The probability of a design-basis flood event at a given ISFSI site is unlikely because geographical features and environmental factors specific to that site are considered in the site selection process. Some possible sources of a flood are:

- overflow from a river or stream due to unusually heavy rain, snow-melt runoff, a dam or major water supply line break caused by a seismic event (earthquake)
- high tides produced by a hurricane
- tsunami (tidal wave) caused by an underwater earthquake or volcanic eruption

12.2.9.2 Analysis of Flood

The analysis of the flood event is presented in Section 3.7.3. The coefficient of friction between carbon steel and concrete used in the analysis is 0.35 [6,8].

Based on minimum cask weight and maximum projected area, the analysis shows that a water flow rate of 21.9 ft/sec is required to overturn the concrete cask. This is greater than the design basis floodwater velocity of 15 ft/second. Therefore, cask tip-over does not occur. The analysis shows that a flood depth of 50 feet exerts a hydrostatic pressure on the TSC and the concrete cask of 22 psi, which results in stresses in the TSC shell. The TSC structural evaluation for the increased external pressure due to flood conditions is presented in Section 3.7.1. The evaluation shows that there is no adverse consequence to the TSC as a result of the hydrostatic pressure due to the flood condition.

The concrete cask is a thick monolithic structure and is not affected by the hydrostatic pressure due to the design-basis flood. Compressive stresses in the concrete cask are included in

Section 3.7.3. The maximum combined stresses for the load combination due to dead, live, thermal and flood loading are less than the allowable stress.

12.2.9.3 Corrective Actions

Inspection of the array of concrete casks is required following a flood. While the cask does not tip over, a potential exists for collection of debris or accumulation of silt at the base of the cask, which could clog or obstruct the air inlets or outlets. Blocked inlets require removal of the debris, silt, excessive standing water, etc. Verify proper operation of the temperature monitoring system, if used, as flood conditions may have impaired its operation.

12.2.9.4 Radiological Impact

There are no dose radiological consequences for this event.

12.2.10 Lightning Strike

This section reports the results of the evaluation of the impact of a lightning strike on the concrete cask. The evaluation shows that the cask does not experience adverse effects due to a lightning strike.

12.2.10.1 Cause of Lightning Strike

A lightning strike is a random weather-related event. Because the concrete cask is located on an unsheltered pad, the cask may be subject to a lightning strike. The probability of a lightning strike is primarily dependent on the geographical location of the ISFSI site, as some geographical regions experience a higher frequency of storms containing lightning than others.

12.2.10.2 Detection of Lightning Strike

A lightning strike on a concrete cask may be visually detected at the time of the strike, or by visible surface discoloration at the point of entry or exit of the current flow. Most reactor sites in locations experiencing a frequency of lightning-bearing storms have lightning detection systems as an aid to ensuring stability of site electric power.

12.2.10.3 Analysis of the Lightning Strike Event

The analysis assumes that the lightning strikes the upper-most metal surface and proceeds through the concrete cask liner to the ground. The integrated maximum current for a lightning strike is a peak current of 250 kiloamps over a period of 260 microseconds, and a continuing current of up to 2 kiloamps for 2 seconds in the case of severe lightning discharges [9]. Due to the extremely short time for the duration, the lack of conductivity of the concrete, and its large thermal mass, the only area affected will be the surface of the concrete cask. Therefore, the increase in concrete cask bulk temperature attributed to Joulean heating is not significant.

12.2.10.4 Corrective Actions

The array of the concrete casks should be visually inspected for any damage following the lightning event and actions taken as appropriate.

12.2.10.5 Radiological Impact

There are no dose radiological consequences due to this event.

12.2.11 Tornado and Tornado-Driven Missiles

This section provides the results of the evaluation of the strength and stability of the concrete cask for a maximum tornado wind loading and for the impacts of tornado-generated missiles. The design basis tornado characteristics are selected in accordance with NRC Regulatory Guide 1.76 [10].

The evaluation demonstrates that the concrete cask remains stable in tornado wind loading in conjunction with impact from a high-energy tornado missile. The performance of the cask is not significantly affected by the tornado event.

12.2.11.1 Cause of Tornado and Tornado-Driven Missiles

A tornado is a random weather event. Probability of its occurrence is dependent upon the time of the year and geographical areas. Wind-loading and tornado-driven missiles have the potential for causing damage from pressure differential loading and from impact loading.

12.2.11.2 Detection of Tornado and Tornado-Driven Missiles

A tornado event is expected to be visually observed. Advance warning of a tornado and of tornado sightings may be received from the National Weather Service, local radio and television stations, local law enforcement personnel, and site personnel.

12.2.11.3 Analysis of Tornado and Tornado-Driven Missiles

The detailed analysis of the effects of tornado winds and tornado driven-missiles is provided in Section 3.7.3. Classical techniques are used to evaluate the loading conditions based on NUREG-0800 [11]. The concrete cask stability is evaluated based on the design wind pressure calculated in accordance with ANSI/ASCE 7-93 [12] and using classical free body stability analysis methods. Local damage to the concrete shell is assessed using a formula developed in NSS 5-940.1 [13]. The local shear strength of the concrete shell is evaluated on the basis of ACI

349-85 [14], Section 12.12.2.1, without considering the reinforcing and the steel internal shell. The concrete shell shear capacity is also evaluated for missile loading using ACI 349-85, Section 12.7.

The cask configuration used in the analysis combines the height of the tallest (Group 2 PWR) cask with the weight and center of gravity of the lightest (Group 1 PWR) cask. This configuration bounds all other configurations for cask stability.

Tornado Wind Loading (Concrete Cask)

To evaluate concrete cask wind loading, the tornado wind velocity (360 mph) is transformed into an effective pressure applied to the cask using procedures delineated in ANSI/ASCE 7-93. From Section 3.7.3, comparison of the calculated pressure to the overturning moment shows that the factor of safety against overturning is 2.44.

The calculated stresses in the concrete due to the tornado wind load are included in the load combination for the concrete evaluation. As shown in Section 3.7.3, the maximum combined stresses for the load combination of dead, live, thermal, and tornado winds are less than the allowable stress.

Tornado Missile Loading (Concrete Cask)

The concrete cask is designed to withstand the effects of impacts associated with postulated tornado-generated missiles identified in NUREG-0800, Section 3.5.1.4.III.4, Spectrum I missiles. These missiles consist of the following.

- massive high kinetic energy missile (4,000 lb automobile, with a frontal area of 20 square ft that deforms on impact)
- 280 lb, 8-inch-diameter armor piercing artillery shell
- one-inch diameter solid steel sphere

All of these missiles are assumed to impact in a manner that produces the maximum damage at a velocity of 126 mph (35% of the maximum tornado wind speed of 360 mph). The concrete cask has no openings except for the four outlets at the top and four inlets at the bottom. The upper openings are configured such that a one-inch diameter solid steel missile cannot directly impact the TSC. The TSC is protected from small missiles entering the lower inlets by a steel pedestal (bottom plate). Therefore, a detailed analysis of the impact on the TSC of a 1-inch diameter steel missile is not required.

Concrete Shell Local Damage Prediction (Penetration Missile)

Local damage to the cask body is assessed using the NSS 5-940.1 [13] formula as the basis for predicting depth of penetration and minimum concrete thickness requirements to prevent scabbing. The minimum concrete shell thickness required to prevent scabbing is three times the predicted penetration depth of 5.82 inches based on the NSS 5-940.1 formula, or 17.46 inches. The concrete cask wall thickness includes 26.5 inches of concrete, which is more than the thickness required to prevent damage due to the penetration missile.

Closure Plate Local Damage Prediction (Penetration Missile)

The concrete cask is closed with a 6.75-inch thick concrete and steel lid that is bolted in place. The penetration thickness is evaluated using the methodology in Topical Report BC-TOP-9A [15], as presented in Section 3.7.3. The calculated penetration thickness is 0.65 inch. Taking credit for only the 0.75-inch steel plate, the factor of safety against penetration is 1.15. Therefore, the concrete cask closure can sustain penetration missile impact without the additional protection provided by the concrete.

Overall Damage Prediction for a Tornado Missile Impact (High-Energy Missile)

The concrete cask is a free-standing structure. Therefore, the principal consideration in overall damage response is the potential of upsetting or overturning the cask as a result of the impact of a high-energy missile. Based on the detailed analysis presented in Section 3.7.3, it is concluded that the cask can sustain an impact from the defined massive high kinetic energy missile and does not overturn since the energy of the missile is less than that required to overturn the cask. The factor of safety against overturning is 3.48.

Combined Tornado Wind and Missile Loading (High-Energy Missile)

The cask rotation due to the heavy missile impact is calculated in Section 3.7.3. This analysis compares the total energy available for overturning to the energy required for overturning and shows that the factor of safety against overturning is 2.06.

Local Shear Strength Capacity of the Concrete Shell (High-Energy Missile)

The shear strength of the concrete at the top edge of the concrete shell due to a high-energy missile impact, based on ACI 349-85, is determined in Section 3.7.3. In the analysis, the force developed by the massive high kinetic energy missile having a frontal area of 20 sq ft, is evaluated using the methodology presented in Topical Report, BC-TOP-9A [15]. The required missile contact area based on the concrete punching shear strength (neglecting reinforcing) is calculated as 1.3 sq ft, which is much less than 20 sq feet. Thus, the concrete shell alone, based on the concrete conical punching strength and discounting the steel reinforcement and shell, has sufficient capacity to react to the high-energy missile impact force.

The effects of tornado winds and missiles are considered both separately and combined in accordance with NUREG-800, Section 3.3.2 II.3.d. For the case of tornado wind plus missile loading, the stability of the cask is assessed and found to be acceptable. Therefore, overturning of the cask under the combined effects of tornado winds, plus tornado-generated missiles, does not occur.

Tornado Effects on the TSC

The postulated tornado wind loading and missile impacts are not capable of overturning the cask, or penetrating the protective boundary established by the concrete cask. Consequently, there is no effect on the TSC. Stresses resulting from the tornado-induced decreased external pressure are bounded by the stresses due to the accident internal pressure discussed in Section 12.2.1.

12.2.11.4 Corrective Actions

A tornado is not expected to result in the need to take any corrective action other than an inspection of the concrete cask array at the ISFSI. This inspection would be directed at ensuring that air inlets and outlets had not become blocked by wind-blown debris and at checking for obvious (concrete) surface damage.

12.2.11.5 Radiological Impact

Damage to the concrete cask after a design-basis tornado accident will not result in radiation exposure at the controlled area boundary in excess of 5 rem to the whole body or any organ. The penetrating missile impact is estimated to reduce the concrete shielding thickness, locally at the point of impact, by approximately six inches. Cask surface dose rates are recalculated for the highest normal condition dose rate PWR and BWR payloads with a cask model that reduces the concrete radius by 6 inches over the entire cask height. This evaluation resulted in maximum localized surface dose rates of less than 600 mrem/hr for both the PWR and BWR configurations.

As the potential high dose rate areas at the top of the concrete cask incorporate a 0.75-inch steel plate, which is not penetrated by missile impact loadings, the top axial post-accident dose rates are bounded by the previously presented post-accident radial dose rates.

12.2.12 Tip-Over of Concrete Cask

Tip-over of the concrete cask is a nonmechanistic, hypothetical accident that presents a bounding case for evaluation. There are no design basis accidents that result in the tip-over of the cask.

Functionally, the cask does not suffer significant adverse consequences due to this event. The concrete cask, TSC, and basket maintain performance requirements for design basis structural integrity, shielding, geometry, criticality control of the contents, and content confinement.

Results of the evaluation show that supplemental shielding at the bottom of the concrete cask may be necessary, following the tip-over, until the cask can be uprighted. The potential for increased dose rates is due to the design of the concrete cask, which provides significantly less shielding to the bottom, as these surfaces are not normally accessible or contributing to the off-site dose.

12.2.12.1 Cause of Cask Tip-Over

A tip-over of the cask is possible in an earthquake that significantly exceeds the design basis described in Section 12.2.8. No events related to the defined design bases will result in a cask tip-over.

12.2.12.2 Detection of Cask Tip-Over

The tipped-over configuration of the concrete cask will be obvious during site inspection following the initiating event.

12.2.12.3 Analysis of Cask Tip-Over

The detailed analyses of the tip-over event are presented in Section 3.7.3 for the bounding PWR and BWR configurations. This section presents a summary of the results of the analyses. For a tip-over event to occur, the center of gravity of the concrete cask and loaded TSC must be displaced beyond its outer radius, i.e., the point of rotation. When the center of gravity passes beyond the point of rotation, the potential energy of the cask and TSC is converted to kinetic energy as the cask and TSC rotate toward a horizontal orientation on the ISFSI pad. The subsequent motion of the cask is governed by the structural characteristics of the cask, the ISFSI pad and the underlying soil.

The objective of the evaluation of the response of the concrete cask in the tip-over event is to determine the maximum acceleration to be used in the structural evaluation of the loaded TSC and basket.

The MAGNASTOR system includes a single concrete cask design, which holds canisters of two different heights, loaded with either PWR or BWR fuel baskets. The concrete cask is analyzed with conservative fuel heights, canister lengths, concrete pad thicknesses, and soil densities. To bound a range of ISFSI geometries, standard pad and oversized pad configurations are evaluated. The accelerations are evaluated at the inner surface of the cask liner, which physically corresponds to the interface of the liner and the loaded TSC nearest the plane of impact. The following table is a summary of accelerations for both pad configurations.

	Position Measured from the Bottom of the Concrete Cask (inches)		Acceleration (g)	
Top of the TSC closure lid	PWR Group 1	PWR Group 2	PWR Group 1	PWR Group 2
	197.9	214.6	32.8	35.70

The BWR finite element model and methodology is similar to that for the PWR configuration. The maximum accelerations at key locations of the concrete cask liner that are required in the evaluation of the loaded BWR TSC/basket model are listed as follows.

Location	Acceleration Standard Pad (g)	Acceleration Oversized Pad (g)
Top of Basket	26.4	26.6
Top of Canister Closure Lid	29.5	29.6

12.2.12.4 Analysis of TSC and Basket for Cask Tip-Over Event

The detailed structural evaluations for the TSC and basket are provided in Section 3.7.1 and Section 3.7.2, respectively. ANSYS finite element models are used to evaluate the side impact loading condition. A 40g inertial load for the canister and 35g for the baskets is conservatively considered. Comparison of maximum stress results to the allowable stress intensities shows that the TSC and fuel tubes are structurally adequate for the concrete cask tip-over condition and satisfy the stress criteria in accordance with the ASME Code, Section III, Division I, Subsection NB and NG, respectively.

For the TSC stress evaluation, the minimum factor of safety is calculated to be 1.24, which occurs in the TSC shell at the lower termination point of the concrete cask standoffs. The minimum factor of safety for the TSC closure weld, which includes a 0.8 weld quality factor, is 1.39. For the PWR and BWR basket stress evaluation, the following table is a summary of the stress results and the factors of safety (FS) for both the PWR and BWR basket configurations.

Stress Location	P_m (ksi)			$P_m + P_b$ (ksi)		
	S_{int}	S_{allow}	FS	S_{int}	S_{allow}	FS
PWR Fuel Tube	46.1	47.67	1.16	43.8	61.29	1.40
PWR Corner Weldment	N/A	N/A	N/A	35.8	47.88	1.34
PWR Side Weldment	N/A	N/A	N/A	35.4	47.88	1.35
BWR Fuel Tube	42.7	47.88	1.12	52.5	61.56	1.17
BWR Corner Weldment	N/A	N/A	N/A	35.7	47.88	1.34
BWR Side Weldment	N/A	N/A	N/A	35.8	47.88	1.34

As the table shows, the minimum factors of safety are 1.16 and 1.12 for the PWR and BWR baskets, respectively. These results indicate that the basket structural integrity is maintained during the tip-over event.

Retainer strips are used to support and protect the neutron absorber in the fuel tubes. The retainer strip assembly consists of retainer and corner clips made of Type 304 stainless steel fixed to the fuel tube using welded posts and plug welds. For the tip-over, the PWR fuel tube neutron absorber is analyzed with the support of weld posts. The BWR fuel tube neutron absorber is analyzed without the support of weld posts. The neutron absorber, retainer strip, and corner clips are analyzed using LS-DYNA models and classical hand calculations. Results of the LS-DYNA analysis show the permanent deformation of the PWR neutron absorber is less than the thickness of the retainer strip, 0.015 inch. The BWR neutron remains elastic during impact. Additionally, the weld post, retainer, corner clips, and associated welds have a sufficient factor of safety. Therefore, the neutron absorber and retainer strip are acceptable in accordance with established criteria.

12.2.12.5 Corrective Actions

The most important recovery action required following a concrete cask tip-over is the shielding, or uprighting, of the cask to minimize the personnel exposure from the exposed bottom end. The uprighting operation will require a heavy lift capability and rigging expertise. The concrete cask must be returned to the vertical position by rotation around a convenient bottom edge using a method and rigging that controls the rotation to the vertical position.

The surface and top and bottom edges of the concrete cask are expected to exhibit cracking and possibly loss of concrete down to the layer of the external reinforcing bar cage. If only minor damage occurs, the concrete may be repairable by using grout. Otherwise, it may be necessary to remove the TSC, at the earliest possible time, for installation in an undamaged concrete cask.

If required, the storage pad should be repaired to preclude the intrusion of water that could cause further deterioration of the pad in freeze-thaw cycles.

12.2.12.6 Radiological Impact

There is a potential for an adverse radiological consequence in the hypothetical tip-over event, as the bottom end of the concrete cask and the TSC have significantly less shielding than in the radial direction. However, due to the small surface area exposed, relative to the size of the ISFSI, the dose rate at the site boundary will not exceed 5 rem/hour. Following a tip-over event, personnel access to the bottom area of the cask should be restricted, and supplemental shielding may be used until the concrete cask can be uprighted.

Damage to the edges or surface of the concrete cask may occur following a tip-over, which could result in a minor increase in localized dose rates.

12.2.13 Full Blockage of the Concrete Cask Air Inlets

This section presents the results of the evaluation of the concrete cask for the steady-state effects of full blockage of the air inlets at the normal ambient temperature (76°F). The analysis conservatively used 100°F. The evaluation estimates the duration of the event that would result in the fuel cladding, the fuel basket or the concrete cask components reaching their design basis limiting temperatures (see Chapter 4 for the allowable temperatures for accident conditions), or the TSC reaching its accident internal pressure limit. The evaluation demonstrates that there are no adverse consequences due to this accident, provided that blockage of the concrete cask air inlets is cleared within 58 hours.

12.2.13.1 Cause of Full Blockage

The likely cause of complete cask air inlet blockage is the covering of the base of the cask with snow, water, or earth in a catastrophic event that is significantly beyond the design basis earthquake or a landslide. This hypothetical event is a bounding accident and is not considered credible.

12.2.13.2 Detection of Full Blockage

Blockage of the cask air inlets will be visually detected during the general site inspection following an earthquake, landslide, or other events with a potential for such blockage. In addition, the cask inlets and outlets will be visually inspected to verify their unblocked condition, or the concrete temperature differential measured every 24 hours, limiting the potential for a full blockage event to go undetected.

12.2.13.3 Analysis of Full Blockage

The evaluation of this event is presented in Section 4.6.3. The evaluation assumes initial normal storage conditions, with the sudden loss of convective cooling of the TSC in the concrete cask (simulating the full blockage of the air inlets and outlets). The loss of convective cooling results in the fairly rapid and sustained heat-up of the TSC and the concrete cask. Transient analysis is performed using the two-dimensional concrete cask and TSC thermal model. The spent fuel cladding, fuel basket and concrete cask component temperatures do not reach their accident condition limits for a time period of approximately 72 hours after initiation of the event. The TSC internal pressure will reach the analyzed maximum pressure in approximately 58 hours after a complete blockage occurs. The calculation of the maximum TSC internal pressure considers a helium temperature of 677°F and 100% failure of the fuel rods. Therefore, at least two of the air inlets are required to be cleared of blockage within 58 hours of the initiation of the event.

12.2.13.4 Corrective Actions

The obstruction(s) blocking two of the air inlets must be removed within 58 hours, and all blockage should be removed at the earliest possible date. The nature of the obstruction may indicate that other actions are required to prevent recurrence of the blockage.

12.2.13.5 Radiological Impact

There are no significant radiological consequences for this event, as the concrete cask retains its shielding performance. Dose to personnel may result from opening of the concrete cask, if access is required to clear the inlets of debris. The higher dose rates at the air inlets (448 mrem/hr for a 37 kW payload) will result in an increase in operator dose as a result of clearing the inlets. If it is assumed that a worker kneeling with his hands on the inlets requires 15 minutes to clear each inlet, the estimated extremity dose is a total of 448 mrem for clearing four air inlets. The whole body dose will be slightly less. In addition, some dose will be incurred clearing debris away from the concrete cask body. This dose is estimated at less than 50 mrem per cask, assuming one hour is spent near each concrete cask's exterior surface.

12.3 References

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Chapter 13
Operating Controls and Limits

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Appendices

13 OPERATING CONTROLS AND LIMITS

This chapter identifies operating controls and limits, technical parameters and surveillance requirements imposed to ensure the safe operation of the MAGNASTOR SYSTEM.

Appendix A includes the Technical Specifications for the MAGNASTOR SYSTEM.

- Use and Application
- Approved Contents
- Limiting Condition for Operations (LCO) Applicability
- Design Features
- Administrative Controls and Programs

Appendix B presents the Approved Contents for the MAGNASTOR SYSTEM.

Appendix C defines the Technical Specifications Bases for the MAGNASTOR SYSTEM.

Appendix A
Technical Specifications for the MAGNASTOR SYSTEM

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1.0 USE AND APPLICATION

1.1 Definitions

NOTE

The defined terms of this section appear in capitalized type and are applicable throughout these Technical Specifications and Bases.

Term	Definition
ACTIONS	ACTIONS shall be that part of a Specification that prescribes Required Actions to be taken under designated Conditions within specified Completion Times.
ASSEMBLY AVERAGE FUEL ENRICHMENT	Value calculated by averaging the ^{235}U wt % enrichment over the entire fuel region (UO_2) of an individual fuel assembly, including axial blankets, if present.
ASSEMBLY DEFECT	Any change in the physical as-built condition of the assembly, with the exception of normal in-reactor changes such as elongation from irradiation growth or assembly bow. Example of assembly defects include: (a) missing rods, (b) broken or missing grids or grid straps (spacer), and (c) missing or broken grid springs, etc. An assembly with a defect is damaged only if it cannot meet its fuel-specific and system-related functions.
BREACHED SPENT FUEL ROD	Spent fuel with cladding defects that permit the release of gas from the interior of the fuel rod. A fuel rod breach may be a minor defect (i.e., hairline crack or pinhole), allowing the rod to be classified as undamaged, or be a gross breach requiring a damaged fuel classification.
BURNUP	Assembly Average Burnup: Value calculated by averaging the burnup over the entire fuel region (UO_2) of an individual fuel assembly. Peak Average Rod Burnup: Value calculated by averaging the burnup in a rod over the length of the rod, then using the highest burnup calculated for any rod as the peak average rod burnup. Nonfuel Assembly Hardware Burnup: Equivalent accumulated irradiation exposure for activation evaluation.
CONCRETE CASK	The CONCRETE CASK is the vertical storage module that receives, holds and protects the sealed TSC for storage at the ISFSI. The CONCRETE CASK passively provides the radiation shielding, structural protection, and heat dissipation capabilities for the safe storage of spent fuel in a TSC.

(continued)

DAMAGED FUEL

Spent nuclear fuel (SNF) that cannot fulfill its fuel-specific or system-related function. Spent fuel is classified as damaged under the following conditions.

1. There is visible deformation of the rods in the SNF assembly.
   Note: This is not referring to the uniform bowing that occurs in the reactor; this refers to bowing that significantly opens up the lattice spacing.

2. Individual fuel rods are missing from the assembly and the missing rods are not replaced by a solid dummy rod that displaces a volume equal to, or greater than, the original fuel rod.

3. The SNF assembly has missing, displaced or damaged structural components such that either:

   3.1. Radiological and/or criticality safety is adversely affected (e.g., significantly changed rod pitch); or

   3.2. The assembly cannot be handled by normal means (i.e., crane and grapple).

Assemblies with the following structural defects meet MAGNASTOR system-related functional requirements and are, therefore, classified as undamaged.

   3.3. Assemblies with missing or damaged grids, grid straps and/or grid springs resulting in an unsupported fuel rod length not to exceed 60 inches. Assemblies containing fuel rods with damaged or missing grids, grid straps, and/or grid springs producing an unsupported length greater than 60 inches are classified as damaged.

4. Any SNF assembly that contains fuel rods for which reactor operating records (or other records or tests) cannot support the conclusion that they do not contain gross breaches.
   Note: Breached fuel rods with minor cladding defects (i.e, pinhole leaks or hairline cracks that will not permit significant release of particulate matter from the spent fuel rod) meet MAGNASTOR system-related functional requirements and are, therefore, classified as undamaged.

5. The SNF assembly is no longer in the form of an intact fuel bundle (e.g., consists of or contains debris such as loose fuel pellets or rod segments).

(continued)

GROSSLY BREACHED SPENT FUEL ROD	A breach in the spent fuel cladding that is larger than a pinhole or hairline crack. A gross cladding breach may be established by visual examination with the capability to determine if the fuel pellet can be seen through the cladding, or through a review of reactor operating records indicating the presence of heavy metal isotopes.
INDEPENDENT SPENT FUEL STORAGE INSTALLATION (ISFSI)	The facility within the perimeter fence licensed for storage of spent fuel within MAGNASTOR SYSTEMS (see also 10 CFR 72.3).
INITIAL PEAK PLANAR–AVERAGE ENRICHMENT	The INITIAL PEAK PLANAR-AVERAGE ENRICHMENT is the maximum planar-average enrichment at any height along the axis of the fuel assembly. The INITIAL PEAK PLANAR-AVERAGE ENRICHMENT may be higher than the bundle (assembly) average enrichment.
INTACT FUEL (ASSEMBLY or ROD)	Any fuel that can fulfill all fuel-specific and system-related functions and that is not breached.
LOADING OPERATIONS	LOADING OPERATIONS include all licensed activities while an MAGNASTOR SYSTEM is being loaded with fuel assemblies. LOADING OPERATIONS begin when the first assembly is placed in the TSC and end when the loaded MAGNASTOR SYSTEM is placed on or lifted by the transporter.
MAGNASTOR SYSTEM	The MAGNASTOR (Modular Advanced Generation Nuclear All-purpose STORage) SYSTEM includes the components certified for loading and storage of spent fuel assemblies at an ISFSI. The MAGNASTOR SYSTEM consists of a CONCRETE CASK, a TRANSFER CASK, and a TSC.
OPERABLE	A system, component, or device is OPERABLE when it is capable of performing its specified safety functions.
STANDARD FUEL	Irradiated fuel assemblies having the same configuration as when originally fabricated, consisting generally of the end fittings, fuel rods, guide tubes, and integral hardware. For PWR fuel, a flow mixer, an in-core instrument thimble, a burnable poison rod insert, a control element assembly, or a stainless steel rod insert is considered to be a component of STANDARD FUEL. For BWR fuel, the channel is considered to be an integral hardware component of STANDARD FUEL.

(continued)

STORAGE OPERATIONS	STORAGE OPERATIONS include all licensed activities that are performed at the ISFSI, while a MAGNASTOR CONCRETE CASK containing spent fuel is in place at its designated storage location on the storage pad.
TRANSFER CASK	TRANSFER CASK is a shielded lifting device designed to hold the TSC during LOADING OPERATIONS, TRANSFER OPERATIONS, and UNLOADING OPERATIONS.
TRANSFER OPERATIONS	TRANSFER OPERATIONS include all licensed activities involved in using a MAGNASTOR TRANSFER CASK to move a loaded and sealed TSC from a CONCRETE CASK to another CONCRETE CASK.
TRANSPORT OPERATIONS	TRANSPORT OPERATIONS include all licensed activities performed on a loaded MAGNASTOR CONCRETE CASK when it is being moved to and from its designated location on the ISFSI. TRANSPORT OPERATIONS begin when the loaded CONCRETE CASK is placed on or lifted by a transporter and end when the CONCRETE CASK is set down in its storage position on the ISFSI pad.
TRANSPORTABLE STORAGE CANISTER (TSC)	The TRANSPORTABLE STORAGE CANISTER (TSC) is the container consisting of a basket in a weldment composed of a cylindrical shell welded to a baseplate, a closure lid, a closure ring, and redundant port covers at the vent and the drain ports. The TSC provides the confinement boundary for the radioactive material contained in the TSC cavity.
TSC TRANSFER FACILITY	The TSC TRANSFER FACILITY includes: 1) a transfer location for the lifting and transfer of a TRANSFER CASK and placement of a TSC into or out of a CONCRETE CASK; and 2) either a stationary lift device or a mobile lifting device used to lift the TRANSFER CASK and TSC, but not licensed as part of the 10 CFR 50 facility.

(continued)

UNDAMAGED FUEL	Spent nuclear fuel that can meet all fuel specific and system-related functions. UNDAMAGED FUEL is spent nuclear fuel that is not DAMAGED FUEL, as defined herein, and does not contain assembly structural defects that adversely affect radiological and/or criticality safety. As such, UNDAMAGED FUEL may contain: a) Breached spent fuel rods (i.e, rods with minor defects up to hairline cracks or pinholes) but can not contain grossly breached fuel rods; b) Grid, grid strap, and/or grid spring damage provided that the unsupported length of the fuel rod does not exceed 60 inches.
UNLOADING OPERATIONS	UNLOADING OPERATIONS include the activities required to remove the fuel assemblies from a sealed MAGNASTOR TSC. UNLOADING OPERATIONS begin with the placement of the TSC in a TRANSFER CASK in an unloading facility and end when the last fuel assembly has been removed from the TSC.

1.0 USE AND APPLICATION

1.2 Logical Connectors

PURPOSE

The purpose of this section is to explain the meaning of logical connectors.

Logical connectors are used in Technical Specifications (TS) to discriminate between, and yet connect, discrete Conditions, Required Actions, Completion Times, Surveillances, and Frequencies. The only logical connectors that appear in Technical Specifications are "AND" and "OR". The physical arrangement of these connectors constitutes logical conventions with specific meanings.

BACKGROUND

Several levels of logic may be used to state Required Actions. These levels are identified by the placement (or nesting) of the logical connectors and by the number assigned to each Required Action. The first level of logic is identified by the first digit of the number assigned to a Required Action and the placement of the logical connector in the first level of nesting (i.e., left justified with the number of the Required Action). The successive levels of logic are identified by additional digits of the Required Action number and by successive indentations of the logical connectors.

When logical connectors are used to state a Condition, Completion Time, Surveillance, or Frequency, only the first level of logic is used, and the logical connector is left justified with the statement of the Condition, Completion Time, Surveillance, or Frequency.

EXAMPLES

The following examples illustrate the use of logical connectors.

EXAMPLE 1.2-1

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. LCO not met	A.1 Verify . . .	
	AND	
	A.2 Restore . . .	

In this example, the logical connector "AND" is used to indicate that when in Condition A, both Required Actions A.1 and A.2 must be completed.

(continued)

EXAMPLES (continued)

EXAMPLE 1.2-2

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. LCO not met	A.1 Stop . . . OR A.2.1 Verify . . . AND A.2.2 A.2.2.1 Reduce . . . OR A.2.2.2 Perform . . . OR A.3 Remove . . .	

This example represents a more complicated use of logical connectors. Required Actions A.1, A.2, and A.3 are alternative choices, only one of which must be performed as indicated by the use of the logical connector "OR" and the left justified placement. Any one of these three Actions may be chosen. If A.2 is chosen, then both A.2.1 and A.2.2 must be performed as indicated by the logical connector "AND". Required Action A.2.2 is met by performing A.2.2.1 or A.2.2.2. The indented position of the logical connector "OR" indicates that A.2.2.1 and A.2.2.2 are alternative choices, only one of which must be performed.

1.0 USE AND APPLICATION

1.3 Completion Times

PURPOSE	The purpose of this section is to establish the Completion Time convention and to provide guidance for its use.
BACKGROUND	Limiting Conditions for Operation (LCOs) specify the lowest functional capability or performance levels of equipment required for safe operation of the facility. The ACTIONS associated with an LCO state conditions that typically describe the ways in which the requirements of the LCO can fail to be met. Specified with each stated Condition are Required Action(s) and Completion Time(s).
DESCRIPTION	The Completion Time is the amount of time allowed for completing a Required Action. It is referenced to the time of discovery of a situation (e.g., equipment or variable not within limits) that requires entering an ACTIONS Condition unless otherwise specified, provided that MAGNASTOR is in a specified condition stated in the Applicability of the LCO. Required Actions must be completed prior to the expiration of the specified Completion Time. An ACTIONS Condition remains in effect and the Required Actions apply until the Condition no longer exists or MAGNASTOR is not within the LCO Applicability. Once a Condition has been entered, subsequent subsystems, components, or variables expressed in the Condition, discovered to be not within limits, will not result in separate entry into the Condition unless specifically stated. The Required Actions of the Condition continue to apply to each additional failure, with Completion Times based on initial entry into the Condition.

(continued)

EXAMPLES

The following examples illustrate the use of Completion Times with different types of Conditions and changing Conditions.

EXAMPLE 1.3-1

ACTIONS

CONDITION	REQUIRED ACTION		COMPLETION TIME
B. Required Action and associated Completion Time not met	B.1	Perform Action B.1	12 hours
	AND		
	B.2	Perform Action B.2	36 hours

Condition B has two Required Actions. Each Required Action has its own Completion Time. Each Completion Time is referenced to the time that Condition B is entered.

The Required Actions of Condition B are to complete action B.1 within 12 hours AND complete action B.2 within 36 hours. A total of 12 hours is allowed for completing action B.1 and a total of 36 hours (not 48 hours) is allowed for completing action B.2 from the time that Condition B was entered. If action B.1 is completed within six hours, the time allowed for completing action B.2 is the next 30 hours because the total time allowed for completing action B.2 is 36 hours.

(continued)

EXAMPLES (continued)

EXAMPLE 1.3-2

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. One system not within limit.	A.1 Restore system to within limit.	7 days
B. Required Action and associated Completion Time not met.	B.1 Complete action B.1 AND B.2 Complete action B.2	12 hours 36 hours

When a system is determined not to meet the LCO, Condition A is entered. If the system is not restored within 7 days, Condition B is also entered, and the Completion Time clocks for Required Actions B.1 and B.2 start. If the system is restored after Condition B is entered, Conditions A and B are exited, and therefore, the Required Actions of Condition B may be terminated.

(continued)

EXAMPLES (continued)

EXAMPLE 1.3-3

ACTIONS

NOTE
Separate Condition entry is allowed for each component.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. LCO not met	A.1 Restore compliance with LCO.	4 hours
B. Required Action and associated Completion Time not met.	B.1 Complete action B.1	6 hours
	AND	
	B.2 Complete action B.2	12 hours

The Note above the ACTIONS table is a method of modifying how the Completion Time is tracked. If this method of modifying how the Completion Time is tracked was applicable only to a specific Condition, the Note would appear in that Condition rather than at the top of the ACTIONS Table.

The Note allows Condition A to be entered separately for each component, and Completion Times to be tracked on a per component basis. When a component is determined to not meet the LCO, Condition A is entered and its Completion Time starts. If subsequent components are determined to not meet the LCO, Condition A is entered for each component and separate Completion Times are tracked for each component.

IMMEDIATE COMPLETION TIME

When "Immediately" is used as a Completion Time, the Required Action should be pursued without delay and in a controlled manner.

1.0 USE AND APPLICATION

1.4 Frequency

PURPOSE	The purpose of this section is to define the proper use and application of Frequency requirements.
DESCRIPTION	Each Surveillance Requirement (SR) has a specified Frequency in which the Surveillance must be met in order to meet the associated Limiting Condition for Operation (LCO). An understanding of the correct application of the specified Frequency is necessary for compliance with the SR. Each "specified Frequency" is referred to throughout this section and each of the Specifications of Section 3.0, Surveillance Requirement (SR) Applicability. The "specified Frequency" consists of requirements of the Frequency column of each SR. Situations where a Surveillance could be required (i.e., its Frequency could expire), but where it is not possible or not desired that it be performed until sometime after the associated LCO is within its Applicability, represent potential SR 3.0.4 conflicts. To avoid these conflicts, the SR (i.e., the Surveillance or the Frequency) is stated such that it is only "required" when it can be and should be performed. With an SR satisfied, SR 3.0.4 imposes no restriction. The use of "met" or "performed" in these instances conveys specific meanings. Surveillance is "met" only after the acceptance criteria are satisfied. Known failure of the requirements of Surveillance, even without Surveillance specifically being "performed", constitutes a Surveillance not "met".

(continued)

EXAMPLES

The following examples illustrate the various ways that Frequencies are specified.

EXAMPLE 1.4-1

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
Verify pressure within limit	12 hours

Example 1.4-1 contains the type of SR most often encountered in the Technical Specifications (TS). The Frequency specifies an interval (12 hours) during which the associated Surveillance must be performed at least one time. Performance of the Surveillance initiates the subsequent interval. Although the Frequency is stated as 12 hours, an extension of the time interval to 1.25 times the interval specified in the Frequency is allowed by SR 3.0.2 for operational flexibility. The measurement of this interval continues at all times, even when the SR is not required to be met per SR 3.0.1 (such as when the equipment or variables are outside specified limits, or the facility is outside the Applicability of the LCO). If the interval specified by SR 3.0.2 is exceeded while the facility is in a condition specified in the Applicability of the LCO, the LCO is not met in accordance with SR 3.0.1.

If the interval as specified by SR 3.0.2 is exceeded while the facility is not in a condition specified in the Applicability of the LCO for which performance of the SR is required, the Surveillance must be performed within the Frequency requirements of SR 3.0.2, prior to entry into the specified condition. Failure to do so would result in a violation of SR 3.0.4.

(continued)

EXAMPLES

(continued)

EXAMPLE 1.4-2

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
Verify flow is within limit	Once within 12 hours prior to starting activity AND 24 hours thereafter

Example 1.4-2 has two Frequencies. The first is a one-time performance Frequency, and the second is of the type shown in Example 1.4-1. The logical connector "AND" indicates that both Frequency requirements must be met. Each time the example activity is to be performed, the Surveillance must be performed within 12 hours prior to starting the activity.

The use of "once" indicates a single performance will satisfy the specified Frequency (assuming no other Frequencies are connected by "AND"). This type of Frequency does not qualify for the 25% extension allowed by SR 3.0.2.

"Thereafter" indicates future performances must be established per SR 3.0.2, but only after a specified condition is first met (i.e., the "once" performance in this example). If the specified activity is canceled or not performed, the measurement of both intervals stops. New intervals start upon preparing to restart the specified activity.

2.0 [Reserved]

3.0 LIMITING CONDITION FOR OPERATION (LCO) APPLICABILITY

LCO 3.0.1	LCOs shall be met during specified conditions in the Applicability, except as provided in LCO 3.0.2.
LCO 3.0.2	Upon failure to meet an LCO, the Required Actions of the associated Conditions shall be met, except as provided in LCO 3.0.5. If the LCO is met or is no longer applicable prior to expiration of the specified Completion Time(s), completion of the Required Action(s) is not required, unless otherwise stated
LCO 3.0.3	Not applicable to MAGNASTOR.
LCO 3.0.4	When an LCO is not met, entry into a specified condition in the Applicability shall not be made except when the associated ACTIONS to be entered permit continued operation in the specified condition in the Applicability for an unlimited period of time. This Specification shall not prevent changes in specified conditions in the Applicability that are required to comply with ACTIONS or that are related to the unloading of MAGNASTOR. Exceptions to this Condition are stated in the individual Specifications. These exceptions allow entry into specified conditions in the Applicability where the associated ACTIONS to be entered allow operation in the specified conditions in the Applicability only for a limited period of time.
LCO 3.0.5	This exception to LCO 3.0.2 is not applicable for the MAGNASTOR SYSTEM to return to service under administrative control to perform the testing.

3.0 SURVEILLANCE REQUIREMENT (SR) APPLICABILITY

SR 3.0.1	SRs shall be met during the specified conditions in the Applicability for individual LCOs, unless otherwise stated in the SR. Failure to meet Surveillance, whether such failure is experienced during the performance of the Surveillance or between performances of the Surveillance, shall be a failure to meet the LCO. Failure to perform Surveillance within the specified Frequency shall be a failure to meet the LCO, except as provided in SR 3.0.3. Surveillances do not have to be performed on equipment or variables outside specified limits.
SR 3.0.2	The specified Frequency for each SR is met if the Surveillance is performed within 1.25 times the interval specified in the Frequency, as measured from the previous performance or as measured from the time a specified condition of the Frequency is met. For Frequencies specified as "once," the above interval extension does not apply. If a Completion Time requires periodic performance on a "once per..." basis, the above Frequency extension applies to each performance after the initial performance. Exceptions to this Specification are stated in the individual Specifications.
SR 3.0.3	If it is discovered that Surveillance was not performed within its specified Frequency, then compliance with the requirement to declare the LCO not met may be delayed from the time of discovery up to 24 hours or up to the limit of the specified Frequency, whichever is less. This delay period is permitted to allow performance of the Surveillance. If the Surveillance is not performed within the delay period, the LCO must immediately be declared not met, and the applicable Condition(s) must be entered. When the Surveillance is performed within the delay period and the Surveillance is not met, the LCO must immediately be declared not met, and the applicable Condition(s) must be entered.
SR 3.0.4	Entry into a specified Condition in the Applicability of an LCO shall not be made, unless the LCO's Surveillances have been met within their specified Frequency. This provision shall not prevent entry into specified conditions in the Applicability that are required to comply with Actions or that are related to the unloading of MAGNASTOR.

3.1 MAGNASTOR SYSTEM Integrity

3.1.1 Transportable Storage Canister (TSC)

LCO 3.1.1 The TSC shall be dry and helium filled. The following vacuum drying times shall be met as appropriate.

1. The time duration from the beginning of canister draining through completion of vacuum dryness test and backfill with helium shall not exceed the following:

PWR Drying with 8 Hours TSC Transfer

Heat Load (kW)	Vacuum Time Limit (hours)	Helium Backfill (hours)	TSC Transfer Time (hours)
≤20	No limit	0	8
25	50	0	8
30	19	7	8
35.5	15	7	8

PWR Drying with Maximum TSC Transfer

Heat Load (kW)	Vacuum Time Limit (hours)	Helium Backfill (hours)	TSC Transfer Time (hours)
≤25	No limit	24	48
30	32	24	22
35.5	24	24	22

BWR Drying with 8 Hours TSC Transfer

Heat Load (kW)	Vacuum Time Limit (hours)	Helium Backfill (hours)	TSC Transfer Time (hours)
≤15	No limit	0	8
20	No limit	0	8
25	No limit	0	8
29	34	6	8
30	31	6	8
33	26	6	8

(continued)

(continued)

BWR Drying with Maximum TSC Transfer

Heat Load (kW)	Vacuum Time Limit (hours)	Helium Backfill (hours)	TSC Transfer Time (hours)
≤25	No limit	24	65
29	No limit	24	32
3030	44	24	32
33	33	24	32

2. The time duration from the end of cooling, either by 24 hours in the pool or by the annulus circulating water system, through completion of vacuum dryness test and backfill with helium shall not exceed the following:

	Heat Load	Time Limit (hours)
PWR	35.5	11
BWR	33	16

APPLICABILITY: Prior to TRANSPORT OPERATIONS

(continued)

ACTIONS

NOTE

Separate Condition entry is allowed for each TSC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. TSC cavity vacuum drying pressure limit not met.	A.1 Perform an engineering evaluation to determine the quantity of moisture remaining in the TSC.	7 days
	AND	
	A.2 Develop and initiate corrective actions necessary to return the TSC to an analyzed condition.	30 days
B. TSC helium backfill density limit not met.	B.1 Perform an engineering evaluation to determine the effect of helium density differential.	72 hours
	AND	
	B.2 Develop and initiate corrective actions necessary to return the TSC to an analyzed condition.	14 days
C. Required Actions and associated Completion Times not met.	C.1 Remove all fuel assemblies from the TSC.	30 days

(continued)

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.1.1	Verify TSC cavity vacuum drying pressure is less than or equal to 10 torr for greater than or equal to 10 minutes with the vacuum pump turned off and isolated.	Once, prior to TRANSPORT OPERATIONS.
SR 3.1.1.2	Following vacuum drying and evacuation to < 3 torr, backfill the cavity with high purity helium until a mass M_{helium} corresponding to the free volume of the TSC measured during draining (V_{TSC}), multiplied by the helium density (L_{helium}) required for the design basis heat load and specified in Table , is reached.	Once, prior to TRANSPORT OPERATIONS.

Table 3-1 Helium Mass per Unit Volume for MAGNASTOR TSCs

Fuel Type	Helium Density (g/liter)
PWR	0.694 – 0.802
BWR	0.704 – 0.814

3.1 MAGNASTOR SYSTEM Integrity

3.1.2 CONCRETE CASK Heat Removal System

LCO 3.1.2 The CONCRETE CASK Heat Removal System shall be OPERABLE.

APPLICABILITY: During STORAGE OPERATIONS

ACTIONS

NOTE
Separate Condition entry is allowed for each MAGNASTOR SYSTEM.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. CONCRETE CASK Heat Removal System inoperable.	A.1 Ensure adequate heat removal to prevent exceeding short-term temperature limits.	Immediately
	AND	
	A.2 Restore CONCRETE CASK Heat Removal System to OPERABLE status.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.2.1	Verify that the difference between the average CONCRETE CASK air outlet temperature and ISFSI ambient temperature indicates that the CONCRETE CASK Heat Removal System is operable in accordance with the FSAR thermal evaluation.	24 hours
	OR	
	Visually verify all CONCRETE CASK air inlet and outlet screens are free of blockage.	24 hours

3.2 MAGNASTOR SYSTEM Criticality Control for PWR Fuel

3.2.1 Dissolved Boron Concentration

LCO 3.2.1 The dissolved boron concentration in the water in the TSC cavity shall be greater than, or equal to, the concentration specified in Appendix B, Table 2-3. A minimum concentration of 1,500 ppm is required for all PWR fuel types. Higher concentrations are required, depending on the fuel type and enrichment.

APPLICABILITY: During LOADING OPERATIONS and UNLOADING OPERATIONS with water and at least one fuel assembly in the TSC.

ACTIONS

NOTE

Separate Condition entry is allowed for each TSC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Dissolved boron concentration not met.	A.1 Suspend LOADING OPERATIONS or UNLOADING OPERATIONS	Immediately
	AND	
	A.2 Suspend positive reactivity additions.	Immediately
	AND	
	A.3 Initiate action to restore boron concentration to within limits.	Immediately

(continued)

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.2.1.1	Verify the dissolved boron concentration is met using two independent measurements.	Once within 4 hours prior to commencing LOADING OPERATIONS or UNLOADING OPERATIONS. <u>AND</u> Every 24 hours thereafter while the TSC is in the spent fuel pool or while water is in the TSC.

3.3 MAGNASTOR SYSTEM Radiation Protection

3.3.1 CONCRETE CASK Maximum Surface Dose Rate

LCO 3.3.1 The maximum surface dose rates for the CONCRETE CASK, Reference Figure 3.1, shall not exceed the following limits:

a. PWR and BWR – 95 mrem/hour gamma and 5 mrem/hour neutron on the vertical concrete surfaces; and

b. PWR and BWR – 450 mrem/hour (neutron + gamma) on the top.

APPLICABILITY: Prior to start of STORAGE OPERATIONS

ACTIONS

---NOTE---

Separate Condition entry is allowed for each MAGNASTOR® SYSTEM.

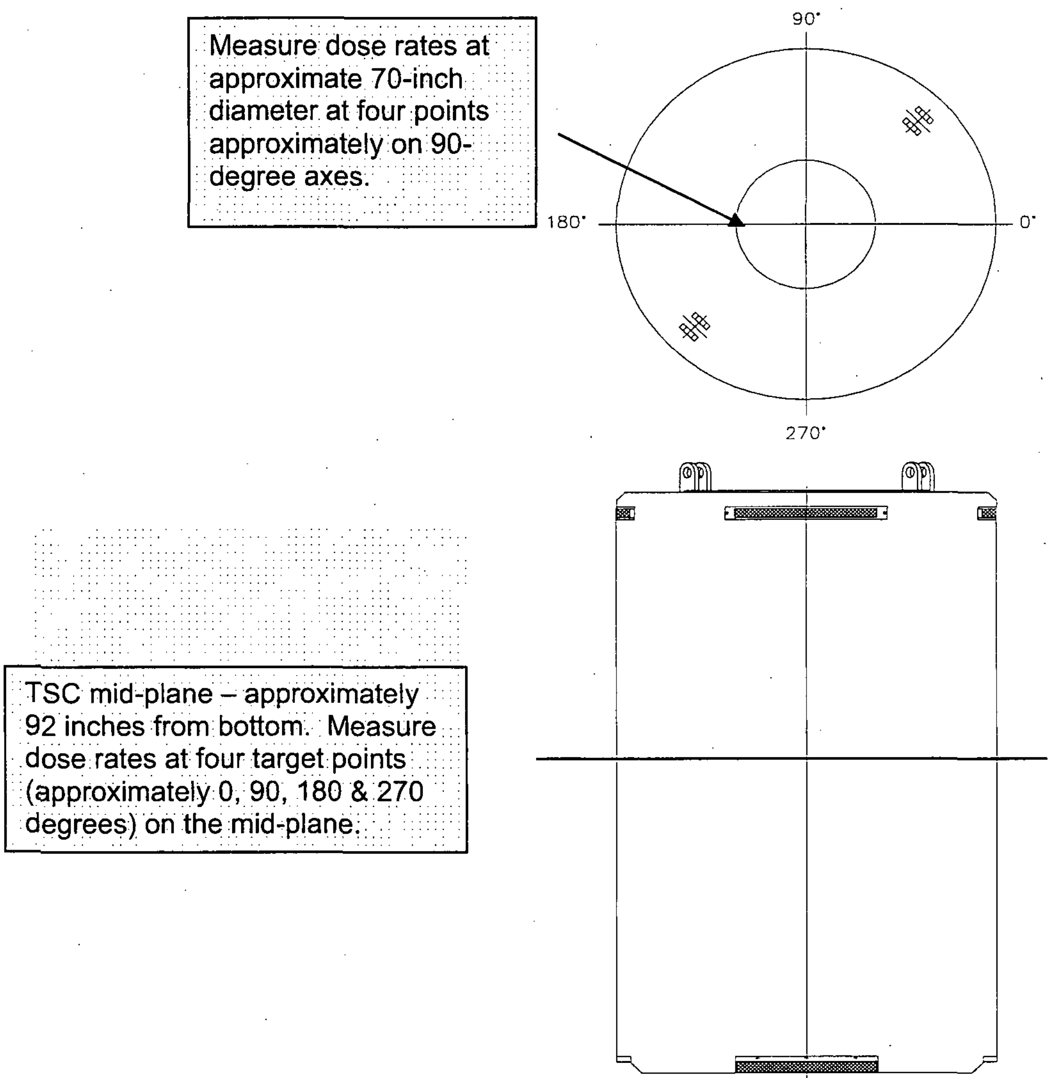
CONDITION	REQUIRED ACTION	COMPLETION TIME
A. CONCRETE CASK maximum surface dose rate limits not met	A.1 Administratively verify correct fuel loading	24 hours
	<u>AND</u>	
	A.2 Perform analysis to verify compliance with the ISFSI radiation protection requirements of 10 CFR 20 and 10 CFR 72	7 days
B. Required Action and associated Completion Time not met	B.1 Perform (and document) an engineering assessment and take appropriate corrective action to ensure the dose limits of 10 CFR 20 and 10 CFR 72 are not exceeded	60 days

(continued)

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.3.1.1	Verify maximum surface dose rates of CONCRETE CASK loaded with a TSC containing fuel assemblies are within limits. Dose rates shall be measured at the locations shown in Figure 3-1.	Prior to start of STORAGE OPERATIONS of the first loaded CONCRETE CASK placed on the ISFSI pad

Figure 3-1 CONCRETE CASK Surface Dose Rate Measurement



4.0 DESIGN FEATURES

4.1 Design Features Significant to Safety

4.1.1 Criticality Control

a) Minimum ^{10}B loading in the neutron absorber material:

Neutron Absorber Type	Required Minimum Effective Areal Density (^{10}B g/cm^2)		% Credit Used in Criticality Analyses	Required Minimum Actual Areal Density (^{10}B g/cm^2)	
	PWR Fuel	BWR Fuel		PWR Fuel	BWR Fuel
Borated Aluminum Alloy	0.036	0.027	90	0.04	0.03
Borated MMC	0.036	0.027	90	0.04	0.03
Boral	0.036	0.027	75	0.048	0.036

b) Acceptance and qualification testing of neutron absorber material shall be in accordance with Sections 10.1.6.4.5, 10.1.6.4.6 and 10.1.6.4.7. These sections of the FSAR are hereby incorporated into the MAGNASTOR CoC.

c) Soluble boron concentration in the PWR fuel pool and water in the TSC shall be in accordance with LCO 3.2.1, with a minimum water temperature 5-10°F higher than the minimum needed to ensure solubility.

d) Minimum fuel tube orthogonal (x, y) pitch

PWR basket — 9.249 inches
BWR basket — 6.166 inches

4.1.2 Fuel Cladding Integrity

The licensee shall ensure that fuel oxidation and the resultant consequences are precluded during canister loading and unloading operations.

4.1.3 Transfer Cask Shielding

The nominal configuration transfer cask radial bulk shielding (i.e., shielding integral to the transfer cask; excludes supplemental shielding) must provide a minimum radiation shield equivalent to 2 inches of steel and 3.25 inches of lead gamma shielding and 2.25 inches of NS-4-FR (with 0.6 wt % B_4C and 6.0 wt % H) neutron shielding. Material and dimensions of the individual shield layers may vary provided maximum calculated radial dose rates of 1100 mrem/hr (PWR system) and 1600 mrem/hr (BWR system) are maintained on the vertical surface.

(continued)

4.2 Codes and Standards

The American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code), 2001 Edition with Addenda through 2003, Section III, Subsection NB, is the governing Code for the design, material procurement, fabrication, and testing of the TSC.

The ASME Code, 2001 Edition with Addenda through 2003, Section III, Subsection NG, is the governing Code for the design, material procurement, fabrication and testing of the spent fuel baskets.

The American Concrete Institute Specifications ACI-349 and ACI-318 govern the CONCRETE CASK design and construction, respectively.

The American National Standards Institute ANSI N14.6 (1993) and NUREG-0612 govern the TRANSFER CASK design, operation, fabrication, testing, inspection, and maintenance.

4.2.1 Alternatives to Codes, Standards, and Criteria

Table 2.1-2 of the FSAR lists approved alternatives to the ASME Code for the design, procurement, fabrication, inspection and testing of MAGNASTOR SYSTEM TSCs and spent fuel baskets.

4.2.2 Construction/Fabrication Alternatives to Codes, Standards, and Criteria

Proposed alternatives to ASME Code, Section III, 2001 Edition with Addenda through 2003, including alternatives authorized in Table 2.1-2 of the FSAR, may be used when authorized by the Director of the Office of Nuclear Material Safety and Safeguards or designee. The request for such alternatives should demonstrate that:

1. The proposed alternatives would provide an acceptable level of quality and safety, or
2. Compliance with the specified requirements of ASME Code, Section III, Subsections NB and NG, 2001 Edition with Addenda through 2003, would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.

Requests for alternatives shall be submitted in accordance with 10 CFR 72.4.

(continued)

4.3 Site-Specific Parameters and Analyses

This section presents site-specific parameters and analytical bases that must be verified by the MAGNASTOR SYSTEM user. The parameters and bases presented in Section 4.3.1 are those applied in the design bases analysis.

4.3.1 Design Basis Specific Parameters and Analyses

The design basis site-specific parameters and analyses that require verification by the MAGNASTOR SYSTEM user are:

a. A temperature of 76°F is the maximum average yearly temperature. The three-day average ambient temperature shall be ≤106°F.

b. The allowed temperature extremes, averaged over a three-day period, shall be ≥–40°F and ≤133°F.

c. The analyzed flood condition of 15 fps water velocity and a depth of 50 ft of water (full submergence of the loaded cask) are not exceeded.

d. The potential for fire and explosion shall be addressed, based on site-specific considerations. This includes the condition that the fuel tank of the cask handling equipment used to move the loaded CONCRETE CASK onto or from the ISFSI site contains no more than 50 gallons of fuel.

e. In cases where engineered features (i.e., berms, shield walls) are used to ensure that requirements of 10 CFR 72.104(a) are met, such features are to be considered important to safety and must be evaluated to determine the applicable Quality Assurance Category on a site-specific basis.

f. The TRANSFER CASK shall not be operated and used when surrounding air temperature is < 0°F.

g. The CONCRETE CASK shall not be lifted by the lifting lugs with surrounding air temperatures < 0°F.

h. Loaded CONCRETE CASK lifting height limit ≤24 inches.

(continued)

4.4 TSC Handling and Transfer Facility

The TSC provides a leaktight confinement boundary and is evaluated for normal and off-normal handling loads. A handling and transfer facility is not required for TSC and TRANSFER CASK handling and transfer operations within a 10 CFR 50 licensed facility.

Movements of the TRANSFER CASK and TSC outside of a 10 CFR 50 licensed facility are not permitted unless a TSC TRANSFER FACILITY is designed, operated, fabricated, tested, inspected, and maintained in accordance with the following requirements. These requirements do not apply to handling heavy loads under a 10 CFR 50 license.

The permanent or stationary weldment structure of the TSC TRANSFER FACILITY shall be designed to comply with the stress limits of ASME Code, Section III, Subsection NF, Class 3 for linear structures. All compression loaded members shall satisfy the buckling criteria of ASME Code, Section III, Subsection NF.

The reinforced concrete structure of the facility shall be designed in accordance with ACI-349 and the factored load combinations set forth in ACI-318 for the loads defined in Table 4-1 shall apply. TRANSFER CASK and TSC lifting devices installed in the handling facility shall be designed, fabricated, operated, tested, inspected, and maintained in accordance with NUREG-0612, Section 5.1.

If mobile load lifting and handling equipment is used at the facility, that equipment shall meet the guidelines of NUREG-0612, Section 5.1, with the following conditions:

a. The mobile lifting device (i.e., crane) shall have a minimum safety factor of two over the allowable load table for the lifting device in accordance with the guidance of NUREG-0612, Section 5.1.6 (1)(a), and shall be capable of stopping and holding the load during a design earthquake event;

b. The mobile lifting device shall contain ≤50 gallons of flammable liquid during operation inside the ISFSI;

c. Mobile cranes are not required to meet the guidance of NUREG-0612, Section 5.1.6(2) for new cranes;

d. The mobile lifting device shall conform to the requirements of ASME B30.5, "Mobile and Locomotive Cranes";

e. Movement of the TSC or CONCRETE CASK in a horizontal orientation is not permitted.

Table 4-1 Load Combinations and Service Condition Definitions for the TSC Handling and Transfer Facility Structure

Load Combination	ASME Section III Service Condition for Definition of Allowable Stress	Note
D* D + S	Level A	All primary load bearing members must satisfy Level A stress limits
D + M + W'[1] D + F D + E D + Y	Level D	Factor of safety against overturning shall be ≥ 1.1, if applicable.

D = Crane hook dead load
D* = Apparent crane hook dead load
S = Snow and ice load for the facility site
M = Tornado missile load of the facility site[1]
W' = Tornado wind load for the facility site[1]
F = Flood load for the facility site
E = Seismic load for the facility site
Y = Tsunami load for the facility site

1. Tornado missile load may be reduced or eliminated based on a Probabilistic Risk Assessment for the facility site.

5.0 ADMINISTRATIVE CONTROLS AND PROGRAMS

The following programs shall be established, implemented and maintained.

5.1 Radioactive Effluent Control Program

5.1.1 A program shall be established and maintained to implement the requirements of 10 CFR 72.44 (d) or 10 CFR 72.126, as appropriate.

5.1.2 A program shall be established to monitor ISFSI effluents if established surface contamination limits exceed the values specified in Regulatory Guide 1.86 (June 1974).

5.2 TSC Loading, Unloading, and Preparation Program

A program shall be established and maintained to implement the FSAR, Chapter 9 requirements for loading fuel and components into the TSC, unloading fuel and components from the TSC, and preparing the TSC and CONCRETE CASK for storage. The requirements of the program for loading and preparing the TSC shall be completed prior to removing the TSC from the 10 CFR 50 structure. The program shall provide for evaluation and control of the following FSAR requirements during the applicable operation:

a. Verify that no TRANSFER CASK handling or CONCRETE CASK handling using the lifting lugs occurs when the ambient temperature is < 0°F.

b. The water temperature of a water-filled, or partially filled, loaded TSC shall be shown by analysis and/or measurement to be less than boiling at all times.

c. Verify that the drying time, cavity vacuum pressure, and component and gas temperatures ensure that the fuel cladding temperature limit of 400°C is not exceeded during TSC preparation activities, and that the TSC is adequately dry. For fuel with burnup > 45 GWd/MTU, limit cooling cycles to ≤10 for temperature changes greater than 65°C.

d. Verify that the helium backfill purity and mass assure adequate heat transfer and preclude fuel cladding corrosion.

e. The integrity of the inner port cover welds to the closure lid at the vent port and at the drain port shall be verified in accordance with the procedures in Section 9.1.1.

f. Verify that the time to complete the transfer of the TSC from the TRANSFER CASK to the CONCRETE CASK and from a CONCRETE CASK to another CONCRETE CASK assures that the fuel cladding temperature limit of 400°C is not exceeded.

(continued)

g. The surface dose rates of the CONCRETE CASK are adequate to allow proper storage and to assure consistency with the offsite dose analysis.

h. The equipment used to move the loaded CONCRETE CASK onto or from the ISFSI site contains no more than 50 gallons of flammable liquid.

This program will control limits, surveillances, compensatory measures and appropriate completion times to assure the integrity of the fuel cladding at all times in preparation for and during LOADING OPERATIONS, UNLOADING OPERATIONS, TRANSPORT OPERATIONS, TRANSFER OPERATIONS and STORAGE OPERATIONS, as applicable.

5.3 Transport Evaluation Program

A program that provides a means for evaluating transport route conditions shall be developed to ensure that the design basis impact g-load drop limits are met. For lifting of the loaded TRANSFER CASK or CONCRETE CASK using devices that are integral to a structure governed by 10 CFR 50 regulations, 10 CFR 50 requirements apply. This program evaluates the site-specific transport route conditions and controls, including the transport route road surface conditions; road and route hazards; security during transport; ambient temperature; and equipment operability and lift heights. The program shall also consider drop event impact g-loading and route subsurface conditions, as necessary.

5.4 ISFSI Operations Program

A program shall be established to implement FSAR requirements for ISFSI operations.

At a minimum, the program shall include the following criteria to be verified and controlled:

a. Minimum CONCRETE CASK center-to-center spacing.

b. ISFSI pad parameters (i.e., thickness, concrete strength, soil modulus, reinforcement, etc.) are consistent with the FSAR analyses.

c. Maximum CONCRETE CASK lift heights ensure that the g-load limits analyzed in the FSAR are not exceeded.

(continued)

5.5 Radiation Protection Program

5.5.1 Each cask user shall ensure that the 10 CFR 50 radiation protection program appropriately addresses dry storage cask loading and unloading, and ISFSI operations, including transport of the loaded CONCRETE CASK outside of facilities governed by 10 CFR 50. The radiation protection program shall include appropriate controls and monitoring for direct radiation and surface contamination, ensuring compliance with applicable regulations, and implementing actions to maintain personnel occupational exposures ALARA. The actions and criteria to be included in the program are provided as follows.

5.5.2 Each user shall perform a written evaluation of the TRANSFER CASK and associated operations, 30 days prior to first use, to verify that it meets public, occupational, and ALARA requirements (including shielding design and dose characteristics) in 10 CFR Part 20, and that it is consistent with the program elements of each user's radiation protection program. The evaluation should consider both normal operations and unanticipated occurrences, such as handling equipment malfunctions, during use of the transfer cask.

5.5.3 As part of the evaluation pursuant to 10 CFR 72.212(b)(2)(i)(C), the licensee shall perform an analysis to confirm that the dose limits of 10 CFR 72.104(a) will be satisfied under actual site conditions and ISFSI configuration, considering the number of casks to be deployed and the cask contents.

5.5.4 Establish limits on the surface contamination of the CONCRETE CASK, TSC and TRANSFER CASK, and procedures for the verification of meeting the established limits prior to removal of the components from the 10 CFR 50 structure.

5.6 Special Requirements for the First System Placed in Service

The heat transfer characteristics and thermal performance of the MAGNASTOR SYSTEM will be validated by recorded mass flow measurements in the air flow cooling passages of the first system placed in service with a heat load equal to or greater than 30 kW. A letter report summarizing the results of the measurements with respect to analyses of the actual canister content will be submitted to the NRC in accordance with 10 CFR 72.4 within 60 days of placing the loaded cask on the ISFSI pad. The report will include a comparison of the calculated mass flow of the MAGNASTOR SYSTEM at the loaded heat load to the measured mass flow. A report is not required to be submitted for the MAGNASTOR SYSTEMs that are subsequently loaded, provided that the performance of the first system placed in service with a heat load of ≥30 kW is demonstrated by the comparison of the calculated and measured mass flow rates.

Appendix B
Approved Contents for the MAGNASTOR System

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1.0 FUEL SPECIFICATIONS AND LOADING CONDITIONS

MAGNASTOR is designed to provide passive dry storage of canistered PWR and BWR fuel. The system requires few operating controls. The principal controls and limits for MAGNASTOR are satisfied by the selection of fuel for storage that meets the Approved Contents presented in this section and in the tables for MAGNASTOR design basis spent fuels.

If any Fuel Specification or Loading Condition of this section is violated, the following actions shall be completed:

- The affected fuel assemblies shall be placed in a safe condition.
- Within 24 hours, notify the NRC Operations Center.
- Within 60 days, submit a special report that describes the cause of the violation and actions taken to restore or demonstrate compliance and prevent reoccurrence.

2.0 FUEL TO BE STORED IN THE MAGNASTOR SYSTEM

UNDAMAGED FUEL ASSEMBLIES meeting the limits specified in Tables 2-1 through 2-22 of the FSAR may be stored in the MAGNASTOR SYSTEM.

Table 2-1 PWR Fuel Assembly Limits

I. PWR Fuel

A. Allowable Contents

1. Uranium PWR UNDAMAGED FUEL ASSEMBLIES listed in Tables 2-2 and 2-3 and meeting the following specifications:

a. Cladding Type:	Zirconium-based alloy.
b. Enrichment, Post-irradiation Cooling Time and Average Assembly Burnup:	Generic maximum enrichment limits are shown in Table 2-2. Fuel type specific maximum enrichments at various minimum soluble boron levels are defined in Table 2-3 . For variable enrichment fuel assemblies, maximum enrichments represent peak rod enrichments. Combined minimum enrichment, maximum assembly average burnup and minimum cool time limits are shown in Tables 2-13 through 2-20. For assembly average burnup levels below those shown in Tables 2-13 through 2-20, an assembly minimum cool time is specified in Table 2-11, provided that the minimum initial assembly average enrichment limits are applied.
c. Decay Heat Per Assembly (Preferential Loading):	≤ 1,200 watts
d. Nominal Fresh Fuel Assembly Length (in.):	≤ 178.3
e. Nominal Fresh Fuel Assembly Width (in.):	≤ 8.54
f. Fuel Assembly Weight (lbs.):	≤1,680, including nonfuel-bearing components

B. Quantity per TSC: Up to 37 PWR UNDAMAGED FUEL ASSEMBLIES. Fuel storage locations not containing a fuel assembly shall have an empty fuel cell insert installed.

C. PWR UNDAMAGED FUEL ASSEMBLIES may contain a flow mixer (thimble plug), instrument thimble, a burnable poison rod assembly, or a control element assembly consistent with Table 2-2. Nonfuel hardware may be located within the active fuel elevation of either the guide tubes or the instrument tube. Nonfuel hardware must not be located in the active fuel elevation of the guide tubes and the instrument tube simultaneously. Assembly lattices not containing the nominal number of fuel rods specified in Table 2-3 must contain solid filler rods that displace a volume equal to, or greater than, that of the fuel rod that the filler rod replaces. Assemblies may have stainless steel rods inserted to displace guide tube "dashpot" water. Loading activated nonfuel hardware requires extended fuel assembly cool times, and Table 2-4 presents the additional fuel assembly cool times required. Minimum BPRA and thimble plug cool times as a function of burnup (exposure) are shown in Tables 2-5 and 2-6. Alternatively, the ^{60}Co curie limits in Tables 2-5 and 2-6 may be used to establish site-specific nonfuel hardware constraints.

Table 2-1 PWR Fuel Assembly Limits (continued)

D. Spacers may be used in a TSC to axially position fuel assemblies to facilitate handling.

E. Unenriched fuel assemblies are not authorized for loading. Unenriched axial blankets are permitted.

F. Fuel may be loaded uniformly at a maximum heat load of 959 watts/assembly. Alternatively, a preferential loading pattern may be applied as described in Table 2-7 and Figure 2-1.

G. CEAs are restricted to the center 9 basket locations. Minimum CEA cool time is 10 years with a maximum equivalent exposure of 180,000 MWd/MTU.

Table 2-2 PWR Fuel Assembly Characteristics

Characteristic	14×14	14×14	15×15	15×15	16×16	17×17
Max Initial Enrichment (wt % ^{235}U)	5.0	5.0	5.0	5.0	5.0	5.0
Min Initial Enrichment (wt % ^{235}U)	1.3	1.3	1.3	1.3	1.3	1.3
Number of Fuel Rods	176	179	204	208	236	264
Max Assembly Average Burnup (MWd/MTU)	60,000	60,000	60,000	60,000	60,000	60,000
Peak Average Rod Burnup (MWd/MTU)	62,500	62,500	62,500	62,500	62,500	62,500
Min Cool Time (years)	4	4	4	4	4	4
Max Weight (lb) per Storage Location	1,680	1,680	1,680	1,680	1,680	1,680
Max Decay Heat (Watts) per Preferential Storage Location	1,200	1,200	1,200	1,200	1,200	1,200

- All reported enrichment values are nominal preirradiation fabrication values.
- Maximum initial enrichment is based on a minimum soluble boron concentration in the spent fuel pool water. Required soluble boron content is fuel type and enrichment specific. Minimum soluble boron content varies between 1,500 and 2,500 ppm. Maximum initial enrichment represents the peak fuel rod enrichment for variably-enriched fuel assemblies.
- Maximum uniform heat load is 959 watts per storage location.

Table 2-3 Bounding PWR Fuel Assembly Loading Criteria

Assembly Type	No. of Fuel Rods	No. of Guide Tubes[1]	Max Load (MTU)	Max. Initial Enrichment (wt% ^{235}U)[2]					Geometry[3]				
				Min Soluble Boron 1500 ppm	Min Soluble Boron 1750 ppm	Min Soluble Boron 2000 ppm	Min Soluble Boron 2250 pm	Min Soluble Boron 2500 ppm	Max Pitch (inch)	Min Clad OD (inch)	Min Clad Thick. (inch)	Max Pellet OD (inch)	Max Active Length (inch)
BW15H1	208	17	0.4858	3.70%	4.10%	4.40%	4.70%	5.00%	0.568	0.43	0.0265	0.3686	144.0
BW15H2	208	17	0.4988	3.70%	4.00%	4.30%	4.60%	4.90%	0.568	0.43	0.025	0.3735	144.0
BW15H3	208	17	0.5006	3.70%	4.00%	4.30%	4.60%	4.90%	0.568	0.428	0.023	0.3742	144.0
BW15H4	208	17	0.4690	3.80%	4.20%	4.50%	4.80%	5.00%	0.568	0.414	0.022	0.3622	144.0
BW17H1	264	25	0.4799	3.70%	4.00%	4.30%	4.60%	4.90%	0.502	0.377	0.022	0.3252	144.0
CE14H1	176	5	0.4167	4.50%	4.80%	5.00%	5.00%	5.00%	0.58	0.44	0.026	0.3805	137.0
CE16H1	236	5	0.4463	4.40%	4.80%	5.00%	5.00%	5.00%	0.5063	0.382	0.025	0.325	150.0
WE14H1	179	17	0.4188	4.70%	5.00%	5.00%	5.00%	5.00%	0.556	0.40	0.0162	0.3674	145.2
WE15H1	204	21	0.4720	3.80%	4.20%	4.50%	4.80%	5.00%	0.563	0.422	0.0242	0.3669	144.0
WE15H2	204	21	0.4469	4.00%	4.40%	4.70%	5.00%	5.00%	0.563	0.417	0.0265	0.357	144.0
WE17H1	264	25	0.4740	3.70%	4.10%	4.40%	4.70%	5.00%	0.496	0.372	0.0205	0.3232	144.0
WE17H2	264	25	0.4327	4.00%	4.30%	4.70%	5.00%	5.00%	0.496	0.36	0.0225	0.3088	144.0

1 Combined number of guide and instrument tubes.
2 Specified soluble boron concentrations are independent of whether an assembly contains a nonfuel insert.
3 Assembly characteristics represent cold, unirradiated, normal configurations.

Table 2-4 Additional Fuel Assembly Cool Time Required to Load PWR Nonfuel Hardware

Core (Assembly)	Cool Time (years)		
	BPRA	TP	CEA
CE 14×14	--	--	0.1
WE 14×14	0.5	0.1	0.5
WE 15×15	0.5	0.1	0.7
B&W 15×15	0.1	0.1	0.1
CE 16×16	--	--	0.1
WE 17×17	0.5	0.1	0.7
B&W 17×17	0.1	0.1	0.1

Note: Additional fuel assembly cooling time to be added to the minimum fuel assembly cool time based on assembly initial enrichment and assembly average burnup listed in Table 2-13 through 2-20.

Table 2-5 Allowed BPRA Burnup and Cool Time Combinations

Maximum Burnup (GWd/MTU)	Minimum Cool Time (yrs)				
	WE 14×14	WE 15×15	B&W 15×15	WE 17×17	B&W 17×17
10	0.5	0.5	0.5	0.5	0.5
15	0.5	0.5	0.5	0.5	0.5
20	0.5	1.0	2.0	2.0	0.5
25	1.0	2.5	3.5	3.5	1.0
30	2.5	4.0	5.0	5.0	2.5
32.5	3.0	4.5	6.0	6.0	3.0
35	3.5	5.0	6.0	6.0	3.5
37.5	4.0	6.0	7.0	7.0	4.0
40	4.5	6.0	7.0	7.0	4.5
45	5.0	7.0	8.0	8.0	6.0
50	6.0	8.0	9.0	9.0	7.0
55	7.0	8.0	10.0	9.0	7.0
60	7.0	9.0	10.0	10.0	8.0
65	8.0	10.0	12.0	12.0	8.0
70	8.0	10.0	12.0	12.0	9.0
Max ^{60}Co Activity (Ci)	718	733	19	637	26

Note: Specified minimum cool times for BPRAs are independent of the required minimum cool times for the fuel assembly containing the BPRA.

Table 2-6 Allowed Thimble Plug Burnup and Cool Time Combinations

Maximum Burnup (GWd/MTU)	Minimum Cool Time (yrs)				
	WE 14×14	WE 15×15	B&W 15×15	WE 17×17	B&W 17×17
45	2.0	3.5	7.0	5.0	6.0
90	6.0	7.0	10.0	9.0	10.0
135	7.0	9.0	12.0	10.0	12.0
180	8.0	9.0	14.0	12.0	12.0
^{60}Co Activity (Ci)	63.5	64.1	56.9	64.0	63.6

Note: Specified minimum cool times for thimble plugs are independent of the required minimum cool times for the fuel assembly containing the thimble plug.

Table 2-7 PWR Fuel Preferential Loading Pattern Definition

Zone Description (see Figure 2-1)	Designator	Maximum Heat Load (W/assy)	# Assemblies
Inner Zone	A	922	9
Middle Zone	B	1,200	12
Outer Zone	C	800	16

Figure 2-1 Schematic of PWR Fuel Preferential Loading Pattern

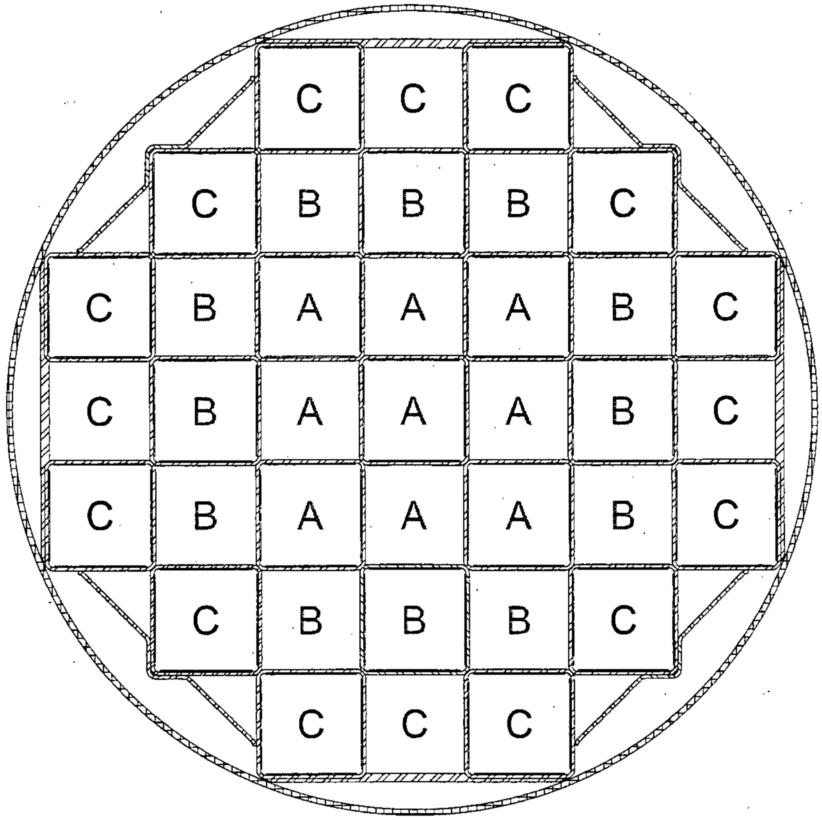


Table 2-8 BWR Fuel Assembly Limits

I. BWR FUEL

A. Allowable Contents

1. Uranium BWR UNDAMAGED FUEL ASSEMBLIES listed in Tables 2-9 and 2-10 and meeting the following specifications:

a. Cladding Type:	Zirconium-based alloy.
b. Enrichment: Post-irradiation Cooling Time and Assembly Average Burnup	Generic maximum INITIAL PEAK PLANAR-AVERAGE ENRICHMENTS are shown in Table 2-9. Fuel type specific enrichment limits for the 87-assembly and 82-assembly BWR fuel basket configurations are defined in Table 2-10. Combined minimum enrichment, maximum assembly average burnup and minimum cool time limits are shown in Table 2-21 and Table 2-22. For assembly average burnup levels below those shown in Table 2-21 and Table 2-22, an assembly minimum cool time is specified in Table 2-12, provided that the minimum initial assembly average enrichment limits are applied.
c. Decay Heat per Assembly:	≤ 379 watts
d. Nominal Fresh Fuel Design Assembly Length (in.):	≤ 176.2
e. Nominal Fresh Fuel Design Assembly Width (in.):	≤ 5.52
f. Fuel Assembly Weight (lb):	≤ 704, including channels

B. Quantity per TSC: Up to 87 BWR UNDAMAGED FUEL ASSEMBLIES. With the exception of the designated nonfuel locations in the 82-assembly basket configuration, fuel storage locations not containing a fuel assembly shall have an empty fuel cell insert installed. Prior to use of the 82-assembly configuration, the center cell weldment and upper weldments with blocking strap must be in place to physically block the designated nonfuel locations.

C. BWR fuel assemblies may be unchanneled, or channeled with zirconium-based alloy channels.

D. BWR fuel assemblies with stainless steel channels are not authorized.

E. Assembly lattices not containing the assembly type-specific nominal number of fuel rods (see Table 2-10) must contain solid filler rods that displace a volume equal to, or greater than, that of the fuel rod that the filler rod replaces.

F. Spacers may be used in a TSC to axially position BWR fuel assemblies to facilitate handling.

G. Unenriched fuel assemblies are not authorized for loading. Unenriched axial blankets are permitted.

H. Allowable fuel assembly locations for the 82-assembly fuel basket configuration are shown in Figure 2-2.

Table 2-9 BWR Fuel Assembly Characteristics

Characteristic	Fuel Class 7×7	8×8	9×9	10×10
Max Initial Enrichment (wt % ^{235}U)	4.5	4.5	4.5	4.5
Number of Fuel Rods	48/49	59/60/61/ 62/63/64	72/74[a]/76 / 79/80	91[a]/92[a]/ 96[a]/100
Max Assembly Average Burnup (MWd/MTU)	60,000	60,000	60,000	60,000
Peak Average Rod Burnup (MWd/MTU)	62,500	62,500	62,500	62,500
Min Cool Time (years)	4	4	4	4
Min Average Enrichment (wt % ^{235}U)	1.3	1.3	1.3	1.3
Max Weight (lb) per Storage Location	704	704	704	704
Max Decay Heat (Watts) per Storage Location	379	379	379	379

- Each BWR fuel assembly may include a zirconium-based alloy channel.
- Assembly weight includes the weight of the channel.
- Maximum initial enrichment is the peak planar-average enrichment.
- Water rods may occupy more than one fuel lattice location. Fuel assembly to contain nominal number of water rods for the specific assembly design.
- All enrichment values are nominal preirradiation fabrication values.
- Spacers may be used to axially position fuel assemblies to facilitate handling.

[a] Assemblies may contain partial-length fuel rods.

Table 2-10 BWR Fuel Assembly Loading Criteria

Assembly Type	Number of Fuel Rods	Number of Partial Length Rods [1]	Max Loading (MTU)	87-Assy Max Enrichment (wt% ^{235}U)	82-Assy Max Enrichment (wt% ^{235}U)	Geometry [3,4] Max Pitch (inch)	Min Clad OD (inch)	Min Clad Thick. (inch)	Max Pellet OD (inch)	Max Active Length (inch)
B7_48A	48	N/A	0.1981	4.00%	4.50%	0.7380	0.5700	0.03600	0.4900	144.0
B7_49A	49	N/A	0.2034	3.80%	4.50%	0.7380	0.5630	0.03200	0.4880	146.0
B7_49B	49	N/A	0.2115	3.80%	4.50%	0.7380	0.5630	0.03200	0.4910	150.0
B8_59A	59	N/A	0.1828	3.90%	4.50%	0.6400	0.4930	0.03400	0.4160	150.0
B8_60A	60	N/A	0.1815	3.80%	4.50%	0.6417	0.4840	0.03150	0.4110	150.0
B8_60B	60	N/A	0.1841	3.80%	4.50%	0.6400	0.4830	0.03000	0.4140	150.0
B8_61B	61	N/A	0.1872	3.80%	4.50%	0.6400	0.4830	0.03000	0.4140	150.0
B8_62A	62	N/A	0.1921	3.80%	4.50%	0.6417	0.4830	0.02900	0.4160	150.0
B8_63A	63	N/A	0.1985	3.80%	4.50%	0.6420	0.4840	0.02725	0.4195	150.0
B8_64A	64	N/A	0.2017	3.80%	4.50%	0.6420	0.4840	0.02725	0.4195	150.0
B8_64B[5]	64	N/A	0.1755	3.60%	4.30%	0.6090	0.4576	0.02900	0.3913	150.0
B9_72A	72	N/A	0.1803	3.80%	4.50%	0.5720	0.4330	0.02600	0.3740	150.0
B9_74A	74[2]	8	0.1873	3.70%	4.30%	0.5720	0.4240	0.02390	0.3760	150.0
B9_76A	76	N/A	0.1914	3.50%	4.20%	0.5720	0.4170	0.02090	0.3750	150.0
B9_79A	79	N/A	0.2000	3.70%	4.40%	0.5720	0.4240	0.02390	0.3760	150.0
B9_80A	80	N/A	0.1821	3.80%	4.50%	0.5720	0.4230	0.02950	0.3565	150.0
B10_91A	91[2]	8	0.1906	3.70%	4.50%	0.5100	0.3957	0.02385	0.3420	150.0
B10_92A	92[2]	14	0.1966	3.80%	4.50%	0.5100	0.4040	0.02600	0.3455	150.0
B10_96A[5]	96[2]	12	0.1787	3.70%	4.30%	0.4880	0.3780	0.02430	0.3224	150.0
B10_100A[5]	100	N/A	0.1861	3.60%	4.40%	0.4880	0.3780	0.02430	0.3224	150.0

[1] Location of the partial length rods is illustrated in Figure 2-3.
[2] Assemblies may contain partial-length fuel rods.
[3] Assembly characteristics represent cold, unirradiated, nominal configurations.
[4] Maximum channel thickness allowed is 120 mils (nominal).
[5] Composed of four subchannel clusters.

Figure 2-2 82-Assembly BWR Basket Pattern

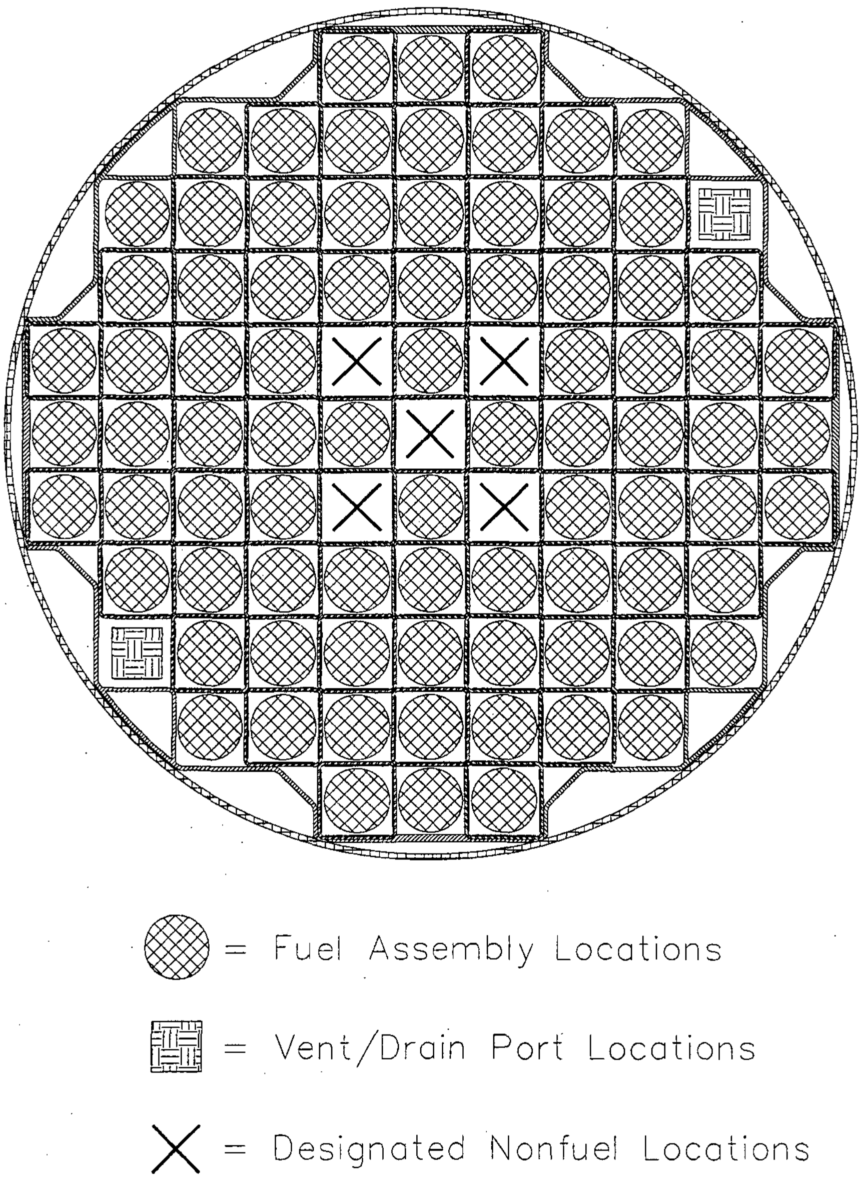
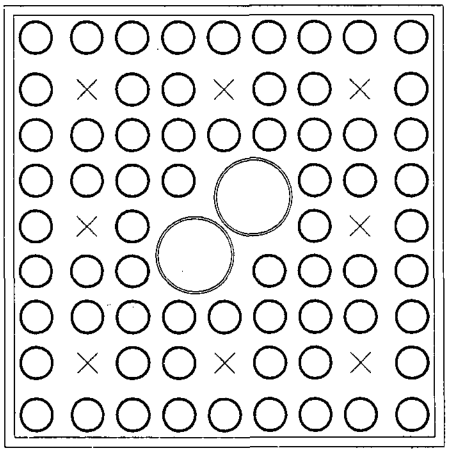


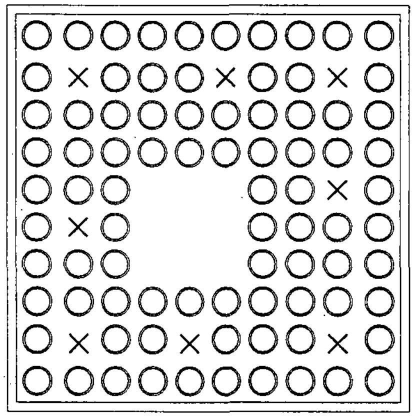
Figure 2-3 BWR Partial Length Fuel Rod Location Sketches



○ = Fuel Rod Location

× = Partial Rod Location

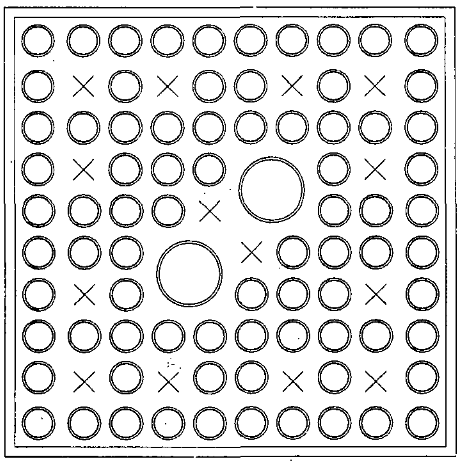
B9_74A 8 Partial Length Rods



○ = Fuel Rod Location

× = Partial Rod Location

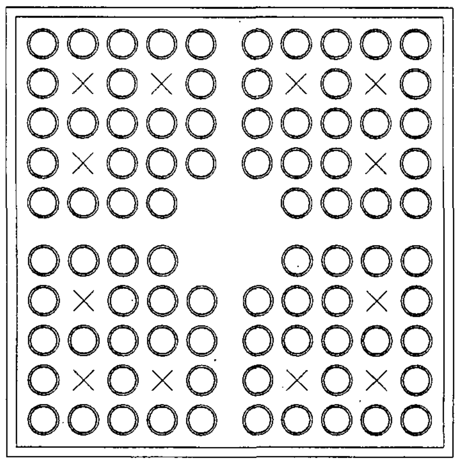
B10_91A 8 Partial Length Rods



○ = Fuel Rod Location

× = Partial Rod Location

B10_92A 14 Partial Length Rods



○ = Fuel Rod Location

× = Partial Rod Location

B10_96A 12 Partial Length Rods

Table 2-11 PWR Loading Table – Low Assembly Average Burnup Enrichment Limits

Max. Assembly Avg. Burnup (MWd/MTU)	Min. Assembly Avg. Initial Enrichment (wt% ^{235}U)	Minimum Cool Time (yrs)			
Heat Load per Assy	--	959 W	800 W	922 W	1,200 W
10,000	1.3	4.0	4.0	4.0	4.0
15,000	1.5	4.0	4.0	4.0	4.0
20,000	1.7	4.0	4.0	4.0	4.0
25,000	1.9	4.0	4.3	4.0	4.0
30,000	2.1	4.4	5.2	4.5	4.0

Table 2-12 BWR Loading Table – Low Assembly Average Burnup Enrichment Limits

Max. Assembly Avg. Burnup (MWd/MTU)	Min. Assembly Avg. Initial Enrichment (wt% ^{235}U)	Minimum Cool Time (yrs)
10,000	1.3	4.0
15,000	1.5	4.0
20,000	1.7	4.0
25,000	1.9	4.0
30,000	2.1	4.3

Table 2-13 Loading Table for PWR Fuel – 959 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	30 < Assembly Average Burnup ≤ 32.5 GWd/MTU Minimum Cooling Time (years)						
	CE 14x14	WE 14x14	WE 15x15	B&W 15x15	CE 16x16	WE 17x17	B&W 17x17
2.1 ≤ E < 2.3	4.1	4.1	4.6	4.7	4.4	4.7	4.7
2.3 ≤ E < 2.5	4.0	4.1	4.5	4.7	4.4	4.6	4.6
2.5 ≤ E < 2.7	4.0	4.0	4.5	4.6	4.3	4.6	4.6
2.7 ≤ E < 2.9	4.0	4.0	4.5	4.5	4.3	4.5	4.5
2.9 ≤ E < 3.1	4.0	4.0	4.4	4.5	4.2	4.5	4.5
3.1 ≤ E < 3.3	4.0	4.0	4.4	4.5	4.2	4.5	4.5
3.3 ≤ E < 3.5	4.0	4.0	4.3	4.4	4.2	4.4	4.4
3.5 ≤ E < 3.7	4.0	4.0	4.3	4.4	4.1	4.4	4.4
3.7 ≤ E < 3.9	4.0	4.0	4.3	4.4	4.1	4.4	4.4
3.9 ≤ E < 4.1	4.0	4.0	4.2	4.3	4.0	4.3	4.3
4.1 ≤ E < 4.3	4.0	4.0	4.2	4.3	4.0	4.3	4.3
4.3 ≤ E < 4.5	4.0	4.0	4.2	4.3	4.0	4.3	4.3
4.5 ≤ E < 4.7	4.0	4.0	4.1	4.2	4.0	4.2	4.2
4.7 ≤ E < 4.9	4.0	4.0	4.1	4.2	4.0	4.2	4.2
E ≥ 4.9	4.0	4.0	4.1	4.2	4.0	4.2	4.2
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	32.5 < Assembly Average Burnup ≤ 35 GWd/MTU Minimum Cooling Time (years)						
	CE 14x14	WE 14x14	WE 15x15	B&W 15x15	CE 16x16	WE 17x17	B&W 17x17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.3	4.4	5.0	5.1	4.7	5.0	5.0
2.5 ≤ E < 2.7	4.3	4.4	4.9	5.0	4.7	5.0	5.0
2.7 ≤ E < 2.9	4.2	4.3	4.8	5.0	4.6	4.9	4.9
2.9 ≤ E < 3.1	4.2	4.3	4.8	4.9	4.6	4.9	4.9
3.1 ≤ E < 3.3	4.1	4.2	4.7	4.9	4.5	4.8	4.8
3.3 ≤ E < 3.5	4.1	4.2	4.7	4.8	4.5	4.8	4.8
3.5 ≤ E < 3.7	4.1	4.1	4.6	4.8	4.4	4.7	4.7
3.7 ≤ E < 3.9	4.0	4.1	4.6	4.7	4.4	4.7	4.7
3.9 ≤ E < 4.1	4.0	4.1	4.6	4.7	4.4	4.7	4.7
4.1 ≤ E < 4.3	4.0	4.0	4.5	4.7	4.3	4.6	4.6
4.3 ≤ E < 4.5	4.0	4.0	4.5	4.6	4.3	4.6	4.6
4.5 ≤ E < 4.7	4.0	4.0	4.5	4.6	4.3	4.6	4.6
4.7 ≤ E < 4.9	4.0	4.0	4.4	4.6	4.3	4.5	4.5
E ≥ 4.9	4.0	4.0	4.4	4.5	4.2	4.5	4.5

Table 2-13 Loading Table for PWR Fuel – 959 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	35 < Assembly Average Burnup ≤ 37.5 GWd/MTU Minimum Cooling Time (years)						
	CE 14x14	WE 14x14	WE 15x15	B&W 15x15	CE 16x16	WE 17x17	B&W 17x17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.7	4.8	5.5	5.7	5.2	5.6	5.6
2.5 ≤ E < 2.7	4.6	4.7	5.4	5.6	5.1	5.5	5.5
2.7 ≤ E < 2.9	4.6	4.7	5.3	5.5	5.0	5.4	5.4
2.9 ≤ E < 3.1	4.5	4.6	5.3	5.4	5.0	5.4	5.4
3.1 ≤ E < 3.3	4.5	4.5	5.2	5.4	4.9	5.3	5.3
3.3 ≤ E < 3.5	4.4	4.5	5.1	5.3	4.9	5.2	5.2
3.5 ≤ E < 3.7	4.4	4.5	5.0	5.2	4.8	5.2	5.2
3.7 ≤ E < 3.9	4.3	4.4	5.0	5.2	4.8	5.1	5.1
3.9 ≤ E < 4.1	4.3	4.4	5.0	5.1	4.7	5.1	5.1
4.1 ≤ E < 4.3	4.3	4.4	4.9	5.1	4.7	5.0	5.0
4.3 ≤ E < 4.5	4.2	4.3	4.9	5.0	4.7	5.0	5.0
4.5 ≤ E < 4.7	4.2	4.3	4.9	5.0	4.6	5.0	5.0
4.7 ≤ E < 4.9	4.2	4.3	4.8	5.0	4.6	4.9	4.9
E ≥ 4.9	4.1	4.2	4.8	4.9	4.5	4.9	4.9
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**37.5 < Assembly Average Burnup ≤ 40 GWd/MTU Minimum Cooling Time (years)**						
	CE 14x14	WE 14x14	WE 15x15	B&W 15x15	CE 16x16	WE 17x17	B&W 17x17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.0	5.2	5.9	6.1	5.6	6.0	6.0
2.7 ≤ E < 2.9	5.0	5.1	5.9	6.0	5.5	5.9	5.9
2.9 ≤ E < 3.1	4.9	5.0	5.8	6.0	5.5	5.9	5.9
3.1 ≤ E < 3.3	4.9	4.9	5.7	5.9	5.4	5.8	5.8
3.3 ≤ E < 3.5	4.8	4.9	5.7	5.8	5.3	5.7	5.7
3.5 ≤ E < 3.7	4.7	4.8	5.6	5.8	5.2	5.7	5.7
3.7 ≤ E < 3.9	4.7	4.8	5.5	5.7	5.2	5.6	5.6
3.9 ≤ E < 4.1	4.6	4.8	5.5	5.7	5.1	5.6	5.6
4.1 ≤ E < 4.3	4.6	4.7	5.4	5.6	5.1	5.5	5.5
4.3 ≤ E < 4.5	4.5	4.7	5.4	5.6	5.0	5.5	5.5
4.5 ≤ E < 4.7	4.5	4.6	5.3	5.5	5.0	5.4	5.4
4.7 ≤ E < 4.9	4.5	4.6	5.3	5.5	5.0	5.4	5.4
E ≥ 4.9	4.5	4.5	5.2	5.4	4.9	5.4	5.4

Table 2-13 Loading Table for PWR Fuel – 959 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	40 < Assembly Average Burnup ≤ 41 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.3	5.4	6.2	6.4	5.8	6.3	6.3
2.7 ≤ E < 2.9	5.2	5.3	6.1	6.3	5.7	6.2	6.2
2.9 ≤ E < 3.1	5.1	5.2	6.0	6.2	5.7	6.1	6.1
3.1 ≤ E < 3.3	5.0	5.1	5.9	6.1	5.6	6.0	6.0
3.3 ≤ E < 3.5	4.9	5.1	5.9	6.0	5.5	5.9	5.9
3.5 ≤ E < 3.7	4.9	5.0	5.8	6.0	5.5	5.9	5.9
3.7 ≤ E < 3.9	4.8	4.9	5.7	5.9	5.4	5.8	5.8
3.9 ≤ E < 4.1	4.8	4.9	5.7	5.9	5.3	5.8	5.8
4.1 ≤ E < 4.3	4.7	4.9	5.6	5.8	5.3	5.7	5.7
4.3 ≤ E < 4.5	4.7	4.8	5.6	5.8	5.2	5.7	5.7
4.5 ≤ E < 4.7	4.7	4.8	5.5	5.7	5.2	5.6	5.6
4.7 ≤ E < 4.9	4.6	4.7	5.5	5.7	5.1	5.6	5.6
E ≥ 4.9	4.6	4.7	5.5	5.6	5.1	5.6	5.6

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	41 < Assembly Average Burnup ≤ 42 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.5	5.6	6.5	6.7	6.0	6.6	6.6
2.7 ≤ E < 2.9	5.4	5.5	6.4	6.6	5.9	6.5	6.5
2.9 ≤ E < 3.1	5.3	5.4	6.3	6.5	5.9	6.4	6.4
3.1 ≤ E < 3.3	5.2	5.3	6.2	6.4	5.8	6.3	6.3
3.3 ≤ E < 3.5	5.1	5.3	6.1	6.3	5.7	6.2	6.2
3.5 ≤ E < 3.7	5.0	5.2	6.0	6.2	5.7	6.1	6.1
3.7 ≤ E < 3.9	5.0	5.1	5.9	6.2	5.6	6.0	6.0
3.9 ≤ E < 4.1	4.9	5.1	5.9	6.1	5.5	6.0	6.0
4.1 ≤ E < 4.3	4.9	5.0	5.8	6.0	5.5	5.9	5.9
4.3 ≤ E < 4.5	4.9	5.0	5.8	6.0	5.4	5.9	5.9
4.5 ≤ E < 4.7	4.8	4.9	5.7	5.9	5.4	5.8	5.8
4.7 ≤ E < 4.9	4.8	4.9	5.7	5.9	5.3	5.8	5.8
E ≥ 4.9	4.7	4.9	5.7	5.9	5.3	5.8	5.8

Table 2-13 Loading Table for PWR Fuel – 959 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	42 < Assembly Average Burnup ≤ 43 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.7	5.8	6.8	7.0	6.3	6.9	6.9
2.7 ≤ E < 2.9	5.6	5.7	6.7	6.9	6.2	6.8	6.8
2.9 ≤ E < 3.1	5.5	5.6	6.6	6.8	6.0	6.7	6.7
3.1 ≤ E < 3.3	5.4	5.6	6.5	6.7	6.0	6.6	6.6
3.3 ≤ E < 3.5	5.3	5.5	6.4	6.6	5.9	6.5	6.5
3.5 ≤ E < 3.7	5.3	5.4	6.3	6.5	5.9	6.4	6.4
3.7 ≤ E < 3.9	5.2	5.3	6.2	6.5	5.8	6.3	6.3
3.9 ≤ E < 4.1	5.1	5.3	6.1	6.4	5.7	6.2	6.2
4.1 ≤ E < 4.3	5.0	5.2	6.0	6.3	5.7	6.2	6.1
4.3 ≤ E < 4.5	5.0	5.2	6.0	6.2	5.6	6.1	6.1
4.5 ≤ E < 4.7	5.0	5.1	5.9	6.2	5.6	6.0	6.0
4.7 ≤ E < 4.9	4.9	5.0	5.9	6.1	5.5	6.0	6.0
E ≥ 4.9	4.9	5.0	5.8	6.0	5.5	6.0	5.9

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	43 < Assembly Average Burnup ≤ 44 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.9	6.0	7.1	7.4	6.6	7.2	7.2
2.7 ≤ E < 2.9	5.8	5.9	7.0	7.3	6.5	7.0	7.0
2.9 ≤ E < 3.1	5.7	5.8	6.9	7.1	6.4	6.9	6.9
3.1 ≤ E < 3.3	5.6	5.8	6.8	7.0	6.2	6.8	6.8
3.3 ≤ E < 3.5	5.5	5.7	6.7	6.9	6.1	6.8	6.7
3.5 ≤ E < 3.7	5.5	5.6	6.6	6.8	6.0	6.7	6.7
3.7 ≤ E < 3.9	5.4	5.6	6.5	6.8	6.0	6.6	6.6
3.9 ≤ E < 4.1	5.3	5.5	6.4	6.7	5.9	6.5	6.5
4.1 ≤ E < 4.3	5.3	5.4	6.3	6.6	5.9	6.4	6.4
4.3 ≤ E < 4.5	5.2	5.4	6.2	6.5	5.8	6.4	6.4
4.5 ≤ E < 4.7	5.1	5.3	6.2	6.5	5.8	6.3	6.3
4.7 ≤ E < 4.9	5.1	5.3	6.1	6.4	5.7	6.2	6.2
E ≥ 4.9	5.0	5.2	6.0	6.3	5.7	6.2	6.2

Table 2-13 Loading Table for PWR Fuel – 959 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	44 < Assembly Average Burnup ≤ 45 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	6.0	6.2	7.3	7.7	6.7	7.4	7.4
2.9 ≤ E < 3.1	5.9	6.0	7.2	7.6	6.6	7.3	7.3
3.1 ≤ E < 3.3	5.8	6.0	7.0	7.4	6.5	7.2	7.1
3.3 ≤ E < 3.5	5.7	5.9	6.9	7.3	6.4	7.0	7.0
3.5 ≤ E < 3.7	5.7	5.8	6.8	7.2	6.3	6.9	6.9
3.7 ≤ E < 3.9	5.6	5.8	6.8	7.0	6.2	6.9	6.9
3.9 ≤ E < 4.1	5.5	5.7	6.7	7.0	6.2	6.8	6.8
4.1 ≤ E < 4.3	5.5	5.6	6.6	6.9	6.1	6.7	6.7
4.3 ≤ E < 4.5	5.4	5.6	6.5	6.8	6.0	6.7	6.6
4.5 ≤ E < 4.7	5.3	5.5	6.5	6.7	6.0	6.6	6.6
4.7 ≤ E < 4.9	5.3	5.5	6.4	6.7	5.9	6.5	6.5
E ≥ 4.9	5.2	5.4	6.3	6.6	5.9	6.5	6.5

Note: For fuel assembly average burnup greater than 45 GWd/MTU, cool time tables have been revised to account for a 5% margin in heat load.

Table 2-14 Loading Table for PWR Fuel – 911 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	45 < Assembly Average Burnup ≤ 46 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	6.7	6.9	8.5	9.0	7.7	8.6	8.6
2.9 ≤ E < 3.1	6.6	6.8	8.3	8.8	7.5	8.4	8.4
3.1 ≤ E < 3.3	6.5	6.7	8.1	8.6	7.4	8.2	8.2
3.3 ≤ E < 3.5	6.4	6.6	8.0	8.5	7.3	8.1	8.1
3.5 ≤ E < 3.7	6.3	6.5	7.8	8.3	7.1	8.0	7.9
3.7 ≤ E < 3.9	6.2	6.4	7.7	8.2	7.0	7.8	7.8
3.9 ≤ E < 4.1	6.1	6.3	7.6	8.0	6.9	7.7	7.7
4.1 ≤ E < 4.3	6.0	6.2	7.5	7.9	6.9	7.7	7.6
4.3 ≤ E < 4.5	6.0	6.2	7.4	7.8	6.8	7.6	7.6
4.5 ≤ E < 4.7	5.9	6.1	7.3	7.8	6.7	7.5	7.5
4.7 ≤ E < 4.9	5.9	6.0	7.2	7.7	6.7	7.4	7.4
E ≥ 4.9	5.8	6.0	7.2	7.6	6.6	7.3	7.3

Table 2-14 Loading Table for PWR Fuel – 911 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	46 < Assembly Average Burnup ≤ 47 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.0	7.3	9.0	9.6	8.0	9.1	9.1
2.9 ≤ E < 3.1	6.9	7.1	8.8	9.4	7.9	8.9	8.9
3.1 ≤ E < 3.3	6.8	7.0	8.6	9.2	7.8	8.7	8.7
3.3 ≤ E < 3.5	6.7	6.9	8.4	9.0	7.6	8.6	8.6
3.5 ≤ E < 3.7	6.6	6.8	8.3	8.8	7.5	8.4	8.4
3.7 ≤ E < 3.9	6.5	6.7	8.1	8.7	7.4	8.3	8.3
3.9 ≤ E < 4.1	6.4	6.6	8.0	8.5	7.3	8.1	8.1
4.1 ≤ E < 4.3	6.3	6.5	7.9	8.4	7.2	8.0	8.0
4.3 ≤ E < 4.5	6.2	6.5	7.8	8.3	7.1	7.9	7.9
4.5 ≤ E < 4.7	6.1	6.4	7.7	8.2	7.0	7.9	7.8
4.7 ≤ E < 4.9	6.0	6.3	7.6	8.1	6.9	7.8	7.8
E ≥ 4.9	6.0	6.2	7.6	8.0	6.9	7.7	7.7
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**47 < Assembly Average Burnup ≤ 48 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.4	7.7	9.6	10.3	8.6	9.7	9.7
2.9 ≤ E < 3.1	7.2	7.6	9.4	10.0	8.4	9.5	9.5
3.1 ≤ E < 3.3	7.1	7.4	9.1	9.8	8.2	9.3	9.3
3.3 ≤ E < 3.5	7.0	7.2	8.9	9.6	8.0	9.1	9.0
3.5 ≤ E < 3.7	6.9	7.1	8.8	9.4	7.9	8.9	8.9
3.7 ≤ E < 3.9	6.7	7.0	8.6	9.2	7.8	8.8	8.7
3.9 ≤ E < 4.1	6.7	6.9	8.5	9.0	7.6	8.6	8.6
4.1 ≤ E < 4.3	6.6	6.8	8.4	8.9	7.6	8.5	8.5
4.3 ≤ E < 4.5	6.5	6.7	8.2	8.8	7.4	8.4	8.4
4.5 ≤ E < 4.7	6.4	6.7	8.1	8.7	7.4	8.3	8.3
4.7 ≤ E < 4.9	6.3	6.6	8.0	8.6	7.3	8.2	8.2
E ≥ 4.9	6.2	6.5	7.9	8.5	7.2	8.1	8.1

Table 2-14 Loading Table for PWR Fuel – 911 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	48 < Assembly Average Burnup ≤ 49 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.8	8.1	10.2	11.1	9.0	10.4	10.4
2.9 ≤ E < 3.1	7.6	7.9	10.0	10.8	8.8	10.1	10.1
3.1 ≤ E < 3.3	7.5	7.8	9.7	10.5	8.6	9.9	9.8
3.3 ≤ E < 3.5	7.3	7.6	9.5	10.2	8.5	9.7	9.6
3.5 ≤ E < 3.7	7.2	7.5	9.3	10.0	8.3	9.5	9.4
3.7 ≤ E < 3.9	7.0	7.4	9.1	9.8	8.2	9.3	9.3
3.9 ≤ E < 4.1	6.9	7.2	9.0	9.6	8.0	9.1	9.1
4.1 ≤ E < 4.3	6.8	7.1	8.8	9.5	7.9	9.0	9.0
4.3 ≤ E < 4.5	6.8	7.0	8.7	9.3	7.8	8.9	8.9
4.5 ≤ E < 4.7	6.7	6.9	8.6	9.2	7.7	8.8	8.7
4.7 ≤ E < 4.9	6.6	6.9	8.5	9.1	7.6	8.7	8.6
E ≥ 4.9	6.5	6.8	8.4	9.0	7.6	8.6	8.5

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	49 < Assembly Average Burnup ≤ 50 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	8.0	8.3	10.7	11.6	9.4	10.9	10.9
3.1 ≤ E < 3.3	7.8	8.1	10.4	11.3	9.1	10.6	10.6
3.3 ≤ E < 3.5	7.7	7.9	10.1	11.0	9.0	10.3	10.3
3.5 ≤ E < 3.7	7.5	7.8	9.9	10.8	8.8	10.0	10.0
3.7 ≤ E < 3.9	7.4	7.6	9.7	10.5	8.6	9.9	9.9
3.9 ≤ E < 4.1	7.3	7.5	9.5	10.3	8.5	9.7	9.7
4.1 ≤ E < 4.3	7.1	7.4	9.4	10.1	8.3	9.6	9.5
4.3 ≤ E < 4.5	7.0	7.3	9.2	9.9	8.2	9.4	9.4
4.5 ≤ E < 4.7	6.9	7.2	9.1	9.8	8.1	9.3	9.2
4.7 ≤ E < 4.9	6.9	7.1	9.0	9.6	8.0	9.1	9.1
E ≥ 4.9	6.8	7.0	8.9	9.5	7.9	9.0	9.0

Table 2-14 Loading Table for PWR Fuel – 911 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % 235U (E)	50 < Assembly Average Burnup ≤ 51 GWd/MTU Minimum Cooling Time (years)						
	CE 14x14	WE 14x14	WE 15x15	B&W 15x15	CE 16x16	WE 17x17	B&W 17x17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	8.3	8.7	11.5	12.3	10.0	11.6	11.6
3.1 ≤ E < 3.3	8.0	8.5	11.2	12.0	9.8	11.3	11.3
3.3 ≤ E < 3.5	7.9	8.3	10.9	11.7	9.5	11.1	11.1
3.5 ≤ E < 3.7	7.8	8.1	10.6	11.5	9.3	10.8	10.8
3.7 ≤ E < 3.9	7.6	8.0	10.4	11.3	9.1	10.6	10.6
3.9 ≤ E < 4.1	7.5	7.9	10.1	11.1	9.0	10.4	10.4
4.1 ≤ E < 4.3	7.4	7.8	10.0	10.9	8.8	10.2	10.1
4.3 ≤ E < 4.5	7.3	7.6	9.8	10.6	8.7	10.0	10.0
4.5 ≤ E < 4.7	7.1	7.5	9.7	10.5	8.6	9.8	9.8
4.7 ≤ E < 4.9	7.0	7.4	9.5	10.3	8.5	9.7	9.7
E ≥ 4.9	7.0	7.3	9.4	10.1	8.3	9.6	9.6
Minimum Initial Assembly Avg. Enrichment wt % 235U (E)	**51 < Assembly Average Burnup ≤ 52 GWd/MTU Minimum Cooling Time (years)**						
	CE 14x14	WE 14x14	WE 15x15	B&W 15x15	CE 16x16	WE 17x17	B&W 17x17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	8.8	9.3	12.2	13.0	10.7	12.4	12.4
3.1 ≤ E < 3.3	8.5	9.0	11.9	12.6	10.4	12.1	12.0
3.3 ≤ E < 3.5	8.3	8.8	11.6	12.3	10.1	11.8	11.8
3.5 ≤ E < 3.7	8.1	8.6	11.4	11.9	9.9	11.6	11.5
3.7 ≤ E < 3.9	8.0	8.5	11.1	11.7	9.7	11.3	11.3
3.9 ≤ E < 4.1	7.9	8.3	10.9	11.5	9.5	11.1	11.1
4.1 ≤ E < 4.3	7.7	8.1	10.7	11.3	9.3	10.9	10.9
4.3 ≤ E < 4.5	7.6	8.0	10.5	11.1	9.2	10.7	10.7
4.5 ≤ E < 4.7	7.5	7.9	10.3	11.0	9.0	10.5	10.5
4.7 ≤ E < 4.9	7.4	7.8	10.1	10.8	8.9	10.3	10.3
E ≥ 4.9	7.3	7.7	10.0	10.6	8.8	10.2	10.2

Table 2-14 Loading Table for PWR Fuel – 911 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	52 < Assembly Average Burnup ≤ 53 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	9.3	9.8	12.8	13.8	11.4	13.3	13.3
3.1 ≤ E < 3.3	9.0	9.6	12.4	13.5	11.2	13.0	13.0
3.3 ≤ E < 3.5	8.8	9.3	12.1	13.2	10.9	12.6	12.6
3.5 ≤ E < 3.7	8.6	9.1	11.8	12.8	10.6	12.3	12.3
3.7 ≤ E < 3.9	8.4	9.0	11.5	12.6	10.3	12.0	12.0
3.9 ≤ E < 4.1	8.2	8.8	11.3	12.3	10.1	11.8	11.8
4.1 ≤ E < 4.3	8.1	8.6	11.1	12.0	9.9	11.6	11.6
4.3 ≤ E < 4.5	8.0	8.5	10.9	11.8	9.7	11.4	11.4
4.5 ≤ E < 4.7	7.9	8.3	10.7	11.7	9.6	11.2	11.2
4.7 ≤ E < 4.9	7.8	8.2	10.6	11.5	9.4	11.1	11.0
E ≥ 4.9	7.7	8.1	10.4	11.3	9.3	10.9	10.9

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	53 < Assembly Average Burnup ≤ 54 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	9.8	10.5	13.6	14.9	12.2	14.2	14.2
3.1 ≤ E < 3.3	9.6	10.2	13.3	14.4	11.8	13.8	13.8
3.3 ≤ E < 3.5	9.3	9.9	12.9	14.0	11.6	13.5	13.5
3.5 ≤ E < 3.7	9.1	9.7	12.6	13.7	11.3	13.2	13.2
3.7 ≤ E < 3.9	8.9	9.5	12.3	13.4	11.0	12.9	12.9
3.9 ≤ E < 4.1	8.7	9.3	12.0	13.2	10.8	12.6	12.6
4.1 ≤ E < 4.3	8.6	9.1	11.8	12.9	10.6	12.4	12.4
4.3 ≤ E < 4.5	8.4	8.9	11.6	12.6	10.4	12.1	12.1
4.5 ≤ E < 4.7	8.3	8.8	11.4	12.4	10.1	11.9	11.9
4.7 ≤ E < 4.9	8.1	8.7	11.3	12.2	10.0	11.8	11.7
E ≥ 4.9	8.0	8.8	11.1	12.0	9.9	11.6	11.6

Table 2-14 Loading Table for PWR Fuel – 911 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	54 < Assembly Average Burnup ≤ 55 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	10.1	10.9	14.1	15.4	12.7	14.8	14.8
3.3 ≤ E < 3.5	9.9	10.6	13.8	15.0	12.3	14.4	14.4
3.5 ≤ E < 3.7	9.6	10.3	13.5	14.7	12.0	14.0	14.0
3.7 ≤ E < 3.9	9.4	10.1	13.1	14.3	11.8	13.8	13.8
3.9 ≤ E < 4.1	9.2	9.8	12.9	14.0	11.5	13.5	13.5
4.1 ≤ E < 4.3	9.0	9.7	12.6	13.8	11.3	13.3	13.2
4.3 ≤ E < 4.5	8.9	9.5	12.3	13.5	11.1	13.0	13.0
4.5 ≤ E < 4.7	8.7	9.3	12.1	13.3	10.9	12.8	12.7
4.7 ≤ E < 4.9	8.6	9.1	11.9	13.1	10.7	12.6	12.5
E ≥ 4.9	8.5	9.0	11.7	12.9	10.5	12.3	12.3

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	55 < Assembly Average Burnup ≤ 56 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	10.9	11.6	15.1	16.5	13.1	15.8	15.8
3.3 ≤ E < 3.5	10.5	11.3	14.7	16.0	12.8	15.4	15.4
3.5 ≤ E < 3.7	10.2	11.0	14.3	15.7	12.4	15.1	15.0
3.7 ≤ E < 3.9	9.9	10.8	14.0	15.3	12.1	14.7	14.7
3.9 ≤ E < 4.1	9.7	10.5	13.7	15.0	11.9	14.4	14.4
4.1 ≤ E < 4.3	9.5	10.2	13.4	14.7	11.7	14.1	14.1
4.3 ≤ E < 4.5	9.3	10.0	13.2	14.5	11.4	13.8	13.8
4.5 ≤ E < 4.7	9.2	9.9	12.9	14.2	11.2	13.6	13.6
4.7 ≤ E < 4.9	9.0	9.7	12.7	13.9	11.1	13.4	13.4
E ≥ 4.9	8.9	9.5	12.5	13.8	10.9	13.2	13.2

Table 2-14 Loading Table for PWR Fuel – 911 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	56 < Assembly Average Burnup ≤ 57 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	11.5	12.3	16.0	17.4	14.0	16.8	16.8
3.3 ≤ E < 3.5	11.2	12.0	15.6	17.1	13.6	16.4	16.4
3.5 ≤ E < 3.7	10.9	11.7	15.3	16.7	13.3	16.0	16.0
3.7 ≤ E < 3.9	10.6	11.4	14.9	16.3	13.0	15.7	15.6
3.9 ≤ E < 4.1	10.3	11.2	14.6	16.0	12.6	15.4	15.3
4.1 ≤ E < 4.3	10.1	10.9	14.2	15.7	12.4	15.1	15.1
4.3 ≤ E < 4.5	9.9	10.7	14.0	15.4	12.1	14.8	14.8
4.5 ≤ E < 4.7	9.7	10.5	13.8	15.2	11.9	14.5	14.5
4.7 ≤ E < 4.9	9.5	10.3	13.6	14.9	11.7	14.2	14.2
E ≥ 4.9	9.4	10.1	13.4	14.7	11.5	14.0	14.0
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	57 < Assembly Average Burnup ≤ 58 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	12.2	13.2	17.0	18.5	14.9	17.8	17.7
3.3 ≤ E < 3.5	11.9	12.8	16.7	18.1	14.5	17.4	17.4
3.5 ≤ E < 3.7	11.6	12.4	16.2	17.7	14.1	17.0	17.0
3.7 ≤ E < 3.9	11.3	12.1	15.9	17.3	13.8	16.7	16.6
3.9 ≤ E < 4.1	11.0	11.9	15.6	17.0	13.5	16.3	16.3
4.1 ≤ E < 4.3	10.7	11.6	15.3	16.7	13.2	16.0	16.0
4.3 ≤ E < 4.5	10.5	11.4	15.0	16.4	12.9	15.7	15.7
4.5 ≤ E < 4.7	10.3	11.2	14.7	16.1	12.7	15.5	15.4
4.7 ≤ E < 4.9	10.0	10.9	14.4	15.8	12.4	15.2	15.2
E ≥ 4.9	9.9	10.8	14.2	15.6	12.2	15.0	14.9

Table 2-14 Loading Table for PWR Fuel – 911 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	58 < Assembly Average Burnup ≤ 59 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	13.0	14.0	18.0	19.5	15.8	18.8	18.8
3.3 ≤ E < 3.5	12.6	13.6	17.6	19.1	15.4	18.4	18.4
3.5 ≤ E < 3.7	12.2	13.3	17.2	18.7	15.0	18.0	18.0
3.7 ≤ E < 3.9	11.9	12.9	16.9	18.3	14.6	17.7	17.7
3.9 ≤ E < 4.1	11.6	12.6	16.5	18.0	14.3	17.4	17.3
4.1 ≤ E < 4.3	11.4	12.3	16.2	17.7	14.0	17.0	17.0
4.3 ≤ E < 4.5	11.1	12.0	15.9	17.4	13.7	16.7	16.7
4.5 ≤ E < 4.7	10.9	11.8	15.6	17.1	13.5	16.4	16.4
4.7 ≤ E < 4.9	10.7	11.6	15.4	16.8	13.2	16.1	16.1
E ≥ 4.9	10.5	11.4	15.1	16.6	13.0	15.9	15.9

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	59 < Assembly Average Burnup ≤ 60 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	-	-	-	-	-	-	-
3.3 ≤ E < 3.5	13.4	14.4	18.6	20.1	16.3	19.0	19.0
3.5 ≤ E < 3.7	13.0	14.1	18.2	19.7	15.9	18.6	18.5
3.7 ≤ E < 3.9	12.7	13.7	17.8	19.4	15.5	18.2	18.1
3.9 ≤ E < 4.1	12.3	13.4	17.5	19.0	15.2	17.9	17.8
4.1 ≤ E < 4.3	12.0	13.1	17.1	18.7	14.9	17.5	17.5
4.3 ≤ E < 4.5	11.8	12.8	16.8	18.4	14.6	17.2	17.2
4.5 ≤ E < 4.7	11.6	12.6	16.5	18.0	14.3	16.9	16.9
4.7 ≤ E < 4.9	11.3	12.3	16.2	17.8	14.0	16.6	16.6
E ≥ 4.9	11.2	12.1	16.0	17.6	13.8	16.4	16.3

Table 2-15 Loading Table for PWR Fuel – 1,200 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	30 < Assembly Average Burnup ≤ 32.5 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2.3 ≤ E < 2.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2.5 ≤ E < 2.7	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2.7 ≤ E < 2.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2.9 ≤ E < 3.1	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.1 ≤ E < 3.3	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.3 ≤ E < 3.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.5 ≤ E < 3.7	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.7 ≤ E < 3.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.9 ≤ E < 4.1	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.1 ≤ E < 4.3	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.3 ≤ E < 4.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.5 ≤ E < 4.7	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.7 ≤ E < 4.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
E ≥ 4.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**32.5 < Assembly Average Burnup ≤ 35 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.0	4.0	4.0	4.1	4.0	4.1	4.1
2.5 ≤ E < 2.7	4.0	4.0	4.0	4.1	4.0	4.0	4.0
2.7 ≤ E < 2.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2.9 ≤ E < 3.1	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.1 ≤ E < 3.3	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.3 ≤ E < 3.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.5 ≤ E < 3.7	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.7 ≤ E < 3.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
3.9 ≤ E < 4.1	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.1 ≤ E < 4.3	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.3 ≤ E < 4.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.5 ≤ E < 4.7	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.7 ≤ E < 4.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
E ≥ 4.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0

Table 2-15 Loading Table for PWR Fuel – 1,200 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	35 < Assembly Average Burnup ≤ 37.5 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.0	4.0	4.3	4.4	4.2	4.4	4.4
2.5 ≤ E < 2.7	4.0	4.0	4.3	4.4	4.1	4.4	4.4
2.7 ≤ E < 2.9	4.0	4.0	4.2	4.3	4.1	4.3	4.3
2.9 ≤ E < 3.1	4.0	4.0	4.2	4.3	4.0	4.3	4.3
3.1 ≤ E < 3.3	4.0	4.0	4.1	4.2	4.0	4.2	4.2
3.3 ≤ E < 3.5	4.0	4.0	4.1	4.2	4.0	4.2	4.2
3.5 ≤ E < 3.7	4.0	4.0	4.0	4.2	4.0	4.2	4.2
3.7 ≤ E < 3.9	4.0	4.0	4.0	4.1	4.0	4.1	4.1
3.9 ≤ E < 4.1	4.0	4.0	4.0	4.1	4.0	4.1	4.1
4.1 ≤ E < 4.3	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.3 ≤ E < 4.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.5 ≤ E < 4.7	4.0	4.0	4.0	4.0	4.0	4.0	4.0
4.7 ≤ E < 4.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
E ≥ 4.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	37.5 < Assembly Average Burnup ≤ 40 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	4.0	4.1	4.6	4.8	4.4	4.7	4.7
2.7 ≤ E < 2.9	4.0	4.0	4.6	4.7	4.4	4.7	4.7
2.9 ≤ E < 3.1	4.0	4.0	4.5	4.6	4.3	4.6	4.6
3.1 ≤ E < 3.3	4.0	4.0	4.5	4.6	4.3	4.5	4.5
3.3 ≤ E < 3.5	4.0	4.0	4.4	4.5	4.2	4.5	4.5
3.5 ≤ E < 3.7	4.0	4.0	4.4	4.5	4.2	4.5	4.4
3.7 ≤ E < 3.9	4.0	4.0	4.3	4.4	4.1	4.4	4.4
3.9 ≤ E < 4.1	4.0	4.0	4.3	4.4	4.1	4.4	4.4
4.1 ≤ E < 4.3	4.0	4.0	4.2	4.3	4.1	4.3	4.3
4.3 ≤ E < 4.5	4.0	4.0	4.2	4.3	4.0	4.3	4.3
4.5 ≤ E < 4.7	4.0	4.0	4.2	4.3	4.0	4.3	4.3
4.7 ≤ E < 4.9	4.0	4.0	4.1	4.3	4.0	4.3	4.3
E ≥ 4.9	4.0	4.0	4.1	4.2	4.0	4.2	4.2

Table 2-15 Loading Table for PWR Fuel – 1,200 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	40 < Assembly Average Burnup ≤ 41 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	4.2	4.2	4.8	4.9	4.5	4.9	4.9
2.7 ≤ E < 2.9	4.1	4.2	4.7	4.8	4.5	4.8	4.8
2.9 ≤ E < 3.1	4.0	4.1	4.7	4.8	4.4	4.8	4.7
3.1 ≤ E < 3.3	4.0	4.1	4.6	4.7	4.4	4.7	4.7
3.3 ≤ E < 3.5	4.0	4.0	4.5	4.7	4.4	4.6	4.6
3.5 ≤ E < 3.7	4.0	4.0	4.5	4.6	4.3	4.6	4.6
3.7 ≤ E < 3.9	4.0	4.0	4.4	4.5	4.2	4.5	4.5
3.9 ≤ E < 4.1	4.0	4.0	4.4	4.5	4.2	4.5	4.5
4.1 ≤ E < 4.3	4.0	4.0	4.4	4.5	4.2	4.5	4.5
4.3 ≤ E < 4.5	4.0	4.0	4.3	4.4	4.1	4.4	4.4
4.5 ≤ E < 4.7	4.0	4.0	4.3	4.4	4.1	4.4	4.4
4.7 ≤ E < 4.9	4.0	4.0	4.3	4.4	4.1	4.4	4.4
E ≥ 4.9	4.0	4.0	4.2	4.3	4.0	4.4	4.3

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	41 < Assembly Average Burnup ≤ 42 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	4.3	4.4	4.9	5.1	4.7	5.0	5.0
2.7 ≤ E < 2.9	4.2	4.3	4.9	5.0	4.6	5.0	5.0
2.9 ≤ E < 3.1	4.2	4.2	4.8	4.9	4.6	4.9	4.9
3.1 ≤ E < 3.3	4.1	4.2	4.7	4.9	4.5	4.8	4.8
3.3 ≤ E < 3.5	4.0	4.1	4.7	4.8	4.5	4.8	4.8
3.5 ≤ E < 3.7	4.0	4.1	4.6	4.8	4.4	4.7	4.7
3.7 ≤ E < 3.9	4.0	4.1	4.6	4.7	4.4	4.7	4.7
3.9 ≤ E < 4.1	4.0	4.0	4.5	4.6	4.3	4.6	4.6
4.1 ≤ E < 4.3	4.0	4.0	4.5	4.6	4.3	4.6	4.6
4.3 ≤ E < 4.5	4.0	4.0	4.4	4.6	4.3	4.5	4.5
4.5 ≤ E < 4.7	4.0	4.0	4.4	4.5	4.2	4.5	4.5
4.7 ≤ E < 4.9	4.0	4.0	4.4	4.5	4.2	4.5	4.5
E ≥ 4.9	4.0	4.0	4.3	4.5	4.2	4.5	4.5

Table 2-15 Loading Table for PWR Fuel – 1,200 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	42 < Assembly Average Burnup ≤ 43 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	4.4	4.5	5.1	5.3	4.9	5.2	5.2
2.7 ≤ E < 2.9	4.4	4.4	5.0	5.2	4.8	5.1	5.1
2.9 ≤ E < 3.1	4.3	4.4	5.0	5.1	4.7	5.0	5.0
3.1 ≤ E < 3.3	4.2	4.3	4.9	5.0	4.7	5.0	5.0
3.3 ≤ E < 3.5	4.2	4.3	4.8	5.0	4.6	4.9	4.9
3.5 ≤ E < 3.7	4.1	4.2	4.8	4.9	4.5	4.9	4.9
3.7 ≤ E < 3.9	4.1	4.2	4.7	4.9	4.5	4.8	4.8
3.9 ≤ E < 4.1	4.0	4.1	4.7	4.8	4.4	4.8	4.8
4.1 ≤ E < 4.3	4.0	4.1	4.6	4.8	4.4	4.7	4.7
4.3 ≤ E < 4.5	4.0	4.0	4.6	4.7	4.4	4.7	4.7
4.5 ≤ E < 4.7	4.0	4.0	4.5	4.7	4.3	4.7	4.6
4.7 ≤ E < 4.9	4.0	4.0	4.5	4.6	4.3	4.6	4.6
E ≥ 4.9	4.0	4.0	4.4	4.6	4.3	4.6	4.5

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	43 < Assembly Average Burnup ≤ 44 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	4.5	4.6	5.3	5.5	5.0	5.4	5.4
2.7 ≤ E < 2.9	4.5	4.6	5.2	5.4	4.9	5.3	5.3
2.9 ≤ E < 3.1	4.4	4.5	5.1	5.3	4.9	5.2	5.2
3.1 ≤ E < 3.3	4.4	4.4	5.0	5.2	4.8	5.2	5.2
3.3 ≤ E < 3.5	4.3	4.4	5.0	5.1	4.7	5.1	5.1
3.5 ≤ E < 3.7	4.2	4.3	4.9	5.1	4.7	5.0	5.0
3.7 ≤ E < 3.9	4.2	4.3	4.9	5.0	4.6	5.0	5.0
3.9 ≤ E < 4.1	4.1	4.3	4.8	5.0	4.6	4.9	4.9
4.1 ≤ E < 4.3	4.1	4.2	4.8	4.9	4.5	4.9	4.9
4.3 ≤ E < 4.5	4.1	4.2	4.7	4.9	4.5	4.8	4.8
4.5 ≤ E < 4.7	4.0	4.2	4.7	4.8	4.5	4.8	4.8
4.7 ≤ E < 4.9	4.0	4.1	4.6	4.8	4.4	4.8	4.7
E ≥ 4.9	4.0	4.1	4.6	4.8	4.4	4.7	4.7

Table 2-15 Loading Table for PWR Fuel – 1,200 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	44 < Assembly Average Burnup ≤ 45 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	4.6	4.7	5.4	5.6	5.1	5.5	5.5
2.9 ≤ E < 3.1	4.5	4.6	5.3	5.5	5.0	5.4	5.4
3.1 ≤ E < 3.3	4.5	4.6	5.2	5.4	4.9	5.4	5.4
3.3 ≤ E < 3.5	4.4	4.5	5.2	5.4	4.9	5.3	5.3
3.5 ≤ E < 3.7	4.4	4.5	5.1	5.3	4.8	5.2	5.2
3.7 ≤ E < 3.9	4.3	4.4	5.0	5.2	4.8	5.1	5.1
3.9 ≤ E < 4.1	4.3	4.4	5.0	5.1	4.7	5.1	5.1
4.1 ≤ E < 4.3	4.2	4.3	4.9	5.1	4.7	5.0	5.0
4.3 ≤ E < 4.5	4.2	4.3	4.9	5.0	4.6	5.0	5.0
4.5 ≤ E < 4.7	4.1	4.2	4.8	5.0	4.6	4.9	4.9
4.7 ≤ E < 4.9	4.1	4.2	4.8	4.9	4.5	4.9	4.9
E ≥ 4.9	4.0	4.2	4.7	4.9	4.5	4.9	4.8

Note: For fuel assembly average burnup greater than 45 GWd/MTU, cool time tables have been revised to account for a 5% margin in heat load.

Table 2-16 Loading Table for PWR Fuel – 1140 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	45 < Assembly Average Burnup ≤ 46 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	5.0	5.2	6.0	6.2	5.6	6.0	6.0
2.9 ≤ E < 3.1	5.0	5.1	5.9	6.0	5.5	6.0	6.0
3.1 ≤ E < 3.3	4.9	5.0	5.8	6.0	5.5	5.9	5.9
3.3 ≤ E < 3.5	4.8	4.9	5.7	5.9	5.4	5.8	5.8
3.5 ≤ E < 3.7	4.8	4.9	5.6	5.8	5.3	5.7	5.7
3.7 ≤ E < 3.9	4.7	4.8	5.6	5.8	5.2	5.7	5.7
3.9 ≤ E < 4.1	4.6	4.8	5.5	5.7	5.1	5.6	5.6
4.1 ≤ E < 4.3	4.6	4.7	5.4	5.6	5.1	5.5	5.6
4.3 ≤ E < 4.5	4.5	4.6	5.4	5.6	5.0	5.5	5.5
4.5 ≤ E < 4.7	4.5	4.6	5.3	5.5	5.0	5.4	5.4
4.7 ≤ E < 4.9	4.4	4.6	5.3	5.5	4.9	5.4	5.4
E ≥ 4.9	4.4	4.5	5.2	5.4	4.9	5.4	5.3

Table 2-16 Loading Table for PWR Fuel – 1140 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	46 < Assembly Average Burnup ≤ 47 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	5.2	5.4	6.2	6.5	5.8	6.3	6.3
2.9 ≤ E < 3.1	5.1	5.3	6.1	6.4	5.7	6.2	6.2
3.1 ≤ E < 3.3	5.0	5.2	6.0	6.2	5.6	6.1	6.1
3.3 ≤ E < 3.5	5.0	5.1	5.9	6.1	5.6	6.0	6.0
3.5 ≤ E < 3.7	4.9	5.0	5.8	6.0	5.5	5.9	5.9
3.7 ≤ E < 3.9	4.8	5.0	5.8	6.0	5.4	5.9	5.9
3.9 ≤ E < 4.1	4.8	4.9	5.7	5.9	5.3	5.8	5.8
4.1 ≤ E < 4.3	4.7	4.8	5.6	5.8	5.3	5.8	5.7
4.3 ≤ E < 4.5	4.7	4.8	5.6	5.8	5.2	5.7	5.7
4.5 ≤ E < 4.7	4.6	4.7	5.5	5.7	5.2	5.6	5.6
4.7 ≤ E < 4.9	4.6	4.7	5.5	5.7	5.1	5.6	5.6
E ≥ 4.9	4.5	4.7	5.4	5.6	5.0	5.5	5.5
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	47 < Assembly Average Burnup ≤ 48 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	5.4	5.6	6.5	6.8	6.0	6.6	6.6
2.9 ≤ E < 3.1	5.3	5.5	6.4	6.6	5.9	6.5	6.5
3.1 ≤ E < 3.3	5.2	5.4	6.2	6.5	5.8	6.4	6.4
3.3 ≤ E < 3.5	5.1	5.3	6.1	6.4	5.8	6.2	6.2
3.5 ≤ E < 3.7	5.0	5.2	6.0	6.3	5.7	6.2	6.1
3.7 ≤ E < 3.9	5.0	5.1	5.9	6.2	5.6	6.0	6.0
3.9 ≤ E < 4.1	4.9	5.0	5.9	6.1	5.5	6.0	6.0
4.1 ≤ E < 4.3	4.9	5.0	5.8	6.0	5.5	5.9	5.9
4.3 ≤ E < 4.5	4.8	4.9	5.8	6.0	5.4	5.9	5.9
4.5 ≤ E < 4.7	4.8	4.9	5.7	5.9	5.3	5.8	5.8
4.7 ≤ E < 4.9	4.7	4.9	5.7	5.8	5.3	5.8	5.8
E ≥ 4.9	4.7	4.8	5.6	5.8	5.2	5.7	5.7

Table 2-16 Loading Table for PWR Fuel – 1140 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	48 < Assembly Average Burnup ≤ 49 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	5.6	5.8	6.8	7.0	6.3	6.9	6.9
2.9 ≤ E < 3.1	5.5	5.7	6.7	6.9	6.1	6.8	6.7
3.1 ≤ E < 3.3	5.4	5.6	6.5	6.8	6.0	6.6	6.6
3.3 ≤ E < 3.5	5.3	5.5	6.4	6.7	5.9	6.5	6.5
3.5 ≤ E < 3.7	5.2	5.4	6.3	6.6	5.9	6.4	6.4
3.7 ≤ E < 3.9	5.2	5.3	6.2	6.5	5.8	6.3	6.3
3.9 ≤ E < 4.1	5.1	5.2	6.1	6.4	5.7	6.2	6.2
4.1 ≤ E < 4.3	5.0	5.2	6.0	6.3	5.7	6.1	6.1
4.3 ≤ E < 4.5	5.0	5.1	5.9	6.2	5.6	6.0	6.0
4.5 ≤ E < 4.7	4.9	5.0	5.9	6.1	5.5	6.0	6.0
4.7 ≤ E < 4.9	4.8	5.0	5.8	6.0	5.5	5.9	5.9
E ≥ 4.9	4.8	4.9	5.8	6.0	5.4	5.9	5.9
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**49 < Assembly Average Burnup ≤ 50 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	5.7	5.8	6.9	7.3	6.4	7.0	7.0
3.1 ≤ E < 3.3	5.6	5.7	6.8	7.1	6.3	6.9	6.9
3.3 ≤ E < 3.5	5.5	5.6	6.7	7.0	6.2	6.8	6.8
3.5 ≤ E < 3.7	5.4	5.5	6.6	6.9	6.0	6.7	6.7
3.7 ≤ E < 3.9	5.4	5.5	6.5	6.8	6.0	6.6	6.6
3.9 ≤ E < 4.1	5.3	5.4	6.4	6.7	5.9	6.5	6.5
4.1 ≤ E < 4.3	5.2	5.3	6.3	6.6	5.8	6.4	6.4
4.3 ≤ E < 4.5	5.1	5.2	6.2	6.5	5.8	6.3	6.3
4.5 ≤ E < 4.7	5.0	5.2	6.1	6.4	5.7	6.2	6.2
4.7 ≤ E < 4.9	5.0	5.1	6.0	6.3	5.7	6.2	6.2
E ≥ 4.9	4.9	5.0	6.0	6.2	5.6	6.1	6.1

Table 2-16 Loading Table for PWR Fuel – 1140 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	50 < Assembly Average Burnup ≤ 51 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	5.8	6.0	7.3	7.6	6.7	7.4	7.4
3.1 ≤ E < 3.3	5.8	5.9	7.1	7.5	6.6	7.2	7.2
3.3 ≤ E < 3.5	5.7	5.8	7.0	7.3	6.4	7.1	7.0
3.5 ≤ E < 3.7	5.6	5.7	6.8	7.2	6.3	6.9	6.9
3.7 ≤ E < 3.9	5.5	5.7	6.7	7.0	6.2	6.9	6.8
3.9 ≤ E < 4.1	5.4	5.6	6.6	6.9	6.1	6.8	6.8
4.1 ≤ E < 4.3	5.3	5.5	6.5	6.8	6.0	6.7	6.7
4.3 ≤ E < 4.5	5.2	5.4	6.4	6.8	6.0	6.6	6.6
4.5 ≤ E < 4.7	5.2	5.4	6.4	6.7	5.9	6.5	6.5
4.7 ≤ E < 4.9	5.1	5.3	6.3	6.6	5.8	6.4	6.4
E ≥ 4.9	5.0	5.2	6.2	6.5	5.8	6.4	6.3

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	51 < Assembly Average Burnup ≤ 52 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	6.0	6.3	7.6	7.9	6.9	7.7	7.7
3.1 ≤ E < 3.3	5.9	6.1	7.5	7.7	6.8	7.6	7.6
3.3 ≤ E < 3.5	5.8	6.0	7.3	7.6	6.7	7.4	7.4
3.5 ≤ E < 3.7	5.8	5.9	7.1	7.4	6.6	7.3	7.3
3.7 ≤ E < 3.9	5.7	5.9	7.0	7.3	6.5	7.1	7.1
3.9 ≤ E < 4.1	5.6	5.8	6.9	7.1	6.4	7.0	7.0
4.1 ≤ E < 4.3	5.5	5.7	6.8	7.0	6.3	6.9	6.9
4.3 ≤ E < 4.5	5.4	5.6	6.7	6.9	6.2	6.8	6.8
4.5 ≤ E < 4.7	5.4	5.6	6.6	6.8	6.1	6.8	6.8
4.7 ≤ E < 4.9	5.3	5.5	6.5	6.8	6.0	6.7	6.7
E ≥ 4.9	5.2	5.4	6.5	6.7	6.0	6.6	6.6

Table 2-16 Loading Table for PWR Fuel – 1140 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	52 < Assembly Average Burnup ≤ 53 GWd/MTU Minimum Cooling Time (years)						
	CE 14x14	WE 14x14	WE 15x15	B&W 15x15	CE 16x16	WE 17x17	B&W 17x17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	6.3	6.5	7.9	8.3	7.3	8.1	8.1
3.1 ≤ E < 3.3	6.2	6.4	7.7	8.1	7.1	7.9	7.9
3.3 ≤ E < 3.5	6.0	6.3	7.5	7.9	7.0	7.8	7.8
3.5 ≤ E < 3.7	5.9	6.1	7.4	7.8	6.9	7.6	7.6
3.7 ≤ E < 3.9	5.8	6.1	7.2	7.6	6.7	7.5	7.5
3.9 ≤ E < 4.1	5.8	6.0	7.1	7.5	6.6	7.4	7.3
4.1 ≤ E < 4.3	5.7	5.9	7.0	7.4	6.5	7.2	7.2
4.3 ≤ E < 4.5	5.6	5.8	6.9	7.2	6.4	7.1	7.1
4.5 ≤ E < 4.7	5.5	5.7	6.8	7.1	6.4	7.0	7.0
4.7 ≤ E < 4.9	5.5	5.7	6.7	7.0	6.3	6.9	6.9
E ≥ 4.9	5.4	5.6	6.6	6.9	6.2	6.9	6.9

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	53 < Assembly Average Burnup ≤ 54 GWd/MTU Minimum Cooling Time (years)						
	CE 14x14	WE 14x14	WE 15x15	B&W 15x15	CE 16x16	WE 17x17	B&W 17x17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	6.6	6.8	8.3	8.8	7.6	8.6	8.6
3.1 ≤ E < 3.3	6.4	6.7	8.0	8.6	7.5	8.3	8.3
3.3 ≤ E < 3.5	6.3	6.5	7.9	8.3	7.3	8.2	8.1
3.5 ≤ E < 3.7	6.1	6.4	7.7	8.1	7.1	8.0	8.0
3.7 ≤ E < 3.9	6.0	6.3	7.6	8.0	7.0	7.9	7.8
3.9 ≤ E < 4.1	5.9	6.2	7.4	7.8	6.9	7.7	7.7
4.1 ≤ E < 4.3	5.9	6.1	7.3	7.7	6.8	7.6	7.6
4.3 ≤ E < 4.5	5.8	6.0	7.2	7.6	6.7	7.5	7.5
4.5 ≤ E < 4.7	5.7	5.9	7.0	7.5	6.6	7.4	7.3
4.7 ≤ E < 4.9	5.7	5.9	7.0	7.4	6.5	7.2	7.2
E ≥ 4.9	5.6	5.9	6.9	7.3	6.4	7.1	7.1

Table 2-16 Loading Table for PWR Fuel – 1140 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	54 < Assembly Average Burnup ≤ 55 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	6.7	6.9	8.5	9.0	7.8	8.8	8.8
3.3 ≤ E < 3.5	6.6	6.8	8.3	8.8	7.6	8.6	8.6
3.5 ≤ E < 3.7	6.4	6.7	8.1	8.6	7.5	8.4	8.4
3.7 ≤ E < 3.9	6.3	6.6	7.9	8.4	7.3	8.2	8.2
3.9 ≤ E < 4.1	6.2	6.5	7.8	8.2	7.2	8.0	8.0
4.1 ≤ E < 4.3	6.1	6.3	7.6	8.1	7.0	7.9	7.9
4.3 ≤ E < 4.5	6.0	6.2	7.5	7.9	7.0	7.8	7.8
4.5 ≤ E < 4.7	5.9	6.1	7.4	7.8	6.9	7.7	7.7
4.7 ≤ E < 4.9	5.9	6.0	7.3	7.7	6.8	7.6	7.6
E ≥ 4.9	5.8	6.0	7.2	7.6	6.7	7.5	7.5
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	55 < Assembly Average Burnup ≤ 56 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	6.9	7.3	8.9	9.6	8.0	9.3	9.3
3.3 ≤ E < 3.5	6.8	7.1	8.7	9.3	7.8	9.0	9.0
3.5 ≤ E < 3.7	6.7	6.9	8.5	9.1	7.7	8.8	8.9
3.7 ≤ E < 3.9	6.6	6.8	8.3	8.9	7.5	8.7	8.7
3.9 ≤ E < 4.1	6.4	6.7	8.1	8.7	7.4	8.5	8.5
4.1 ≤ E < 4.3	6.3	6.6	8.0	8.5	7.2	8.3	8.3
4.3 ≤ E < 4.5	6.2	6.5	7.9	8.4	7.1	8.2	8.1
4.5 ≤ E < 4.7	6.1	6.4	7.7	8.2	7.0	8.0	8.0
4.7 ≤ E < 4.9	6.0	6.3	7.6	8.1	6.9	7.9	7.9
E ≥ 4.9	6.0	6.2	7.5	8.0	6.8	7.8	7.8

Table 2-16 Loading Table for PWR Fuel – 1140 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	56 < Assembly Average Burnup ≤ 57 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	7.3	7.6	9.4	10.1	8.4	9.8	9.8
3.3 ≤ E < 3.5	7.1	7.4	9.2	9.9	8.2	9.6	9.6
3.5 ≤ E < 3.7	6.9	7.3	9.0	9.6	8.0	9.4	9.3
3.7 ≤ E < 3.9	6.8	7.1	8.8	9.4	7.9	9.1	9.1
3.9 ≤ E < 4.1	6.7	7.0	8.6	9.2	7.7	8.9	8.9
4.1 ≤ E < 4.3	6.6	6.9	8.4	9.0	7.6	8.8	8.8
4.3 ≤ E < 4.5	6.5	6.8	8.2	8.8	7.5	8.6	8.6
4.5 ≤ E < 4.7	6.4	6.7	8.1	8.7	7.3	8.5	8.4
4.7 ≤ E < 4.9	6.3	6.6	8.0	8.5	7.2	8.3	8.3
E ≥ 4.9	6.2	6.5	7.8	8.4	7.1	8.2	8.2
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	57 < Assembly Average Burnup ≤ 58 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	7.6	8.0	10.0	10.8	8.9	10.5	10.4
3.3 ≤ E < 3.5	7.4	7.8	9.7	10.5	8.7	10.2	10.1
3.5 ≤ E < 3.7	7.2	7.6	9.5	10.2	8.4	9.9	9.9
3.7 ≤ E < 3.9	7.1	7.5	9.3	9.9	8.2	9.7	9.6
3.9 ≤ E < 4.1	6.9	7.3	9.0	9.7	8.1	9.5	9.4
4.1 ≤ E < 4.3	6.8	7.1	8.8	9.5	7.9	9.2	9.2
4.3 ≤ E < 4.5	6.7	7.0	8.7	9.3	7.8	9.0	9.0
4.5 ≤ E < 4.7	6.6	6.9	8.5	9.1	7.7	8.9	8.9
4.7 ≤ E < 4.9	6.5	6.8	8.4	8.9	7.5	8.7	8.7
E ≥ 4.9	6.4	6.7	8.2	8.8	7.4	8.6	8.6

Table 2-16 Loading Table for PWR Fuel – 1140 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	58 < Assembly Average Burnup ≤ 59 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	7.9	8.4	10.7	11.5	9.4	11.1	11.1
3.3 ≤ E < 3.5	7.8	8.2	10.3	11.2	9.1	10.8	10.8
3.5 ≤ E < 3.7	7.6	8.0	10.0	10.9	8.9	10.5	10.5
3.7 ≤ E < 3.9	7.4	7.8	9.8	10.6	8.7	10.2	10.2
3.9 ≤ E < 4.1	7.2	7.6	9.5	10.3	8.5	10.0	9.9
4.1 ≤ E < 4.3	7.1	7.5	9.3	10.0	8.3	9.8	9.7
4.3 ≤ E < 4.5	7.0	7.3	9.1	9.8	8.1	9.6	9.5
4.5 ≤ E < 4.7	6.9	7.2	8.9	9.6	8.0	9.4	9.4
4.7 ≤ E < 4.9	6.8	7.1	8.8	9.5	7.9	9.2	9.2
E ≥ 4.9	6.7	7.0	8.7	9.3	7.8	9.0	9.0
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**59 < Assembly Average Burnup ≤ 60 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	-	-	-	-	-	-	-
3.3 ≤ E < 3.5	8.1	8.6	11.0	11.8	9.6	11.2	11.2
3.5 ≤ E < 3.7	7.9	8.4	10.7	11.5	9.4	10.9	10.8
3.7 ≤ E < 3.9	7.7	8.2	10.3	11.2	9.1	10.6	10.5
3.9 ≤ E < 4.1	7.6	8.0	10.1	11.0	8.9	10.3	10.3
4.1 ≤ E < 4.3	7.4	7.8	9.8	10.7	8.7	10.0	10.0
4.3 ≤ E < 4.5	7.3	7.7	9.6	10.4	8.5	9.8	9.8
4.5 ≤ E < 4.7	7.1	7.6	9.4	10.2	8.4	9.7	9.6
4.7 ≤ E < 4.9	7.0	7.4	9.2	10.0	8.2	9.5	9.4
E ≥ 4.9	6.9	7.3	9.1	9.8	8.1	9.3	9.3

Table 2-17 Loading Table for PWR Fuel – 922 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	30 < Assembly Average Burnup ≤ 32.5 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	4.2	4.3	4.8	4.9	4.6	4.9	4.9
2.3 ≤ E < 2.5	4.2	4.2	4.7	4.8	4.5	4.8	4.8
2.5 ≤ E < 2.7	4.1	4.2	4.7	4.8	4.5	4.8	4.8
2.7 ≤ E < 2.9	4.1	4.1	4.6	4.7	4.4	4.7	4.7
2.9 ≤ E < 3.1	4.0	4.1	4.6	4.7	4.4	4.7	4.7
3.1 ≤ E < 3.3	4.0	4.0	4.5	4.6	4.3	4.6	4.6
3.3 ≤ E < 3.5	4.0	4.0	4.5	4.6	4.3	4.6	4.6
3.5 ≤ E < 3.7	4.0	4.0	4.5	4.5	4.3	4.5	4.5
3.7 ≤ E < 3.9	4.0	4.0	4.4	4.5	4.2	4.5	4.5
3.9 ≤ E < 4.1	4.0	4.0	4.4	4.5	4.2	4.5	4.5
4.1 ≤ E < 4.3	4.0	4.0	4.4	4.5	4.2	4.4	4.4
4.3 ≤ E < 4.5	4.0	4.0	4.3	4.4	4.2	4.4	4.4
4.5 ≤ E < 4.7	4.0	4.0	4.3	4.4	4.1	4.4	4.4
4.7 ≤ E < 4.9	4.0	4.0	4.3	4.4	4.1	4.4	4.4
E ≥ 4.9	4.0	4.0	4.3	4.4	4.1	4.4	4.4

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	32.5 < Assembly Average Burnup ≤ 35 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.5	4.6	5.2	5.3	4.9	5.3	5.3
2.5 ≤ E < 2.7	4.4	4.5	5.1	5.3	4.9	5.2	5.2
2.7 ≤ E < 2.9	4.4	4.5	5.0	5.2	4.8	5.1	5.1
2.9 ≤ E < 3.1	4.4	4.4	5.0	5.1	4.8	5.1	5.1
3.1 ≤ E < 3.3	4.3	4.4	4.9	5.0	4.7	5.0	5.0
3.3 ≤ E < 3.5	4.3	4.3	4.9	5.0	4.7	5.0	5.0
3.5 ≤ E < 3.7	4.2	4.3	4.8	5.0	4.6	4.9	4.9
3.7 ≤ E < 3.9	4.2	4.3	4.8	4.9	4.6	4.9	4.9
3.9 ≤ E < 4.1	4.1	4.2	4.8	4.9	4.5	4.9	4.9
4.1 ≤ E < 4.3	4.1	4.2	4.7	4.9	4.5	4.8	4.8
4.3 ≤ E < 4.5	4.1	4.2	4.7	4.8	4.5	4.8	4.8
4.5 ≤ E < 4.7	4.0	4.1	4.7	4.8	4.5	4.8	4.8
4.7 ≤ E < 4.9	4.0	4.1	4.6	4.8	4.4	4.7	4.7
E ≥ 4.9	4.0	4.1	4.6	4.7	4.4	4.7	4.7

Table 2-17 Loading Table for PWR Fuel – 922 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	35 < Assembly Average Burnup ≤ 37.5 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.9	5.0	5.7	5.9	5.4	5.8	5.8
2.5 ≤ E < 2.7	4.8	4.9	5.7	5.8	5.3	5.7	5.7
2.7 ≤ E < 2.9	4.8	4.9	5.6	5.8	5.3	5.7	5.7
2.9 ≤ E < 3.1	4.7	4.8	5.5	5.7	5.2	5.6	5.6
3.1 ≤ E < 3.3	4.6	4.7	5.4	5.6	5.1	5.5	5.5
3.3 ≤ E < 3.5	4.6	4.7	5.4	5.6	5.0	5.5	5.5
3.5 ≤ E < 3.7	4.5	4.6	5.3	5.5	5.0	5.4	5.4
3.7 ≤ E < 3.9	4.5	4.6	5.3	5.4	5.0	5.4	5.4
3.9 ≤ E < 4.1	4.5	4.6	5.2	5.4	4.9	5.3	5.3
4.1 ≤ E < 4.3	4.4	4.5	5.2	5.4	4.9	5.3	5.3
4.3 ≤ E < 4.5	4.4	4.5	5.1	5.3	4.9	5.2	5.2
4.5 ≤ E < 4.7	4.4	4.5	5.1	5.3	4.8	5.2	5.2
4.7 ≤ E < 4.9	4.3	4.4	5.0	5.2	4.8	5.2	5.2
E ≥ 4.9	4.3	4.4	5.0	5.2	4.8	5.1	5.1

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	37.5 < Assembly Average Burnup ≤ 40 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.3	5.4	6.2	6.5	5.9	6.3	6.3
2.7 ≤ E < 2.9	5.2	5.3	6.1	6.4	5.8	6.2	6.2
2.9 ≤ E < 3.1	5.1	5.3	6.0	6.3	5.7	6.1	6.1
3.1 ≤ E < 3.3	5.0	5.2	6.0	6.2	5.6	6.0	6.0
3.3 ≤ E < 3.5	5.0	5.1	5.9	6.1	5.6	6.0	6.0
3.5 ≤ E < 3.7	4.9	5.0	5.9	6.0	5.5	5.9	5.9
3.7 ≤ E < 3.9	4.9	5.0	5.8	6.0	5.5	5.9	5.9
3.9 ≤ E < 4.1	4.8	5.0	5.7	5.9	5.4	5.8	5.8
4.1 ≤ E < 4.3	4.8	4.9	5.7	5.9	5.4	5.8	5.8
4.3 ≤ E < 4.5	4.8	4.9	5.7	5.8	5.3	5.8	5.7
4.5 ≤ E < 4.7	4.7	4.8	5.6	5.8	5.3	5.7	5.7
4.7 ≤ E < 4.9	4.7	4.8	5.6	5.8	5.2	5.7	5.7
E ≥ 4.9	4.6	4.8	5.5	5.7	5.2	5.6	5.6

Table 2-17 Loading Table for PWR Fuel – 922 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	40 < Assembly Average Burnup ≤ 41 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.5	5.6	6.6	6.8	6.0	6.6	6.6
2.7 ≤ E < 2.9	5.4	5.6	6.4	6.7	6.0	6.5	6.5
2.9 ≤ E < 3.1	5.3	5.5	6.3	6.6	5.9	6.4	6.4
3.1 ≤ E < 3.3	5.3	5.4	6.2	6.5	5.8	6.3	6.3
3.3 ≤ E < 3.5	5.2	5.3	6.1	6.4	5.8	6.3	6.2
3.5 ≤ E < 3.7	5.1	5.3	6.1	6.3	5.7	6.2	6.2
3.7 ≤ E < 3.9	5.0	5.2	6.0	6.2	5.7	6.1	6.1
3.9 ≤ E < 4.1	5.0	5.1	5.9	6.2	5.6	6.0	6.0
4.1 ≤ E < 4.3	5.0	5.1	5.9	6.1	5.6	6.0	6.0
4.3 ≤ E < 4.5	4.9	5.0	5.9	6.0	5.5	5.9	5.9
4.5 ≤ E < 4.7	4.9	5.0	5.8	6.0	5.5	5.9	5.9
4.7 ≤ E < 4.9	4.8	5.0	5.8	6.0	5.4	5.9	5.9
E ≥ 4.9	4.8	4.9	5.7	5.9	5.4	5.8	5.8
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	41 < Assembly Average Burnup ≤ 42 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.7	5.9	6.9	7.1	6.4	6.9	6.9
2.7 ≤ E < 2.9	5.6	5.8	6.7	7.0	6.2	6.8	6.8
2.9 ≤ E < 3.1	5.6	5.7	6.6	6.9	6.1	6.7	6.7
3.1 ≤ E < 3.3	5.5	5.6	6.5	6.8	6.0	6.6	6.6
3.3 ≤ E < 3.5	5.4	5.5	6.4	6.7	6.0	6.6	6.5
3.5 ≤ E < 3.7	5.3	5.5	6.4	6.6	5.9	6.5	6.5
3.7 ≤ E < 3.9	5.3	5.4	6.3	6.6	5.9	6.4	6.4
3.9 ≤ E < 4.1	5.2	5.4	6.2	6.5	5.8	6.3	6.3
4.1 ≤ E < 4.3	5.1	5.3	6.1	6.4	5.8	6.3	6.2
4.3 ≤ E < 4.5	5.1	5.2	6.0	6.3	5.7	6.2	6.2
4.5 ≤ E < 4.7	5.0	5.2	6.0	6.3	5.7	6.1	6.1
4.7 ≤ E < 4.9	5.0	5.1	6.0	6.2	5.6	6.1	6.1
E ≥ 4.9	4.9	5.1	5.9	6.2	5.6	6.0	6.0

Table 2-17 Loading Table for PWR Fuel – 922 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	42 < Assembly Average Burnup ≤ 43 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.9	6.1	7.2	7.5	6.7	7.3	7.3
2.7 ≤ E < 2.9	5.8	6.0	7.0	7.4	6.5	7.1	7.1
2.9 ≤ E < 3.1	5.8	5.9	6.9	7.3	6.4	7.0	7.0
3.1 ≤ E < 3.3	5.7	5.8	6.8	7.1	6.3	6.9	6.9
3.3 ≤ E < 3.5	5.6	5.8	6.7	7.0	6.2	6.8	6.8
3.5 ≤ E < 3.7	5.5	5.7	6.7	6.9	6.1	6.8	6.7
3.7 ≤ E < 3.9	5.5	5.6	6.6	6.8	6.1	6.7	6.7
3.9 ≤ E < 4.1	5.4	5.6	6.5	6.8	6.0	6.6	6.6
4.1 ≤ E < 4.3	5.3	5.5	6.4	6.7	6.0	6.5	6.5
4.3 ≤ E < 4.5	5.3	5.5	6.4	6.6	5.9	6.5	6.5
4.5 ≤ E < 4.7	5.2	5.4	6.3	6.6	5.9	6.4	6.4
4.7 ≤ E < 4.9	5.2	5.3	6.2	6.5	5.8	6.4	6.4
E ≥ 4.9	5.1	5.3	6.2	6.5	5.8	6.3	6.3
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**43 < Assembly Average Burnup ≤ 44 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	6.2	6.4	7.6	8.0	6.9	7.7	7.7
2.7 ≤ E < 2.9	6.0	6.2	7.4	7.8	6.8	7.5	7.5
2.9 ≤ E < 3.1	6.0	6.1	7.3	7.7	6.7	7.4	7.4
3.1 ≤ E < 3.3	5.9	6.0	7.2	7.5	6.6	7.3	7.3
3.3 ≤ E < 3.5	5.8	6.0	7.0	7.4	6.5	7.1	7.1
3.5 ≤ E < 3.7	5.8	5.9	6.9	7.3	6.4	7.0	7.0
3.7 ≤ E < 3.9	5.7	5.8	6.9	7.2	6.3	7.0	7.0
3.9 ≤ E < 4.1	5.6	5.8	6.8	7.1	6.3	6.9	6.9
4.1 ≤ E < 4.3	5.5	5.7	6.7	7.0	6.2	6.8	6.8
4.3 ≤ E < 4.5	5.5	5.7	6.7	6.9	6.1	6.8	6.8
4.5 ≤ E < 4.7	5.4	5.6	6.6	6.9	6.0	6.7	6.7
4.7 ≤ E < 4.9	5.4	5.6	6.5	6.8	6.0	6.6	6.6
E ≥ 4.9	5.3	5.5	6.5	6.8	6.0	6.6	6.6

Table 2-17 Loading Table for PWR Fuel – 922 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	44 < Assembly Average Burnup ≤ 45 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	6.3	6.6	7.8	8.3	7.1	7.9	7.9
2.9 ≤ E < 3.1	6.2	6.4	7.7	8.1	7.0	7.8	7.8
3.1 ≤ E < 3.3	6.1	6.3	7.6	7.9	6.9	7.7	7.7
3.3 ≤ E < 3.5	6.0	6.2	7.4	7.8	6.8	7.5	7.5
3.5 ≤ E < 3.7	5.9	6.1	7.3	7.7	6.7	7.4	7.4
3.7 ≤ E < 3.9	5.9	6.0	7.2	7.6	6.6	7.3	7.3
3.9 ≤ E < 4.1	5.8	6.0	7.1	7.5	6.6	7.2	7.2
4.1 ≤ E < 4.3	5.7	5.9	7.0	7.4	6.5	7.1	7.1
4.3 ≤ E < 4.5	5.7	5.9	6.9	7.3	6.4	7.0	7.0
4.5 ≤ E < 4.7	5.6	5.8	6.9	7.2	6.3	7.0	7.0
4.7 ≤ E < 4.9	5.6	5.8	6.8	7.1	6.3	6.9	6.9
E ≥ 4.9	5.5	5.7	6.7	7.0	6.2	6.9	6.9

Note: **For fuel assembly average burnup greater than 45 GWd/MTU, cool time tables have been revised to account for a 5% margin in heat load.**

Table 2-18 Loading Table for PWR Fuel – 876 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	45 < Assembly Average Burnup ≤ 46 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.1	7.4	9.2	9.8	8.2	9.3	9.3
2.9 ≤ E < 3.1	7.0	7.3	9.0	9.6	8.0	9.1	9.0
3.1 ≤ E < 3.3	6.9	7.1	8.8	9.4	7.9	8.9	8.9
3.3 ≤ E < 3.5	6.8	7.0	8.6	9.1	7.8	8.7	8.7
3.5 ≤ E < 3.7	6.7	6.9	8.5	9.0	7.6	8.6	8.6
3.7 ≤ E < 3.9	6.6	6.8	8.3	8.9	7.5	8.5	8.4
3.9 ≤ E < 4.1	6.5	6.7	8.2	8.7	7.4	8.3	8.3
4.1 ≤ E < 4.3	6.4	6.6	8.1	8.6	7.3	8.2	8.2
4.3 ≤ E < 4.5	6.3	6.6	8.0	8.5	7.2	8.1	8.1
4.5 ≤ E < 4.7	6.2	6.5	7.9	8.4	7.2	8.0	8.0
4.7 ≤ E < 4.9	6.2	6.4	7.8	8.3	7.1	8.0	7.9
E ≥ 4.9	6.1	6.4	7.7	8.2	7.0	7.9	7.9

Table 2-18 Loading Table for PWR Fuel – 876 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	46 < Assembly Average Burnup ≤ 47 GWd/MTU Minimum Cooling Time (years)						
	CE 14x14	WE 14x14	WE 15x15	B&W 15x15	CE 16x16	WE 17x17	B&W 17x17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.5	7.8	9.8	10.5	8.7	9.9	9.9
2.9 ≤ E < 3.1	7.4	7.7	9.6	10.3	8.5	9.7	9.7
3.1 ≤ E < 3.3	7.2	7.5	9.3	10.0	8.3	9.5	9.5
3.3 ≤ E < 3.5	7.1	7.4	9.1	9.8	8.1	9.3	9.3
3.5 ≤ E < 3.7	7.0	7.2	9.0	9.6	8.0	9.1	9.1
3.7 ≤ E < 3.9	6.9	7.1	8.8	9.4	7.9	9.0	8.9
3.9 ≤ E < 4.1	6.8	7.0	8.7	9.3	7.8	8.8	8.8
4.1 ≤ E < 4.3	6.7	6.9	8.6	9.1	7.7	8.7	8.7
4.3 ≤ E < 4.5	6.6	6.9	8.4	9.0	7.6	8.6	8.6
4.5 ≤ E < 4.7	6.5	6.8	8.3	8.9	7.5	8.5	8.5
4.7 ≤ E < 4.9	6.5	6.7	8.2	8.8	7.5	8.4	8.4
E ≥ 4.9	6.4	6.7	8.1	8.7	7.4	8.3	8.3
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	47 < Assembly Average Burnup ≤ 48 GWd/MTU Minimum Cooling Time (years)						
	CE 14x14	WE 14x14	WE 15x15	B&W 15x15	CE 16x16	WE 17x17	B&W 17x17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.9	8.3	10.5	11.3	9.2	10.7	10.6
2.9 ≤ E < 3.1	7.7	8.1	10.2	11.1	9.0	10.4	10.3
3.1 ≤ E < 3.3	7.6	7.9	10.0	10.8	8.8	10.1	10.1
3.3 ≤ E < 3.5	7.4	7.8	9.7	10.5	8.7	9.9	9.9
3.5 ≤ E < 3.7	7.3	7.6	9.6	10.3	8.5	9.7	9.7
3.7 ≤ E < 3.9	7.2	7.5	9.4	10.1	8.4	9.5	9.5
3.9 ≤ E < 4.1	7.0	7.4	9.2	9.9	8.2	9.4	9.4
4.1 ≤ E < 4.3	7.0	7.3	9.0	9.7	8.1	9.2	9.2
4.3 ≤ E < 4.5	6.9	7.2	8.9	9.6	8.0	9.1	9.1
4.5 ≤ E < 4.7	6.8	7.1	8.8	9.5	7.9	9.0	9.0
4.7 ≤ E < 4.9	6.7	7.0	8.7	9.4	7.8	8.9	8.9
E ≥ 4.9	6.7	6.9	8.6	9.2	7.7	8.8	8.8

Table 2-18 Loading Table for PWR Fuel – 876 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	48 < Assembly Average Burnup ≤ 49 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	8.4	8.8	11.3	12.1	9.9	11.4	11.4
2.9 ≤ E < 3.1	8.2	8.6	11.0	11.8	9.6	11.1	11.1
3.1 ≤ E < 3.3	8.0	8.4	10.7	11.6	9.4	10.9	10.8
3.3 ≤ E < 3.5	7.8	8.2	10.4	11.3	9.2	10.6	10.6
3.5 ≤ E < 3.7	7.7	8.0	10.2	11.1	9.0	10.4	10.4
3.7 ≤ E < 3.9	7.6	7.9	10.0	10.8	8.8	10.2	10.1
3.9 ≤ E < 4.1	7.4	7.8	9.8	10.6	8.7	10.0	9.9
4.1 ≤ E < 4.3	7.3	7.7	9.7	10.4	8.6	9.8	9.8
4.3 ≤ E < 4.5	7.2	7.6	9.5	10.3	8.4	9.7	9.7
4.5 ≤ E < 4.7	7.1	7.5	9.4	10.1	8.3	9.6	9.5
4.7 ≤ E < 4.9	7.0	7.4	9.2	10.0	8.2	9.4	9.4
E ≥ 4.9	6.9	7.3	9.1	9.8	8.1	9.3	9.3

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	49 < Assembly Average Burnup ≤ 50 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	8.7	8.9	11.8	12.7	10.2	11.9	11.9
3.1 ≤ E < 3.3	8.4	8.7	11.5	12.4	10.0	11.7	11.6
3.3 ≤ E < 3.5	8.2	8.5	11.2	12.1	9.8	11.4	11.4
3.5 ≤ E < 3.7	8.1	8.4	11.0	11.8	9.6	11.2	11.1
3.7 ≤ E < 3.9	7.9	8.2	10.7	11.6	9.4	10.9	10.9
3.9 ≤ E < 4.1	7.8	8.0	10.5	11.4	9.2	10.7	10.7
4.1 ≤ E < 4.3	7.7	7.9	10.3	11.2	9.0	10.5	10.5
4.3 ≤ E < 4.5	7.6	7.8	10.1	11.0	8.9	10.4	10.3
4.5 ≤ E < 4.7	7.5	7.7	9.9	10.9	8.8	10.2	10.1
4.7 ≤ E < 4.9	7.4	7.6	9.8	10.7	8.7	10.0	10.0
E ≥ 4.9	7.3	7.6	9.7	10.5	8.6	9.9	9.9

Table 2-18 Loading Table for PWR Fuel – 876 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	50 < Assembly Average Burnup ≤ 51 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	8.9	9.5	12.6	13.7	11.0	12.8	12.8
3.1 ≤ E < 3.3	8.7	9.3	12.2	13.3	10.7	12.5	12.4
3.3 ≤ E < 3.5	8.5	9.0	11.9	13.0	10.5	12.1	12.1
3.5 ≤ E < 3.7	8.4	8.8	11.7	12.7	10.2	11.9	11.9
3.7 ≤ E < 3.9	8.2	8.7	11.5	12.4	10.0	11.7	11.6
3.9 ≤ E < 4.1	8.0	8.5	11.2	12.2	9.8	11.5	11.4
4.1 ≤ E < 4.3	7.9	8.4	11.0	11.9	9.6	11.3	11.2
4.3 ≤ E < 4.5	7.8	8.2	10.9	11.8	9.5	11.1	11.0
4.5 ≤ E < 4.7	7.7	8.1	10.7	11.6	9.3	10.9	10.9
4.7 ≤ E < 4.9	7.6	8.0	10.5	11.4	9.2	10.8	10.7
E ≥ 4.9	7.5	7.9	10.4	11.3	9.1	10.6	10.6
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**51 < Assembly Average Burnup ≤ 52 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	9.5	10.1	13.5	14.3	11.7	13.7	13.7
3.1 ≤ E < 3.3	9.2	9.8	13.2	13.9	11.5	13.4	13.4
3.3 ≤ E < 3.5	9.0	9.6	12.8	13.6	11.2	13.1	13.0
3.5 ≤ E < 3.7	8.8	9.4	12.5	13.3	10.9	12.8	12.7
3.7 ≤ E < 3.9	8.7	9.2	12.2	13.0	10.7	12.5	12.4
3.9 ≤ E < 4.1	8.5	9.0	12.0	12.8	10.4	12.2	12.2
4.1 ≤ E < 4.3	8.3	8.9	11.8	12.5	10.2	12.0	11.9
4.3 ≤ E < 4.5	8.2	8.7	11.6	12.3	10.0	11.8	11.8
4.5 ≤ E < 4.7	8.1	8.6	11.4	12.1	9.9	11.6	11.6
4.7 ≤ E < 4.9	8.0	8.5	11.2	11.9	9.8	11.5	11.5
E ≥ 4.9	7.9	8.3	11.1	11.8	9.6	11.3	11.3

Table 2-18 Loading Table for PWR Fuel – 876 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	52 < Assembly Average Burnup ≤ 53 GWd/MTU Minimum Cooling Time (years)						
	CE 14x14	WE 14x14	WE 15x15	B&W 15x15	CE 16x16	WE 17x17	B&W 17x17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	10.1	10.9	14.0	15.3	12.6	14.7	14.7
3.1 ≤ E < 3.3	9.8	10.5	13.7	14.9	12.2	14.3	14.3
3.3 ≤ E < 3.5	9.6	10.2	13.4	14.6	11.9	14.0	13.9
3.5 ≤ E < 3.7	9.3	10.0	13.1	14.2	11.6	13.7	13.6
3.7 ≤ E < 3.9	9.1	9.9	12.8	13.9	11.4	13.4	13.3
3.9 ≤ E < 4.1	8.9	9.6	12.5	13.7	11.2	13.1	13.1
4.1 ≤ E < 4.3	8.8	9.4	12.2	13.4	11.0	12.9	12.8
4.3 ≤ E < 4.5	8.7	9.2	12.0	13.2	10.8	12.6	12.6
4.5 ≤ E < 4.7	8.5	9.0	11.8	13.0	10.6	12.4	12.4
4.7 ≤ E < 4.9	8.4	8.9	11.7	12.8	10.4	12.2	12.2
E ≥ 4.9	8.3	8.8	11.5	12.6	10.2	12.0	12.0

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	53 < Assembly Average Burnup ≤ 54 GWd/MTU Minimum Cooling Time (years)						
	CE 14x14	WE 14x14	WE 15x15	B&W 15x15	CE 16x16	WE 17x17	B&W 17x17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	10.8	11.6	15.1	16.4	13.5	15.7	15.6
3.1 ≤ E < 3.3	10.5	11.3	14.6	15.9	13.1	15.3	15.3
3.3 ≤ E < 3.5	10.1	11.0	14.2	15.6	12.7	14.9	14.9
3.5 ≤ E < 3.7	9.9	10.7	13.9	15.2	12.4	14.6	14.6
3.7 ≤ E < 3.9	9.7	10.4	13.6	14.9	12.1	14.3	14.2
3.9 ≤ E < 4.1	9.5	10.2	13.4	14.6	11.9	14.0	14.0
4.1 ≤ E < 4.3	9.3	9.9	13.1	14.3	11.7	13.7	13.7
4.3 ≤ E < 4.5	9.1	9.8	12.9	14.0	11.5	13.5	13.5
4.5 ≤ E < 4.7	9.0	9.6	12.6	13.8	11.3	13.3	13.3
4.7 ≤ E < 4.9	8.8	9.5	12.4	13.6	11.1	13.1	13.1
E ≥ 4.9	8.7	9.6	12.2	13.4	10.9	12.9	12.9

Table 2-18 Loading Table for PWR Fuel – 876 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % 235U (E)	54 < Assembly Average Burnup ≤ 55 GWd/MTU Minimum Cooling Time (years)						
	CE 14x14	WE 14x14	WE 15x15	B&W 15x15	CE 16x16	WE 17x17	B&W 17x17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	11.2	12.0	15.6	17.0	13.9	16.3	16.3
3.3 ≤ E < 3.5	10.9	11.7	15.2	16.6	13.6	15.9	15.9
3.5 ≤ E < 3.7	10.6	11.4	14.9	16.2	13.3	15.6	15.6
3.7 ≤ E < 3.9	10.3	11.2	14.5	15.9	13.0	15.3	15.3
3.9 ≤ E < 4.1	10.0	10.9	14.2	15.6	12.7	15.0	14.9
4.1 ≤ E < 4.3	9.9	10.7	13.9	15.3	12.4	14.7	14.6
4.3 ≤ E < 4.5	9.7	10.5	13.7	15.1	12.2	14.4	14.4
4.5 ≤ E < 4.7	9.5	10.2	13.5	14.8	12.0	14.1	14.1
4.7 ≤ E < 4.9	9.3	10.0	13.3	14.6	11.8	13.9	13.9
E ≥ 4.9	9.2	9.9	13.1	14.3	11.6	13.8	13.7

Minimum Initial Assembly Avg. Enrichment wt % 235U (E)	55 < Assembly Average Burnup ≤ 56 GWd/MTU Minimum Cooling Time (years)						
	CE 14x14	WE 14x14	WE 15x15	B&W 15x15	CE 16x16	WE 17x17	B&W 17x17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	11.9	12.8	16.6	18.1	14.5	17.4	17.3
3.3 ≤ E < 3.5	11.5	12.5	16.2	17.6	14.1	17.0	16.9
3.5 ≤ E < 3.7	11.3	12.1	15.8	17.3	13.7	16.6	16.6
3.7 ≤ E < 3.9	11.0	11.8	15.5	17.0	13.4	16.3	16.2
3.9 ≤ E < 4.1	10.7	11.6	15.2	16.6	13.2	15.9	15.9
4.1 ≤ E < 4.3	10.5	11.3	14.9	16.3	12.9	15.7	15.6
4.3 ≤ E < 4.5	10.2	11.1	14.6	16.0	12.6	15.4	15.3
4.5 ≤ E < 4.7	10.0	10.9	14.3	15.8	12.4	15.2	15.1
4.7 ≤ E < 4.9	9.9	10.7	14.1	15.6	12.2	14.9	14.9
E ≥ 4.9	9.7	10.5	13.9	15.3	12.0	14.7	14.6

Table 2-18 Loading Table for PWR Fuel – 876 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	56 < Assembly Average Burnup ≤ 57 GWd/MTU Minimum Cooling Time (years)						
	CE 14x14	WE 14x14	WE 15x15	B&W 15x15	CE 16x16	WE 17x17	B&W 17x17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	12.6	13.6	17.6	19.1	15.5	18.4	18.4
3.3 ≤ E < 3.5	12.3	13.3	17.2	18.7	15.0	18.0	18.0
3.5 ≤ E < 3.7	11.9	13.0	16.8	18.4	14.6	17.7	17.6
3.7 ≤ E < 3.9	11.7	12.6	16.5	18.0	14.3	17.3	17.3
3.9 ≤ E < 4.1	11.4	12.3	16.1	17.7	14.0	17.0	17.0
4.1 ≤ E < 4.3	11.2	12.0	15.8	17.4	13.7	16.7	16.7
4.3 ≤ E < 4.5	10.9	11.8	15.5	17.1	13.5	16.4	16.4
4.5 ≤ E < 4.7	10.7	11.6	15.3	16.8	13.2	16.1	16.1
4.7 ≤ E < 4.9	10.5	11.4	15.1	16.6	13.0	15.8	15.8
E ≥ 4.9	10.3	11.2	14.8	16.3	12.8	15.7	15.6

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	57 < Assembly Average Burnup ≤ 58 GWd/MTU Minimum Cooling Time (years)						
	CE 14x14	WE 14x14	WE 15x15	B&W 15x15	CE 16x16	WE 17x17	B&W 17x17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	13.5	14.5	18.7	20.1	16.4	19.5	19.4
3.3 ≤ E < 3.5	13.1	14.1	18.3	19.8	15.9	19.1	19.0
3.5 ≤ E < 3.7	12.7	13.8	17.9	19.4	15.6	18.7	18.7
3.7 ≤ E < 3.9	12.4	13.4	17.5	19.0	15.3	18.4	18.3
3.9 ≤ E < 4.1	12.1	13.1	17.2	18.7	14.9	18.0	18.0
4.1 ≤ E < 4.3	11.8	12.9	16.9	18.4	14.6	17.7	17.7
4.3 ≤ E < 4.5	11.6	12.6	16.5	18.1	14.3	17.4	17.4
4.5 ≤ E < 4.7	11.4	12.3	16.3	17.8	14.0	17.2	17.1
4.7 ≤ E < 4.9	11.1	12.1	16.0	17.5	13.8	16.9	16.8
E ≥ 4.9	11.0	11.9	15.8	17.3	13.6	16.7	16.6

Table 2-18 Loading Table for PWR Fuel – 876 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	58 < Assembly Average Burnup ≤ 59 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	14.3	15.4	19.7	21.2	17.4	20.5	20.5
3.3 ≤ E < 3.5	13.9	15.0	19.3	20.8	16.9	20.1	20.1
3.5 ≤ E < 3.7	13.5	14.7	18.9	20.4	16.6	19.8	19.7
3.7 ≤ E < 3.9	13.2	14.3	18.5	20.1	16.1	19.4	19.4
3.9 ≤ E < 4.1	12.9	14.0	18.2	19.7	15.8	19.1	19.0
4.1 ≤ E < 4.3	12.6	13.7	17.8	19.4	15.5	18.8	18.7
4.3 ≤ E < 4.5	12.2	13.4	17.6	19.1	15.2	18.4	18.4
4.5 ≤ E < 4.7	12.0	13.1	17.3	18.9	14.9	18.2	18.1
4.7 ≤ E < 4.9	11.8	12.9	17.0	18.6	14.7	17.9	17.8
E ≥ 4.9	11.6	12.7	16.8	18.4	14.5	17.6	17.6
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**59 < Assembly Average Burnup ≤ 60 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	-	-	-	-	-	-	-
3.3 ≤ E < 3.5	14.7	15.9	20.2	21.9	17.9	20.7	20.6
3.5 ≤ E < 3.7	14.3	15.6	19.9	21.5	17.5	20.3	20.2
3.7 ≤ E < 3.9	13.9	15.2	19.5	21.1	17.1	19.9	19.9
3.9 ≤ E < 4.1	13.6	14.9	19.2	20.8	16.8	19.6	19.5
4.1 ≤ E < 4.3	13.3	14.5	18.8	20.5	16.4	19.3	19.2
4.3 ≤ E < 4.5	13.1	14.2	18.5	20.2	16.1	18.9	18.9
4.5 ≤ E < 4.7	12.8	13.9	18.2	19.9	15.8	18.7	18.6
4.7 ≤ E < 4.9	12.5	13.7	18.0	19.6	15.6	18.4	18.3
E ≥ 4.9	12.3	13.5	17.7	19.4	15.4	18.2	18.1

Table 2-19 Loading Table for PWR Fuel – 800 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	30 < Assembly Average Burnup ≤ 32.5 GWd/MTU Minimum Cooling Time (years)						
	14×14 176	14×14 179	15×15 204	15×15 208	16×16 236	17×17 264 WE	17×17 264 B&W
2.1 ≤ E < 2.3	4.8	4.9	5.6	5.7	5.2	5.6	5.6
2.3 ≤ E < 2.5	4.7	4.8	5.5	5.7	5.2	5.6	5.6
2.5 ≤ E < 2.7	4.7	4.8	5.4	5.6	5.1	5.5	5.5
2.7 ≤ E < 2.9	4.6	4.7	5.4	5.5	5.0	5.5	5.5
2.9 ≤ E < 3.1	4.6	4.7	5.3	5.5	5.0	5.4	5.4
3.1 ≤ E < 3.3	4.5	4.6	5.3	5.4	5.0	5.3	5.3
3.3 ≤ E < 3.5	4.5	4.6	5.2	5.4	4.9	5.3	5.3
3.5 ≤ E < 3.7	4.5	4.5	5.1	5.3	4.9	5.2	5.2
3.7 ≤ E < 3.9	4.4	4.5	5.1	5.3	4.8	5.2	5.2
3.9 ≤ E < 4.1	4.4	4.5	5.0	5.2	4.8	5.2	5.1
4.1 ≤ E < 4.3	4.4	4.4	5.0	5.2	4.8	5.1	5.1
4.3 ≤ E < 4.5	4.3	4.4	5.0	5.1	4.8	5.1	5.1
4.5 ≤ E < 4.7	4.3	4.4	5.0	5.1	4.7	5.0	5.0
4.7 ≤ E < 4.9	4.3	4.4	4.9	5.1	4.7	5.0	5.0
E ≥ 4.9	4.3	4.3	4.9	5.0	4.7	5.0	5.0

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	32.5 < Assembly Average Burnup ≤ 35 GWd/MTU Minimum Cooling Time (years)						
	14×14 176	14×14 179	15×15 204	15×15 208	16×16 236	17×17 264 WE	17×17 264 B&W
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	5.2	5.3	6.0	6.3	5.7	6.1	6.1
2.5 ≤ E < 2.7	5.1	5.2	6.0	6.2	5.7	6.0	6.0
2.7 ≤ E < 2.9	5.0	5.2	5.9	6.1	5.6	6.0	6.0
2.9 ≤ E < 3.1	5.0	5.1	5.9	6.0	5.5	5.9	5.9
3.1 ≤ E < 3.3	4.9	5.0	5.8	6.0	5.5	5.9	5.9
3.3 ≤ E < 3.5	4.9	5.0	5.8	5.9	5.4	5.8	5.8
3.5 ≤ E < 3.7	4.9	4.9	5.7	5.9	5.4	5.8	5.8
3.7 ≤ E < 3.9	4.8	4.9	5.7	5.8	5.3	5.8	5.8
3.9 ≤ E < 4.1	4.8	4.9	5.6	5.8	5.3	5.7	5.7
4.1 ≤ E < 4.3	4.7	4.8	5.6	5.8	5.2	5.7	5.7
4.3 ≤ E < 4.5	4.7	4.8	5.5	5.7	5.2	5.6	5.6
4.5 ≤ E < 4.7	4.7	4.8	5.5	5.7	5.2	5.6	5.6
4.7 ≤ E < 4.9	4.6	4.7	5.5	5.7	5.1	5.6	5.6
E ≥ 4.9	4.6	4.7	5.4	5.6	5.1	5.5	5.5

Table 2-19 Loading Table for PWR Fuel – 800 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	35 < Assembly Average Burnup ≤ 37.5 GWd/MTU Minimum Cooling Time (years)						
	14×14 176	14×14 179	15×15 204	15×15 208	16×16 236	17×17 264 WE	17×17 264 B&W
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	5.8	5.9	6.9	7.1	6.4	6.9	6.9
2.5 ≤ E < 2.7	5.7	5.8	6.8	7.0	6.3	6.8	6.8
2.7 ≤ E < 2.9	5.6	5.7	6.7	6.9	6.2	6.7	6.7
2.9 ≤ E < 3.1	5.5	5.7	6.6	6.8	6.1	6.7	6.7
3.1 ≤ E < 3.3	5.5	5.6	6.5	6.8	6.0	6.6	6.6
3.3 ≤ E < 3.5	5.4	5.5	6.4	6.7	6.0	6.5	6.5
3.5 ≤ E < 3.7	5.3	5.5	6.3	6.6	5.9	6.5	6.4
3.7 ≤ E < 3.9	5.3	5.4	6.3	6.5	5.9	6.4	6.4
3.9 ≤ E < 4.1	5.2	5.4	6.2	6.5	5.8	6.3	6.3
4.1 ≤ E < 4.3	5.2	5.3	6.1	6.4	5.8	6.3	6.3
4.3 ≤ E < 4.5	5.1	5.3	6.1	6.4	5.7	6.2	6.2
4.5 ≤ E < 4.7	5.1	5.2	6.0	6.3	5.7	6.2	6.2
4.7 ≤ E < 4.9	5.0	5.2	6.0	6.3	5.7	6.1	6.1
E ≥ 4.9	5.0	5.1	6.0	6.2	5.6	6.1	6.1

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	37.5 < Assembly Average Burnup ≤ 40 GWd/MTU Minimum Cooling Time (years)						
	14×14 176	14×14 179	15×15 204	15×15 208	16×16 236	17×17 264 WE	17×17 264 B&W
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	6.3	6.5	7.7	8.1	7.0	7.8	7.8
2.7 ≤ E < 2.9	6.2	6.4	7.6	8.0	6.9	7.7	7.7
2.9 ≤ E < 3.1	6.1	6.3	7.5	7.8	6.9	7.6	7.6
3.1 ≤ E < 3.3	6.0	6.2	7.4	7.7	6.8	7.4	7.4
3.3 ≤ E < 3.5	5.9	6.1	7.2	7.6	6.7	7.3	7.3
3.5 ≤ E < 3.7	5.9	6.0	7.1	7.5	6.6	7.3	7.2
3.7 ≤ E < 3.9	5.8	6.0	7.1	7.4	6.5	7.2	7.1
3.9 ≤ E < 4.1	5.8	5.9	7.0	7.4	6.5	7.1	7.1
4.1 ≤ E < 4.3	5.7	5.9	6.9	7.3	6.4	7.0	7.0
4.3 ≤ E < 4.5	5.7	5.8	6.9	7.2	6.4	7.0	7.0
4.5 ≤ E < 4.7	5.6	5.8	6.8	7.1	6.3	6.9	6.9
4.7 ≤ E < 4.9	5.6	5.7	6.8	7.1	6.3	6.9	6.9
E ≥ 4.9	5.5	5.7	6.7	7.0	6.2	6.8	6.8

Table 2-19 Loading Table for PWR Fuel – 800 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	40 < Assembly Average Burnup ≤ 41 GWd/MTU Minimum Cooling Time (years)						
	14×14 176	14×14 179	15×15 204	15×15 208	16×16 236	17×17 264 WE	17×17 264 B&W
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	6.6	6.8	8.2	8.7	7.4	8.3	8.3
2.7 ≤ E < 2.9	6.5	6.7	8.0	8.5	7.3	8.1	8.1
2.9 ≤ E < 3.1	6.4	6.6	7.9	8.3	7.2	8.0	8.0
3.1 ≤ E < 3.3	6.3	6.5	7.8	8.2	7.1	7.9	7.9
3.3 ≤ E < 3.5	6.2	6.4	7.7	8.0	7.0	7.8	7.8
3.5 ≤ E < 3.7	6.1	6.3	7.6	8.0	6.9	7.7	7.7
3.7 ≤ E < 3.9	6.0	6.2	7.5	7.9	6.8	7.6	7.6
3.9 ≤ E < 4.1	6.0	6.1	7.4	7.8	6.8	7.5	7.5
4.1 ≤ E < 4.3	5.9	6.1	7.3	7.7	6.7	7.4	7.4
4.3 ≤ E < 4.5	5.9	6.0	7.2	7.6	6.7	7.4	7.3
4.5 ≤ E < 4.7	5.8	6.0	7.1	7.6	6.6	7.3	7.3
4.7 ≤ E < 4.9	5.8	5.9	7.1	7.5	6.6	7.2	7.2
E ≥ 4.9	5.7	5.9	7.0	7.4	6.5	7.2	7.2
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	41 < Assembly Average Burnup ≤ 42 GWd/MTU Minimum Cooling Time (years)						
	14×14 176	14×14 179	15×15 204	15×15 208	16×16 236	17×17 264 WE	17×17 264 B&W
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	6.9	7.1	8.7	9.3	7.8	8.8	8.8
2.7 ≤ E < 2.9	6.8	7.0	8.6	9.0	7.7	8.6	8.6
2.9 ≤ E < 3.1	6.7	6.9	8.4	8.9	7.6	8.5	8.5
3.1 ≤ E < 3.3	6.6	6.8	8.2	8.7	7.5	8.3	8.3
3.3 ≤ E < 3.5	6.5	6.7	8.1	8.6	7.3	8.2	8.2
3.5 ≤ E < 3.7	6.4	6.6	8.0	8.5	7.2	8.1	8.1
3.7 ≤ E < 3.9	6.3	6.5	7.9	8.3	7.1	8.0	8.0
3.9 ≤ E < 4.1	6.2	6.5	7.8	8.2	7.1	7.9	7.9
4.1 ≤ E < 4.3	6.1	6.4	7.7	8.1	7.0	7.8	7.8
4.3 ≤ E < 4.5	6.1	6.3	7.6	8.0	6.9	7.8	7.7
4.5 ≤ E < 4.7	6.0	6.3	7.6	8.0	6.9	7.7	7.7
4.7 ≤ E < 4.9	6.0	6.2	7.5	7.9	6.8	7.6	7.6
E ≥ 4.9	5.9	6.1	7.4	7.8	6.8	7.6	7.6

Table 2-19 Loading Table for PWR Fuel – 800 W/Assembly (continued)

Mimimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	42 < Assembly Average Burnup ≤ 43 GWd/MTU Minimum Cooling Time (years)						
	14×14 176	14×14 179	15×15 204	15×15 208	16×16 236	17×17 264 WE	17×17 264 B&W
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	7.3	7.5	9.3	9.9	8.3	9.4	9.4
2.7 ≤ E < 2.9	7.1	7.4	9.1	9.7	8.1	9.2	9.2
2.9 ≤ E < 3.1	7.0	7.2	8.9	9.5	8.0	9.0	9.0
3.1 ≤ E < 3.3	6.9	7.1	8.8	9.3	7.9	8.9	8.8
3.3 ≤ E < 3.5	6.8	7.0	8.6	9.2	7.8	8.7	8.7
3.5 ≤ E < 3.7	6.7	6.9	8.5	9.0	7.7	8.6	8.6
3.7 ≤ E < 3.9	6.6	6.8	8.4	8.9	7.6	8.5	8.5
3.9 ≤ E < 4.1	6.5	6.8	8.2	8.8	7.5	8.4	8.4
4.1 ≤ E < 4.3	6.5	6.7	8.1	8.7	7.4	8.3	8.3
4.3 ≤ E < 4.5	6.4	6.6	8.0	8.6	7.3	8.2	8.2
4.5 ≤ E < 4.7	6.3	6.6	8.0	8.5	7.2	8.1	8.1
4.7 ≤ E < 4.9	6.2	6.5	7.9	8.4	7.2	8.0	8.0
E ≥ 4.9	6.2	6.4	7.8	8.3	7.1	8.0	8.0

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	43 < Assembly Average Burnup ≤ 44 GWd/MTU Minimum Cooling Time (years)						
	14×14 176	14×14 179	15×15 204	15×15 208	16×16 236	17×17 264 WE	17×17 264 B&W
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	7.7	8.0	10.0	10.8	8.8	10.0	10.1
2.7 ≤ E < 2.9	7.5	7.8	9.7	10.5	8.7	9.9	9.8
2.9 ≤ E < 3.1	7.4	7.7	9.5	10.2	8.5	9.7	9.6
3.1 ≤ E < 3.3	7.2	7.5	9.3	10.0	8.3	9.5	9.4
3.3 ≤ E < 3.5	7.1	7.4	9.2	9.8	8.2	9.3	9.3
3.5 ≤ E < 3.7	7.1	7.3	9.0	9.7	8.0	9.1	9.1
3.7 ≤ E < 3.9	6.9	7.2	8.9	9.5	8.0	9.0	9.0
3.9 ≤ E < 4.1	6.8	7.1	8.8	9.4	7.9	8.9	8.9
4.1 ≤ E < 4.3	6.7	7.0	8.7	9.2	7.8	8.8	8.8
4.3 ≤ E < 4.5	6.7	6.9	8.5	9.1	7.7	8.7	8.7
4.5 ≤ E < 4.7	6.6	6.9	8.5	9.0	7.6	8.6	8.6
4.7 ≤ E < 4.9	6.6	6.8	8.4	8.9	7.6	8.5	8.5
E ≥ 4.9	6.5	6.8	8.3	8.9	7.5	8.5	8.4

Table 2-19 Loading Table for PWR Fuel – 800 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	44 < Assembly Average Burnup ≤ 45 GWd/MTU Minimum Cooling Time (years)						
	14×14 176	14×14 179	15×15 204	15×15 208	16×16 236	17×17 264 WE	17×17 264 B&W
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.9	8.2	10.5	11.4	9.2	10.6	10.6
2.9 ≤ E < 3.1	7.8	8.1	10.2	11.1	9.0	10.4	10.4
3.1 ≤ E < 3.3	7.6	7.9	10.0	10.8	8.8	10.1	10.1
3.3 ≤ E < 3.5	7.5	7.8	9.8	10.6	8.7	9.9	9.9
3.5 ≤ E < 3.7	7.3	7.7	9.6	10.4	8.6	9.8	9.8
3.7 ≤ E < 3.9	7.2	7.6	9.5	10.2	8.4	9.6	9.6
3.9 ≤ E < 4.1	7.1	7.5	9.3	10.0	8.3	9.5	9.5
4.1 ≤ E < 4.3	7.0	7.4	9.2	9.9	8.2	9.4	9.3
4.3 ≤ E < 4.5	7.0	7.3	9.1	9.8	8.1	9.2	9.2
4.5 ≤ E < 4.7	6.9	7.2	9.0	9.7	8.0	9.1	9.1
4.7 ≤ E < 4.9	6.8	7.1	8.9	9.6	7.9	9.0	9.0
E ≥ 4.9	6.8	7.0	8.8	9.5	7.9	9.0	8.9

Note: **For fuel assembly average burnup greater than 45 GWd/MTU, cool time tables have been revised to account for a 5% margin in heat load.**

Table 2-20 Loading Table for PWR Fuel – 760 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	45 < Assembly Average Burnup ≤ 46 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	9.2	9.8	12.8	13.9	11.2	13.0	13.0
2.9 ≤ E < 3.1	9.0	9.6	12.5	13.6	10.9	12.7	12.7
3.1 ≤ E < 3.3	8.9	9.4	12.1	13.3	10.6	12.4	12.4
3.3 ≤ E < 3.5	8.7	9.1	11.9	13.0	10.4	12.1	12.1
3.5 ≤ E < 3.7	8.6	9.0	11.8	12.8	10.2	11.9	11.9
3.7 ≤ E < 3.9	8.4	8.8	11.6	12.5	10.0	11.8	11.7
3.9 ≤ E < 4.1	8.3	8.7	11.4	12.3	9.9	11.6	11.5
4.1 ≤ E < 4.3	8.1	8.6	11.2	12.2	9.7	11.4	11.4
4.3 ≤ E < 4.5	8.0	8.5	11.1	12.0	9.6	11.3	11.3
4.5 ≤ E < 4.7	7.9	8.4	10.9	11.9	9.5	11.2	11.1
4.7 ≤ E < 4.9	7.9	8.3	10.8	11.7	9.4	11.0	11.0
E ≥ 4.9	7.8	8.2	10.7	11.6	9.3	10.9	10.9

Table 2-20 Loading Table for PWR Fuel – 760 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	46 < Assembly Average Burnup ≤ 47 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	9.9	10.6	13.8	15.0	12.0	13.9	13.9
2.9 ≤ E < 3.1	9.7	10.3	13.5	14.7	11.7	13.7	13.7
3.1 ≤ E < 3.3	9.4	10.0	13.2	14.4	11.4	13.4	13.4
3.3 ≤ E < 3.5	9.2	9.8	12.9	14.0	11.2	13.1	13.1
3.5 ≤ E < 3.7	9.0	9.6	12.7	13.8	11.0	12.9	12.8
3.7 ≤ E < 3.9	8.9	9.4	12.4	13.6	10.8	12.6	12.6
3.9 ≤ E < 4.1	8.8	9.3	12.2	13.4	10.6	12.5	12.4
4.1 ≤ E < 4.3	8.6	9.1	12.0	13.2	10.4	12.2	12.2
4.3 ≤ E < 4.5	8.5	9.0	11.8	13.0	10.3	12.1	12.0
4.5 ≤ E < 4.7	8.4	8.9	11.7	12.8	10.1	11.9	11.9
4.7 ≤ E < 4.9	8.3	8.8	11.6	12.7	10.0	11.8	11.8
E ≥ 4.9	8.2	8.7	11.5	12.5	9.9	11.7	11.7

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	47 < Assembly Average Burnup ≤ 48 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	10.6	11.4	14.9	16.1	12.9	15.1	15.1
2.9 ≤ E < 3.1	10.4	11.1	14.5	15.8	12.5	14.7	14.7
3.1 ≤ E < 3.3	10.0	10.8	14.1	15.5	12.2	14.4	14.4
3.3 ≤ E < 3.5	9.9	10.5	13.9	15.2	12.0	14.1	14.0
3.5 ≤ E < 3.7	9.6	10.3	13.6	14.9	11.8	13.8	13.8
3.7 ≤ E < 3.9	9.5	10.1	13.4	14.6	11.6	13.6	13.6
3.9 ≤ E < 4.1	9.3	9.9	13.2	14.4	11.4	13.4	13.4
4.1 ≤ E < 4.3	9.1	9.8	13.0	14.1	11.2	13.2	13.2
4.3 ≤ E < 4.5	9.0	9.6	12.8	14.0	11.1	13.0	13.0
4.5 ≤ E < 4.7	8.9	9.5	12.6	13.8	10.9	12.9	12.8
4.7 ≤ E < 4.9	8.8	9.3	12.4	13.6	10.8	12.7	12.7
E ≥ 4.9	8.7	9.2	12.3	13.5	10.7	12.5	12.5

Table 2-20 Loading Table for PWR Fuel – 760 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	48 < Assembly Average Burnup ≤ 49 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	11.4	12.2	16.0	17.3	13.9	16.2	16.2
2.9 ≤ E < 3.1	11.1	11.8	15.6	17.0	13.5	15.8	15.8
3.1 ≤ E < 3.3	10.8	11.6	15.3	16.6	13.2	15.5	15.5
3.3 ≤ E < 3.5	10.6	11.3	14.9	16.3	12.9	15.2	15.2
3.5 ≤ E < 3.7	10.3	11.1	14.7	16.0	12.7	14.9	14.9
3.7 ≤ E < 3.9	10.1	10.9	14.4	15.7	12.4	14.6	14.6
3.9 ≤ E < 4.1	9.9	10.7	14.1	15.5	12.1	14.4	14.4
4.1 ≤ E < 4.3	9.7	10.4	13.9	15.2	12.0	14.1	14.1
4.3 ≤ E < 4.5	9.6	10.2	13.7	15.0	11.8	13.9	13.9
4.5 ≤ E < 4.7	9.5	10.1	13.5	14.9	11.7	13.8	13.8
4.7 ≤ E < 4.9	9.3	9.9	13.4	14.6	11.5	13.6	13.6
E ≥ 4.9	9.2	9.8	13.2	14.5	11.4	13.5	13.5

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	49 < Assembly Average Burnup ≤ 50 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	11.9	12.4	16.8	18.2	14.5	17.0	17.0
3.1 ≤ E < 3.3	11.6	12.1	16.4	17.8	14.1	16.6	16.6
3.3 ≤ E < 3.5	11.3	11.8	16.0	17.5	13.8	16.3	16.2
3.5 ≤ E < 3.7	11.1	11.6	15.7	17.2	13.6	16.0	16.0
3.7 ≤ E < 3.9	10.8	11.4	15.5	16.9	13.3	15.7	15.7
3.9 ≤ E < 4.1	10.6	11.2	15.2	16.6	13.1	15.5	15.5
4.1 ≤ E < 4.3	10.4	11.0	14.9	16.3	12.9	15.3	15.2
4.3 ≤ E < 4.5	10.2	10.8	14.7	16.1	12.7	15.0	15.0
4.5 ≤ E < 4.7	10.1	10.6	14.5	15.9	12.5	14.9	14.8
4.7 ≤ E < 4.9	9.9	10.5	14.3	15.7	12.3	14.6	14.6
E ≥ 4.9	9.8	10.3	14.1	15.5	12.2	14.5	14.5

Table 2-20 Loading Table for PWR Fuel – 760 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	50 < Assembly Average Burnup ≤ 51 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	12.4	13.4	17.8	19.3	15.6	18.1	18.1
3.1 ≤ E < 3.3	12.1	13.1	17.5	19.0	15.2	17.8	17.8
3.3 ≤ E < 3.5	11.8	12.7	17.2	18.7	14.9	17.4	17.4
3.5 ≤ E < 3.7	11.5	12.4	16.8	18.3	14.5	17.2	17.1
3.7 ≤ E < 3.9	11.3	12.1	16.5	18.0	14.3	16.9	16.8
3.9 ≤ E < 4.1	11.1	11.9	16.2	17.7	14.0	16.6	16.5
4.1 ≤ E < 4.3	10.9	11.7	16.0	17.5	13.8	16.3	16.3
4.3 ≤ E < 4.5	10.7	11.5	15.8	17.3	13.6	16.1	16.0
4.5 ≤ E < 4.7	10.5	11.4	15.5	17.1	13.4	15.8	15.9
4.7 ≤ E < 4.9	10.4	11.2	15.3	16.8	13.2	15.7	15.7
E ≥ 4.9	10.2	11.1	15.2	16.7	13.1	15.5	15.5
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**51 < Assembly Average Burnup ≤ 52 GWd/MTU Minimum Cooling Time (years)**						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	13.3	14.3	19.0	20.1	16.7	19.4	19.3
3.1 ≤ E < 3.3	12.9	14.0	18.6	19.7	16.3	19.0	18.9
3.3 ≤ E < 3.5	12.6	13.6	18.2	19.4	15.9	18.6	18.6
3.5 ≤ E < 3.7	12.3	13.3	17.9	19.1	15.6	18.3	18.3
3.7 ≤ E < 3.9	12.0	13.1	17.6	18.8	15.3	18.0	17.9
3.9 ≤ E < 4.1	11.8	12.8	17.4	18.5	15.0	17.7	17.7
4.1 ≤ E < 4.3	11.6	12.5	17.1	18.2	14.8	17.5	17.4
4.3 ≤ E < 4.5	11.4	12.3	16.8	18.0	14.5	17.3	17.2
4.5 ≤ E < 4.7	11.2	12.1	16.6	17.7	14.4	17.0	17.0
4.7 ≤ E < 4.9	11.1	11.9	16.4	17.5	14.1	16.8	16.8
E ≥ 4.9	10.9	11.8	16.2	17.4	13.9	16.6	16.5

Table 2-20 Loading Table for PWR Fuel – 760 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	52 < Assembly Average Burnup ≤ 53 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	14.2	15.3	19.7	21.3	17.8	20.5	20.5
3.1 ≤ E < 3.3	13.8	15.0	19.3	20.9	17.4	20.1	20.1
3.3 ≤ E < 3.5	13.5	14.6	18.9	20.6	17.1	19.8	19.7
3.5 ≤ E < 3.7	13.1	14.3	18.6	20.3	16.7	19.5	19.4
3.7 ≤ E < 3.9	12.9	14.2	18.3	19.9	16.4	19.2	19.1
3.9 ≤ E < 4.1	12.6	13.7	18.0	19.6	16.0	18.9	18.8
4.1 ≤ E < 4.3	12.3	13.5	17.7	19.4	15.8	18.6	18.5
4.3 ≤ E < 4.5	12.1	13.2	17.5	19.1	15.6	18.4	18.3
4.5 ≤ E < 4.7	11.9	13.0	17.3	18.8	15.3	18.2	18.1
4.7 ≤ E < 4.9	11.8	12.8	17.0	18.7	15.2	17.9	17.8
E ≥ 4.9	11.6	12.6	16.9	18.5	14.9	17.7	17.7

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	53 < Assembly Average Burnup ≤ 54 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	15.2	16.4	20.9	22.5	18.9	21.7	21.6
3.1 ≤ E < 3.3	14.8	16.0	20.4	22.1	18.5	21.3	21.3
3.3 ≤ E < 3.5	14.4	15.6	20.0	21.8	18.1	21.0	20.9
3.5 ≤ E < 3.7	14.0	15.2	19.7	21.4	17.7	20.6	20.6
3.7 ≤ E < 3.9	13.7	14.9	19.4	21.1	17.4	20.3	20.3
3.9 ≤ E < 4.1	13.4	14.6	19.1	20.8	17.2	20.1	20.0
4.1 ≤ E < 4.3	13.2	14.4	18.9	20.5	16.9	19.8	19.7
4.3 ≤ E < 4.5	12.9	14.1	18.6	20.3	16.6	19.5	19.5
4.5 ≤ E < 4.7	12.7	13.9	18.3	20.1	16.4	19.3	19.2
4.7 ≤ E < 4.9	12.5	13.6	18.1	19.8	16.1	19.0	19.0
E ≥ 4.9	12.4	13.9	17.9	19.6	15.9	18.8	18.8

Table 2-20 Loading Table for PWR Fuel – 760 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	54 < Assembly Average Burnup ≤ 55 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	15.7	17.1	21.6	23.2	19.6	22.5	22.4
3.3 ≤ E < 3.5	15.4	17.7	21.2	22.9	19.2	22.1	22.1
3.5 ≤ E < 3.7	15.0	16.3	20.9	22.6	18.9	21.8	21.8
3.7 ≤ E < 3.9	14.6	16.0	20.6	22.2	18.5	21.5	21.5
3.9 ≤ E < 4.1	14.4	15.7	20.2	21.9	18.3	21.2	21.2
4.1 ≤ E < 4.3	14.1	15.4	19.9	21.7	18.0	20.9	20.9
4.3 ≤ E < 4.5	13.8	15.1	19.7	21.4	17.7	20.7	20.6
4.5 ≤ E < 4.7	13.6	14.9	19.4	21.2	17.5	20.5	20.4
4.7 ≤ E < 4.9	13.4	14.6	19.2	21.0	17.2	20.2	20.1
E ≥ 4.9	13.2	14.4	19.0	20.7	17.0	19.9	19.9

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	55 < Assembly Average Burnup ≤ 56 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	16.8	18.1	22.7	24.4	20.2	23.6	23.6
3.3 ≤ E < 3.5	16.3	17.7	22.4	24.1	19.8	23.3	23.3
3.5 ≤ E < 3.7	15.9	17.3	21.9	23.7	19.5	23.0	22.9
3.7 ≤ E < 3.9	15.6	17.0	21.7	23.4	19.2	22.6	22.6
3.9 ≤ E < 4.1	15.3	16.7	21.4	23.1	18.8	22.4	22.3
4.1 ≤ E < 4.3	15.0	16.4	21.0	22.9	18.5	22.1	22.0
4.3 ≤ E < 4.5	14.8	16.1	20.8	22.6	18.3	21.8	21.8
4.5 ≤ E < 4.7	14.5	15.8	20.5	22.4	17.9	21.6	21.5
4.7 ≤ E < 4.9	14.3	15.6	20.3	22.2	17.8	21.3	21.3
E ≥ 4.9	14.0	15.4	20.0	21.9	17.6	21.1	21.1

Table 2-20 Loading Table for PWR Fuel – 760 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	56 < Assembly Average Burnup ≤ 57 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	17.7	19.2	23.8	25.6	21.3	24.7	24.7
3.3 ≤ E < 3.5	17.3	18.8	23.4	25.2	20.9	24.4	24.4
3.5 ≤ E < 3.7	16.9	18.4	23.1	24.9	20.5	24.0	24.0
3.7 ≤ E < 3.9	16.6	18.1	22.7	24.6	20.2	23.7	23.7
3.9 ≤ E < 4.1	16.2	17.7	22.4	24.3	19.9	23.5	23.5
4.1 ≤ E < 4.3	15.9	17.4	22.2	24.0	19.6	23.2	23.2
4.3 ≤ E < 4.5	15.7	17.1	21.9	23.8	19.3	23.0	22.9
4.5 ≤ E < 4.7	15.4	16.8	21.6	23.5	19.1	22.7	22.6
4.7 ≤ E < 4.9	15.2	16.6	21.4	23.3	18.8	22.5	22.4
E ≥ 4.9	15.0	16.4	21.2	23.0	18.6	22.2	22.2

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	57 < Assembly Average Burnup ≤ 58 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	18.8	20.2	24.9	26.7	22.3	25.8	25.8
3.3 ≤ E < 3.5	18.3	19.9	24.6	26.3	22.0	25.5	25.5
3.5 ≤ E < 3.7	17.9	19.5	24.2	26.0	21.6	25.2	25.2
3.7 ≤ E < 3.9	17.6	19.1	23.9	25.7	21.3	24.9	24.8
3.9 ≤ E < 4.1	17.3	18.8	23.6	25.4	20.9	24.6	24.6
4.1 ≤ E < 4.3	16.9	18.4	23.3	25.1	20.6	24.4	24.3
4.3 ≤ E < 4.5	16.6	18.1	23.0	24.9	20.4	24.1	24.0
4.5 ≤ E < 4.7	16.3	17.9	22.8	24.6	20.0	23.8	23.8
4.7 ≤ E < 4.9	16.1	17.6	22.5	24.4	19.9	23.6	23.6
E ≥ 4.9	15.8	17.4	22.3	24.2	19.7	23.4	23.3

Table 2-20 Loading Table for PWR Fuel – 760 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	58 < Assembly Average Burnup ≤ 59 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	19.8	21.3	25.9	27.7	23.4	26.9	26.9
3.3 ≤ E < 3.5	19.3	20.9	25.6	27.4	23.0	26.7	26.6
3.5 ≤ E < 3.7	18.9	20.5	25.3	27.1	22.7	26.3	26.2
3.7 ≤ E < 3.9	18.6	20.2	24.9	26.8	22.3	26.0	25.9
3.9 ≤ E < 4.1	18.2	19.8	24.6	26.5	22.0	25.7	25.7
4.1 ≤ E < 4.3	17.9	19.5	24.3	26.2	21.7	25.5	25.4
4.3 ≤ E < 4.5	17.6	19.2	24.1	26.0	21.4	25.2	25.2
4.5 ≤ E < 4.7	17.3	18.9	23.9	25.8	21.2	25.0	24.9
4.7 ≤ E < 4.9	17.1	18.7	23.6	25.5	20.9	24.7	24.7
E ≥ 4.9	16.8	18.4	23.4	25.3	20.7	24.5	24.4

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	59 < Assembly Average Burnup ≤ 60 GWd/MTU Minimum Cooling Time (years)						
	CE 14×14	WE 14×14	WE 15×15	B&W 15×15	CE 16×16	WE 17×17	B&W 17×17
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	-	-	-	-	-	-	-
3.3 ≤ E < 3.5	20.3	22.0	26.7	28.4	24.1	27.2	27.1
3.5 ≤ E < 3.7	20.0	21.5	26.4	28.1	23.7	26.8	26.7
3.7 ≤ E < 3.9	19.6	21.2	26.0	27.8	23.4	26.5	26.5
3.9 ≤ E < 4.1	19.3	20.8	25.7	27.6	23.1	26.2	26.2
4.1 ≤ E < 4.3	18.9	20.5	25.4	27.3	22.7	26.0	25.9
4.3 ≤ E < 4.5	18.6	20.2	25.2	27.1	22.5	25.7	25.6
4.5 ≤ E < 4.7	18.3	20.0	24.9	26.8	22.2	25.5	25.4
4.7 ≤ E < 4.9	18.0	19.7	24.7	26.6	22.0	25.2	25.2
E ≥ 4.9	17.7	19.5	24.4	26.4	21.7	25.0	24.9

Table 2-21 Loading Table for BWR Fuel – 379 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	30 < Assembly Average Burnup ≤ 32.5 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	4.3	4.6	4.0	4.5	4.0	4.5	4.4
2.3 ≤ E < 2.5	4.2	4.6	4.0	4.5	4.0	4.4	4.4
2.5 ≤ E < 2.7	4.2	4.5	4.0	4.4	4.0	4.4	4.3
2.7 ≤ E < 2.9	4.1	4.5	4.0	4.4	4.0	4.3	4.3
2.9 ≤ E < 3.1	4.1	4.4	4.0	4.3	4.0	4.3	4.2
3.1 ≤ E < 3.3	4.0	4.4	4.0	4.3	4.0	4.2	4.2
3.3 ≤ E < 3.5	4.0	4.3	4.0	4.2	4.0	4.2	4.1
3.5 ≤ E < 3.7	4.0	4.3	4.0	4.2	4.0	4.2	4.1
3.7 ≤ E < 3.9	4.0	4.3	4.0	4.2	4.0	4.1	4.0
3.9 ≤ E < 4.1	4.0	4.2	4.0	4.1	4.0	4.1	4.0
4.1 ≤ E < 4.3	4.0	4.2	4.0	4.1	4.0	4.1	4.0
4.3 ≤ E < 4.5	4.0	4.2	4.0	4.1	4.0	4.0	4.0
4.5 ≤ E < 4.7	4.0	4.1	4.0	4.0	4.0	4.0	4.0
4.7 ≤ E < 4.9	4.0	4.1	4.0	4.0	4.0	4.0	4.0
E ≥ 4.9	4.0	4.1	4.0	4.0	4.0	4.0	4.0
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	32.5 < Assembly Average Burnup ≤ 35 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	4.7	5.0	4.3	4.9	4.0	4.9	4.8
2.5 ≤ E < 2.7	4.6	4.9	4.3	4.8	4.0	4.8	4.7
2.7 ≤ E < 2.9	4.5	4.9	4.2	4.8	4.0	4.7	4.6
2.9 ≤ E < 3.1	4.5	4.8	4.2	4.7	4.0	4.7	4.6
3.1 ≤ E < 3.3	4.4	4.8	4.1	4.7	4.0	4.6	4.5
3.3 ≤ E < 3.5	4.4	4.7	4.0	4.6	4.0	4.6	4.5
3.5 ≤ E < 3.7	4.3	4.7	4.0	4.6	4.0	4.5	4.5
3.7 ≤ E < 3.9	4.3	4.6	4.0	4.5	4.0	4.5	4.4
3.9 ≤ E < 4.1	4.2	4.6	4.0	4.5	4.0	4.5	4.4
4.1 ≤ E < 4.3	4.2	4.5	4.0	4.5	4.0	4.4	4.3
4.3 ≤ E < 4.5	4.2	4.5	4.0	4.4	4.0	4.4	4.3
4.5 ≤ E < 4.7	4.1	4.5	4.0	4.4	4.0	4.4	4.3
4.7 ≤ E < 4.9	4.1	4.5	4.0	4.4	4.0	4.3	4.2
E ≥ 4.9	4.1	4.4	4.0	4.3	4.0	4.3	4.2

Table 2-21 Loading Table for BWR Fuel – 379 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	35 < Assembly Average Burnup ≤ 37.5 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	5.2	5.6	4.7	5.4	4.4	5.4	5.2
2.5 ≤ E < 2.7	5.1	5.5	4.7	5.3	4.3	5.3	5.2
2.7 ≤ E < 2.9	5.0	5.4	4.6	5.3	4.3	5.2	5.1
2.9 ≤ E < 3.1	4.9	5.4	4.5	5.2	4.2	5.1	5.0
3.1 ≤ E < 3.3	4.9	5.3	4.5	5.1	4.1	5.1	4.9
3.3 ≤ E < 3.5	4.8	5.2	4.4	5.0	4.1	5.0	4.9
3.5 ≤ E < 3.7	4.8	5.1	4.4	5.0	4.0	4.9	4.8
3.7 ≤ E < 3.9	4.7	5.1	4.3	4.9	4.0	4.9	4.8
3.9 ≤ E < 4.1	4.6	5.0	4.3	4.9	4.0	4.9	4.7
4.1 ≤ E < 4.3	4.6	5.0	4.3	4.9	4.0	4.8	4.7
4.3 ≤ E < 4.5	4.6	4.9	4.2	4.8	4.0	4.8	4.7
4.5 ≤ E < 4.7	4.5	4.9	4.2	4.8	4.0	4.7	4.6
4.7 ≤ E < 4.9	4.5	4.9	4.1	4.7	4.0	4.7	4.6
E ≥ 4.9	4.5	4.9	4.1	4.7	4.0	4.7	4.6

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	37.5 < Assembly Average Burnup ≤ 40 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	5.7	6.1	5.2	5.9	4.7	5.9	5.7
2.7 ≤ E < 2.9	5.6	6.0	5.1	5.8	4.6	5.8	5.7
2.9 ≤ E < 3.1	5.5	5.9	5.0	5.8	4.6	5.7	5.6
3.1 ≤ E < 3.3	5.5	5.9	4.9	5.7	4.5	5.6	5.5
3.3 ≤ E < 3.5	5.4	5.8	4.9	5.6	4.4	5.6	5.4
3.5 ≤ E < 3.7	5.3	5.7	4.8	5.6	4.4	5.5	5.4
3.7 ≤ E < 3.9	5.2	5.7	4.7	5.5	4.3	5.4	5.3
3.9 ≤ E < 4.1	5.2	5.6	4.7	5.4	4.3	5.4	5.2
4.1 ≤ E < 4.3	5.1	5.6	4.6	5.4	4.3	5.3	5.2
4.3 ≤ E < 4.5	5.0	5.5	4.6	5.3	4.2	5.3	5.1
4.5 ≤ E < 4.7	5.0	5.5	4.5	5.3	4.2	5.2	5.0
4.7 ≤ E < 4.9	5.0	5.4	4.5	5.2	4.1	5.2	5.0
E ≥ 4.9	4.9	5.4	4.5	5.2	4.1	5.1	5.0

Table 2-21 Loading Table for BWR Fuel – 379 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	40 < Assembly Average Burnup ≤ 41 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	6.0	6.5	5.4	6.2	4.9	6.1	6.0
2.7 ≤ E < 2.9	5.9	6.4	5.3	6.1	4.8	6.0	5.9
2.9 ≤ E < 3.1	5.8	6.2	5.2	6.0	4.7	5.9	5.8
3.1 ≤ E < 3.3	5.7	6.1	5.1	5.9	4.7	5.9	5.7
3.3 ≤ E < 3.5	5.6	6.0	5.0	5.9	4.6	5.8	5.6
3.5 ≤ E < 3.7	5.5	6.0	5.0	5.8	4.5	5.7	5.6
3.7 ≤ E < 3.9	5.5	5.9	4.9	5.7	4.5	5.7	5.5
3.9 ≤ E < 4.1	5.4	5.9	4.9	5.7	4.4	5.6	5.5
4.1 ≤ E < 4.3	5.3	5.8	4.8	5.6	4.4	5.5	5.4
4.3 ≤ E < 4.5	5.3	5.8	4.8	5.6	4.4	5.5	5.3
4.5 ≤ E < 4.7	5.2	5.7	4.7	5.5	4.3	5.4	5.3
4.7 ≤ E < 4.9	5.2	5.7	4.7	5.5	4.3	5.4	5.2
E ≥ 4.9	5.1	5.6	4.6	5.4	4.2	5.4	5.2

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	41 < Assembly Average Burnup ≤ 42 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	6.3	6.8	5.6	6.5	5.1	6.4	6.2
2.7 ≤ E < 2.9	6.2	6.7	5.5	6.4	5.0	6.3	6.1
2.9 ≤ E < 3.1	6.0	6.6	5.5	6.3	4.9	6.2	6.0
3.1 ≤ E < 3.3	6.0	6.5	5.4	6.2	4.8	6.1	5.9
3.3 ≤ E < 3.5	5.9	6.4	5.3	6.1	4.8	6.0	5.9
3.5 ≤ E < 3.7	5.8	6.3	5.2	6.0	4.7	5.9	5.8
3.7 ≤ E < 3.9	5.7	6.2	5.1	5.9	4.6	5.9	5.7
3.9 ≤ E < 4.1	5.6	6.1	5.0	5.9	4.6	5.8	5.7
4.1 ≤ E < 4.3	5.6	6.0	5.0	5.8	4.5	5.8	5.6
4.3 ≤ E < 4.5	5.5	6.0	4.9	5.8	4.5	5.7	5.6
4.5 ≤ E < 4.7	5.5	5.9	4.9	5.7	4.5	5.7	5.5
4.7 ≤ E < 4.9	5.4	5.9	4.9	5.7	4.4	5.6	5.5
E ≥ 4.9	5.4	5.8	4.8	5.6	4.4	5.6	5.4

Table 2-21 Loading Table for BWR Fuel – 379 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	42 < Assembly Average Burnup ≤ 43 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	6.6	7.1	5.9	6.8	5.3	6.8	6.6
2.7 ≤ E < 2.9	6.5	7.0	5.8	6.7	5.2	6.6	6.4
2.9 ≤ E < 3.1	6.4	6.9	5.7	6.6	5.1	6.5	6.3
3.1 ≤ E < 3.3	6.3	6.8	5.6	6.5	5.0	6.4	6.2
3.3 ≤ E < 3.5	6.1	6.7	5.5	6.4	4.9	6.3	6.1
3.5 ≤ E < 3.7	6.0	6.6	5.4	6.3	4.9	6.2	6.0
3.7 ≤ E < 3.9	6.0	6.5	5.4	6.2	4.8	6.1	5.9
3.9 ≤ E < 4.1	5.9	6.4	5.3	6.1	4.8	6.0	5.9
4.1 ≤ E < 4.3	5.8	6.3	5.2	6.0	4.7	6.0	5.8
4.3 ≤ E < 4.5	5.8	6.3	5.1	6.0	4.6	5.9	5.8
4.5 ≤ E < 4.7	5.7	6.2	5.1	6.0	4.6	5.9	5.7
4.7 ≤ E < 4.9	5.7	6.1	5.0	5.9	4.6	5.9	5.7
E ≥ 4.9	5.6	6.1	5.0	5.9	4.5	5.8	5.6
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**43 < Assembly Average Burnup ≤ 44 GWd/MTU Minimum Cooling Time (years)**						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	7.0	7.6	6.1	7.2	5.5	7.1	6.9
2.7 ≤ E < 2.9	6.8	7.4	6.0	7.0	5.4	6.9	6.7
2.9 ≤ E < 3.1	6.7	7.3	5.9	6.9	5.3	6.8	6.6
3.1 ≤ E < 3.3	6.6	7.1	5.8	6.8	5.2	6.7	6.5
3.3 ≤ E < 3.5	6.5	7.0	5.7	6.7	5.1	6.6	6.4
3.5 ≤ E < 3.7	6.4	6.9	5.7	6.6	5.0	6.5	6.3
3.7 ≤ E < 3.9	6.3	6.8	5.6	6.5	5.0	6.5	6.2
3.9 ≤ E < 4.1	6.2	6.7	5.5	6.4	4.9	6.4	6.1
4.1 ≤ E < 4.3	6.1	6.7	5.5	6.4	4.9	6.3	6.0
4.3 ≤ E < 4.5	6.0	6.6	5.4	6.3	4.8	6.2	6.0
4.5 ≤ E < 4.7	5.9	6.5	5.3	6.2	4.8	6.1	5.9
4.7 ≤ E < 4.9	5.9	6.5	5.3	6.2	4.7	6.1	5.9
E ≥ 4.9	5.8	6.4	5.2	6.1	4.7	6.0	5.9

Table 2-21 Loading Table for BWR Fuel – 379 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	44 < Assembly Average Burnup ≤ 45 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	7.2	7.9	6.3	7.5	5.6	7.4	7.1
2.9 ≤ E < 3.1	7.0	7.7	6.2	7.3	5.5	7.2	6.9
3.1 ≤ E < 3.3	6.9	7.6	6.1	7.1	5.4	7.0	6.8
3.3 ≤ E < 3.5	6.8	7.4	6.0	7.0	5.4	6.9	6.7
3.5 ≤ E < 3.7	6.7	7.3	5.9	6.9	5.3	6.9	6.6
3.7 ≤ E < 3.9	6.6	7.2	5.8	6.8	5.2	6.8	6.5
3.9 ≤ E < 4.1	6.5	7.1	5.8	6.8	5.1	6.7	6.4
4.1 ≤ E < 4.3	6.4	7.0	5.7	6.7	5.0	6.6	6.3
4.3 ≤ E < 4.5	6.3	6.9	5.6	6.6	5.0	6.5	6.3
4.5 ≤ E < 4.7	6.3	6.8	5.6	6.5	4.9	6.4	6.2
4.7 ≤ E < 4.9	6.2	6.8	5.5	6.5	4.9	6.4	6.1
E ≥ 4.9	6.1	6.7	5.4	6.4	4.8	6.3	6.1

Note: For fuel assembly average burnup greater than 45 GWd/MTU, cool time tables have been revised to account for a 5% margin in heat load.

Table 2-22 Loading Table for BWR Fuel – 360 W/Assembly

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	45 < Assembly Average Burnup ≤ 46 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	8.5	9.3	7.3	8.8	6.3	8.6	8.2
2.9 ≤ E < 3.1	8.3	9.0	7.1	8.6	6.2	8.4	8.0
3.1 ≤ E < 3.3	8.1	8.9	7.0	8.4	6.0	8.2	7.9
3.3 ≤ E < 3.5	8.0	8.8	6.8	8.2	6.0	8.0	7.7
3.5 ≤ E < 3.7	7.9	8.6	6.7	8.0	5.9	7.9	7.6
3.7 ≤ E < 3.9	7.7	8.4	6.7	7.9	5.8	7.8	7.5
3.9 ≤ E < 4.1	7.6	8.3	6.6	7.8	5.8	7.7	7.4
4.1 ≤ E < 4.3	7.5	8.2	6.5	7.7	5.7	7.6	7.3
4.3 ≤ E < 4.5	7.4	8.1	6.4	7.6	5.6	7.5	7.2
4.5 ≤ E < 4.7	7.3	8.0	6.3	7.6	5.6	7.4	7.1
4.7 ≤ E < 4.9	7.2	7.9	6.2	7.5	5.5	7.4	7.0
E ≥ 4.9	7.1	7.8	6.1	7.4	5.4	7.3	7.0

Table 2-22 Loading Table for BWR Fuel – 360 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	46 < Assembly Average Burnup ≤ 47 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	9.1	10.0	7.7	9.3	6.7	9.2	8.7
2.9 ≤ E < 3.1	8.9	9.8	7.5	9.1	6.5	8.9	8.5
3.1 ≤ E < 3.3	8.7	9.5	7.4	8.9	6.4	8.8	8.3
3.3 ≤ E < 3.5	8.5	9.3	7.2	8.7	6.2	8.6	8.2
3.5 ≤ E < 3.7	8.3	9.1	7.0	8.6	6.1	8.4	8.0
3.7 ≤ E < 3.9	8.2	9.0	7.0	8.4	6.0	8.3	7.9
3.9 ≤ E < 4.1	8.0	8.8	6.9	8.3	6.0	8.1	7.8
4.1 ≤ E < 4.3	7.9	8.7	6.8	8.2	5.9	8.0	7.7
4.3 ≤ E < 4.5	7.8	8.6	6.7	8.1	5.8	7.9	7.6
4.5 ≤ E < 4.7	7.7	8.5	6.6	8.0	5.8	7.9	7.5
4.7 ≤ E < 4.9	7.6	8.4	6.5	7.9	5.7	7.8	7.4
E ≥ 4.9	7.5	8.3	6.5	7.8	5.7	7.7	7.4

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	47 < Assembly Average Burnup ≤ 48 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	9.8	10.7	8.2	9.9	6.9	9.8	9.3
2.9 ≤ E < 3.1	9.6	10.5	8.0	9.7	6.8	9.5	9.1
3.1 ≤ E < 3.3	9.3	10.2	7.8	9.5	6.7	9.3	8.9
3.3 ≤ E < 3.5	9.1	9.9	7.7	9.3	6.6	9.2	8.7
3.5 ≤ E < 3.7	8.9	9.7	7.5	9.1	6.5	9.0	8.5
3.7 ≤ E < 3.9	8.7	9.6	7.4	8.9	6.3	8.8	8.4
3.9 ≤ E < 4.1	8.6	9.4	7.2	8.8	6.2	8.7	8.2
4.1 ≤ E < 4.3	8.4	9.3	7.1	8.7	6.1	8.6	8.1
4.3 ≤ E < 4.5	8.3	9.1	7.0	8.6	6.0	8.4	8.0
4.5 ≤ E < 4.7	8.1	9.0	6.9	8.5	6.0	8.3	7.9
4.7 ≤ E < 4.9	8.0	8.9	6.9	8.3	5.9	8.2	7.8
E ≥ 4.9	7.9	8.8	6.8	8.2	5.9	8.1	7.8

Table 2-22 Loading Table for BWR Fuel – 360 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	48 < Assembly Average Burnup ≤ 49 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	10.5	11.6	8.7	10.8	7.3	10.6	9.9
2.9 ≤ E < 3.1	10.2	11.3	8.5	10.4	7.1	10.2	9.7
3.1 ≤ E < 3.3	10.0	11.0	8.3	10.1	7.0	9.9	9.4
3.3 ≤ E < 3.5	9.7	10.7	8.1	9.9	6.9	9.8	9.2
3.5 ≤ E < 3.7	9.5	10.5	7.9	9.7	6.8	9.6	9.0
3.7 ≤ E < 3.9	9.3	10.3	7.8	9.5	6.7	9.4	8.9
3.9 ≤ E < 4.1	9.1	10.1	7.7	9.4	6.5	9.2	8.7
4.1 ≤ E < 4.3	9.0	9.9	7.5	9.2	6.4	9.0	8.6
4.3 ≤ E < 4.5	8.8	9.7	7.4	9.1	6.3	8.9	8.5
4.5 ≤ E < 4.7	8.7	9.6	7.3	8.9	6.3	8.8	8.4
4.7 ≤ E < 4.9	8.6	9.5	7.2	8.9	6.2	8.7	8.3
E ≥ 4.9	8.5	9.3	7.1	8.8	6.1	8.6	8.2
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	49 < Assembly Average Burnup ≤ 50 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	11.0	12.0	9.0	11.2	7.6	11.0	10.3
3.1 ≤ E < 3.3	10.7	11.7	8.8	10.9	7.4	10.7	10.1
3.3 ≤ E < 3.5	10.4	11.5	8.6	10.7	7.2	10.4	9.8
3.5 ≤ E < 3.7	10.2	11.3	8.4	10.4	7.0	10.2	9.7
3.7 ≤ E < 3.9	10.0	11.0	8.2	10.2	7.0	10.0	9.5
3.9 ≤ E < 4.1	9.7	10.8	8.0	10.0	6.8	9.8	9.3
4.1 ≤ E < 4.3	9.6	10.6	7.9	9.8	6.7	9.7	9.1
4.3 ≤ E < 4.5	9.4	10.4	7.8	9.7	6.7	9.5	9.0
4.5 ≤ E < 4.7	9.3	10.2	7.7	9.5	6.6	9.4	8.9
4.7 ≤ E < 4.9	9.1	10.1	7.6	9.4	6.5	9.2	8.7
E ≥ 4.9	9.0	10.0	7.5	9.3	6.4	9.1	8.6

Table 2-22 Loading Table for BWR Fuel – 360 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	50 < Assembly Average Burnup ≤ 51 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	11.8	12.9	9.6	12.0	8.0	11.8	11.1
3.1 ≤ E < 3.3	11.5	12.6	9.4	11.7	7.8	11.5	10.9
3.3 ≤ E < 3.5	11.2	12.3	9.1	11.5	7.6	11.2	10.6
3.5 ≤ E < 3.7	10.9	11.9	8.9	11.1	7.5	11.0	10.3
3.7 ≤ E < 3.9	10.7	11.8	8.7	10.9	7.3	10.7	10.0
3.9 ≤ E < 4.1	10.4	11.6	8.6	10.7	7.2	10.5	9.9
4.1 ≤ E < 4.3	10.3	11.3	8.4	10.5	7.0	10.3	9.7
4.3 ≤ E < 4.5	10.0	11.2	8.3	10.4	7.0	10.1	9.6
4.5 ≤ E < 4.7	9.9	11.0	8.1	10.1	6.8	9.9	9.4
4.7 ≤ E < 4.9	9.8	10.9	8.0	10.0	6.8	9.8	9.3
E ≥ 4.9	9.6	10.7	7.9	9.9	6.7	9.7	9.1
Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	**51 < Assembly Average Burnup ≤ 52 GWd/MTU Minimum Cooling Time (years)**						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	12.7	13.9	10.3	12.9	8.4	12.6	11.9
3.1 ≤ E < 3.3	12.3	13.4	10.0	12.5	8.2	12.3	11.6
3.3 ≤ E < 3.5	11.9	13.2	9.8	12.1	8.0	11.9	11.3
3.5 ≤ E < 3.7	11.7	12.9	9.5	11.9	7.9	11.7	11.0
3.7 ≤ E < 3.9	11.5	12.6	9.3	11.7	7.7	11.4	10.8
3.9 ≤ E < 4.1	11.2	12.4	9.1	11.5	7.6	11.3	10.5
4.1 ≤ E < 4.3	11.0	12.1	8.9	11.3	7.4	11.0	10.3
4.3 ≤ E < 4.5	10.8	11.8	8.8	11.1	7.3	10.9	10.2
4.5 ≤ E < 4.7	10.6	11.7	8.7	10.9	7.2	10.7	10.0
4.7 ≤ E < 4.9	10.5	11.6	8.5	10.7	7.1	10.5	9.9
E ≥ 4.9	10.2	11.4	8.4	10.6	7.0	10.4	9.8

Table 2-22 Loading Table for BWR Fuel – 360 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	52 < Assembly Average Burnup ≤ 53 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	13.6	14.8	11.0	13.7	8.9	13.4	12.7
3.1 ≤ E < 3.3	13.2	14.5	10.7	13.3	8.7	13.1	12.4
3.3 ≤ E < 3.5	12.8	14.1	10.4	13.0	8.5	12.8	12.0
3.5 ≤ E < 3.7	12.6	13.8	10.1	12.7	8.3	12.5	11.8
3.7 ≤ E < 3.9	12.2	13.5	9.8	12.4	8.1	12.2	11.5
3.9 ≤ E < 4.1	11.9	13.2	9.7	12.2	7.9	12.0	11.3
4.1 ≤ E < 4.3	11.7	13.0	9.5	12.0	7.8	11.8	11.1
4.3 ≤ E < 4.5	11.6	12.7	9.3	11.8	7.7	11.5	10.9
4.5 ≤ E < 4.7	11.4	12.5	9.2	11.6	7.6	11.4	10.7
4.7 ≤ E < 4.9	11.2	12.4	9.0	11.5	7.5	11.3	10.5
E ≥ 4.9	11.0	12.1	8.9	11.3	7.4	11.1	10.4

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	53 < Assembly Average Burnup ≤ 54 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	14.5	15.8	11.8	14.6	9.5	14.4	13.6
3.1 ≤ E < 3.3	14.1	15.4	11.4	14.3	9.2	14.0	13.2
3.3 ≤ E < 3.5	13.8	15.1	11.1	13.9	8.9	13.6	12.8
3.5 ≤ E < 3.7	13.4	14.7	10.9	13.6	8.7	13.4	12.6
3.7 ≤ E < 3.9	13.1	14.4	10.6	13.3	8.6	13.1	12.2
3.9 ≤ E < 4.1	12.9	14.1	10.4	13.1	8.4	12.8	12.0
4.1 ≤ E < 4.3	12.6	13.9	10.1	12.8	8.2	12.5	11.8
4.3 ≤ E < 4.5	12.4	13.6	9.9	12.6	8.1	12.3	11.6
4.5 ≤ E < 4.7	12.1	13.4	9.7	12.3	7.9	12.1	11.4
4.7 ≤ E < 4.9	11.9	13.2	9.6	12.2	7.9	11.9	11.2
E ≥ 4.9	11.7	13.1	9.4	12.0	7.8	11.7	11.1

Table 2-22 Loading Table for BWR Fuel – 360 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	54 < Assembly Average Burnup ≤ 55 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	15.0	16.4	12.1	15.2	9.8	14.9	14.1
3.3 ≤ E < 3.5	14.7	16.0	11.9	14.9	9.5	14.6	13.7
3.5 ≤ E < 3.7	14.3	15.7	11.5	14.5	9.3	14.2	13.4
3.7 ≤ E < 3.9	13.9	15.4	11.3	14.2	9.0	13.9	13.1
3.9 ≤ E < 4.1	13.6	15.1	11.1	13.9	8.9	13.6	12.8
4.1 ≤ E < 4.3	13.3	14.7	10.8	13.6	8.7	13.4	12.5
4.3 ≤ E < 4.5	13.1	14.5	10.5	13.4	8.5	13.1	12.3
4.5 ≤ E < 4.7	12.9	14.3	10.4	13.2	8.4	13.0	12.1
4.7 ≤ E < 4.9	12.8	14.1	10.2	13.0	8.3	12.8	11.9
E ≥ 4.9	12.5	13.9	10.0	12.8	8.1	12.5	11.7

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	55 < Assembly Average Burnup ≤ 56 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	15.8	17.5	13.1	16.2	10.4	15.9	15.0
3.3 ≤ E < 3.5	15.5	17.1	12.7	15.8	10.1	15.5	14.6
3.5 ≤ E < 3.7	15.1	16.7	12.3	15.5	9.9	15.2	14.3
3.7 ≤ E < 3.9	14.7	16.3	12.0	15.1	9.7	14.8	13.9
3.9 ≤ E < 4.1	14.4	16.0	11.8	14.9	9.4	14.6	13.6
4.1 ≤ E < 4.3	14.0	15.7	11.5	14.5	9.2	14.3	13.4
4.3 ≤ E < 4.5	13.8	15.4	11.3	14.3	9.0	14.0	13.1
4.5 ≤ E < 4.7	13.7	15.2	11.1	14.1	8.8	13.8	12.9
4.7 ≤ E < 4.9	13.4	15.0	10.9	13.9	8.7	13.7	12.8
E ≥ 4.9	13.3	14.8	10.7	13.7	8.6	13.4	12.5

Table 2-22 Loading Table for BWR Fuel – 360 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	56 < Assembly Average Burnup ≤ 57 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	16.8	18.4	13.8	17.2	11.1	16.9	16.0
3.3 ≤ E < 3.5	16.5	18.1	13.5	16.8	10.9	16.4	15.5
3.5 ≤ E < 3.7	16.0	17.7	13.1	16.4	10.5	16.2	15.2
3.7 ≤ E < 3.9	15.7	17.3	12.9	16.1	10.2	15.7	14.8
3.9 ≤ E < 4.1	15.4	17.1	12.5	15.8	10.0	15.4	14.5
4.1 ≤ E < 4.3	15.1	16.8	12.2	15.4	9.8	15.2	14.3
4.3 ≤ E < 4.5	14.8	16.4	12.0	15.2	9.6	14.8	14.0
4.5 ≤ E < 4.7	14.6	16.2	11.8	15.0	9.4	14.7	13.8
4.7 ≤ E < 4.9	14.3	15.9	11.6	14.7	9.2	14.4	13.5
E ≥ 4.9	14.0	15.7	11.4	14.5	9.0	14.3	13.4

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	57 < Assembly Average Burnup ≤ 58 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	17.8	19.5	14.8	18.2	11.8	17.8	16.8
3.3 ≤ E < 3.5	17.3	19.1	14.4	17.7	11.5	17.5	16.5
3.5 ≤ E < 3.7	17.0	18.7	14.0	17.4	11.2	17.1	16.1
3.7 ≤ E < 3.9	16.6	18.3	13.6	17.0	10.9	16.8	15.7
3.9 ≤ E < 4.1	16.3	17.9	13.3	16.7	10.6	16.4	15.4
4.1 ≤ E < 4.3	15.9	17.7	13.1	16.3	10.3	16.1	15.1
4.3 ≤ E < 4.5	15.7	17.4	12.8	16.1	10.1	15.8	14.8
4.5 ≤ E < 4.7	15.5	17.1	12.5	15.9	9.9	15.5	14.6
4.7 ≤ E < 4.9	15.2	16.9	12.3	15.6	9.8	15.3	14.4
E ≥ 4.9	15.0	16.7	12.1	15.4	9.6	15.1	14.2

Table 2-22 Loading Table for BWR Fuel – 360 W/Assembly (continued)

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	58 < Assembly Average Burnup ≤ 59 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	18.7	20.4	15.7	19.2	12.6	18.9	17.8
3.3 ≤ E < 3.5	18.4	20.0	15.2	18.8	12.2	18.4	17.4
3.5 ≤ E < 3.7	18.0	19.7	14.9	18.4	11.9	18.1	17.1
3.7 ≤ E < 3.9	17.6	19.3	14.5	18.1	11.6	17.7	16.7
3.9 ≤ E < 4.1	17.2	18.9	14.1	17.7	11.2	17.3	16.3
4.1 ≤ E < 4.3	16.9	18.7	13.8	17.4	11.0	17.1	16.1
4.3 ≤ E < 4.5	16.6	18.4	13.6	17.1	10.8	16.8	15.7
4.5 ≤ E < 4.7	16.4	18.0	13.3	16.9	10.6	16.5	15.5
4.7 ≤ E < 4.9	16.1	17.8	13.1	16.6	10.3	16.2	15.3
E ≥ 4.9	15.9	17.6	12.9	16.3	10.2	15.9	15.1

Minimum Initial Assembly Avg. Enrichment wt % ^{235}U (E)	59 < Assembly Average Burnup ≤ 60 GWd/MTU Minimum Cooling Time (years)						
	BWR/2-3 7×7	BWR/4-6 7×7	BWR/2-3 8×8	BWR/4-6 8×8	BWR/2-3 9×9	BWR/4-6 9×9	BWR/4-6 10×10
2.1 ≤ E < 2.3	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-	-	-	-
3.1 ≤ E < 3.3	-	-	-	-	-	-	-
3.3 ≤ E < 3.5	19.3	21.0	16.0	19.7	12.9	19.5	18.4
3.5 ≤ E < 3.7	18.9	20.7	15.6	19.3	12.7	19.1	17.9
3.7 ≤ E < 3.9	18.6	20.3	15.2	19.0	12.3	18.7	17.7
3.9 ≤ E < 4.1	18.2	19.9	14.9	18.7	11.9	18.3	17.3
4.1 ≤ E < 4.3	17.9	19.7	14.5	18.3	11.6	17.9	17.0
4.3 ≤ E < 4.5	17.6	19.4	14.2	18.1	11.4	17.7	16.6
4.5 ≤ E < 4.7	17.3	19.1	14.0	17.7	11.2	17.5	16.4
4.7 ≤ E < 4.9	17.1	18.8	13.8	17.6	11.0	17.2	16.1
E ≥ 4.9	16.9	18.6	13.6	17.3	10.8	16.9	15.9

Appendix C
Technical Specification Bases for the MAGNASTOR SYSTEM

Table of Contents

1.0 INTRODUCTION

This Appendix presents the design or operational condition, or regulatory requirement, which establishes the bases for the Technical Specifications provided in Appendix A.

The section and paragraph numbering used in this Appendix is consistent with the numbering used in Appendix A, Technical Specifications for the MAGNASTOR SYSTEM, and Appendix B, Approved Contents for the MAGNASTOR SYSTEM.

2.0 APPROVED CONTENTS

2.1 Fuel Specifications and Loading Conditions

BASES

BACKGROUND	The MAGNASTOR SYSTEM design requires specifications for the spent fuel to be stored, such as the type of spent fuel, minimum and maximum allowable enrichment prior to irradiation, maximum burnup, minimum acceptable post-irradiation cooling time prior to storage, maximum decay heat, and condition of the spent fuel (i.e., UNDAMAGED FUEL). Other important limitations are the dimensions and weight of the fuel assemblies. The approved contents, which can be loaded into the MAGNASTOR SYSTEM, are specified in Section 2.0 of Appendix B. Specific limitations for the MAGNASTOR SYSTEM are specified in Table 2-1 and 2-8 of Appendix B. These limitations support the assumptions and inputs used in the thermal, structural, shielding, and criticality evaluations performed for the MAGNASTOR SYSTEM.
APPLICABLE SAFETY ANALYSES	To ensure that the closure lid is not placed on a TSC containing an unauthorized fuel assembly, facility procedures require verification of the loaded fuel assemblies to ensure that the correct fuel assemblies have been loaded in the TSC.
APPROVED CONTENTS	Tables 2-1 and 2-8 in Appendix B define the specific fuel assembly characteristics for the PWR and BWR fuel assemblies authorized for loading into the MAGNASTOR SYSTEM. These fuel assembly characteristics include parameters such as cladding material, minimum and maximum enrichment, decay heat generation, post-irradiation cooling time, burnup, and fuel assembly length, width, and weight. The fuel assembly and nonfuel assembly hardware characteristic limits of Tables 2-2 through 2-7 and Tables 2-9 through 2-12 in Appendix B must be met to ensure that the thermal, structural, shielding, and criticality analyses supporting the MAGNASTOR SYSTEM Safety Analysis Report are bounding.

(continued)

APPROVED CONTENT LIMITS AND VIOLATIONS	If any Approved Contents limits of Section 2.0 in Appendix B are violated, the limitations on fuel assemblies to be loaded are not met. Action must be taken to place the affected fuel assembly(s) in a safe condition. This safe condition may be established by returning the affected fuel assembly(s) to the spent fuel pool. However, it is acceptable for the affected fuel assemblies to temporarily remain in the MAGNASTOR SYSTEM, in a wet or dry condition, if that is determined to be a safe condition. NRC notification of the Approved Contents limit violation is required within 24 hours. A written report on the violation must be submitted to the NRC within 60 days. This notification and written report are independent of any reports and notification that may be required by 10 CFR 72.216.
REFERENCES	FSAR, Sections 2.1 and Chapter 6.

3.0 LIMITING CONDITION FOR OPERATION (LCO) APPLICABILITY

BASES

LCOs	LCO 3.0.1, 3.0.2 and 3.0.4 establish the general requirements applicable to all Specifications and apply at all times, unless otherwise stated.
LCO 3.0.1	LCO 3.0.1 establishes the Applicability statement within each individual Specification as the requirement for when the LCO is required to be met (i.e., when the system is in the specific conditions of the Applicability statement of each Specification).

LCO 3.0.2

LCO 3.0.2 establishes that upon discovery of a failure to meet an LCO, the associated ACTIONS shall be met. The Completion Time of each Required Action for an ACTIONS condition is applicable from the point in time that an ACTIONS condition is entered. The Required Actions establish those remedial measures that must be taken within specified Completion Times when the requirements of an LCO are not met. This Specification establishes that:

a. Completion of the Required Actions within the specified Completion Times constitutes compliance with a Specification; and,

b. Completion of the Required Actions is not required when an LCO is met within the specified Completion Time, unless otherwise specified.

There are two basic types of Required Actions. The first type of Required Action specifies a time limit in which the LCO must be met. This time limit is the Completion Time to restore a system or component or to restore variables to within specified limits. Whether stated as a Required Action or not, correction of the entered condition is an action that may always be considered upon entering ACTIONS. The second type of Required Action specifies the remedial measures that permit continued operation that is not further restricted by the Completion Time. In this case, compliance with the Required Actions provides an acceptable level of safety for continued operation.

Completing the Required Actions is not required when an LCO is met or is no longer applicable, unless otherwise stated in the individual Specifications.

The Completion Times of the Required Actions are also applicable when a system or component is removed from service intentionally. The reasons for intentionally relying on the ACTIONS include, but are not limited to, performance of Surveillances, preventive maintenance, corrective maintenance, or investigation of operational problems. Entering ACTIONS for these reasons must be done in a manner that does not compromise safety. Intentional entry into ACTIONS should not be made for operational convenience.

(continued)

BASES (continued)

LCO 3.0.3	This specification is not applicable to the MAGNASTOR SYSTEM.
LCO 3.0.4	LCO 3.0.4 establishes limitations on changes in specified conditions in the Applicability when an LCO is not met. It precludes placing the facility in a specified condition stated in that Applicability (e.g., Applicability desired to be entered) when the following conditions exist: a. Facility conditions are such that the requirements of the LCO would not be met in the Applicability desired to be entered; and, b. Continued noncompliance with the LCO requirements, if the Applicability were entered, would result in being required to exit the Applicability desired to be entered to comply with the Required Actions. Compliance with Required Actions that permit continued operation of the system for an unlimited period of time in a specified condition provides an acceptable level of safety for continued operation. That is without regard to the status of the system. Therefore, in such cases, entry into a specified condition in the Applicability may be made in accordance with the provisions of the Required Actions. The provisions of this Specification should not be interpreted as endorsing the failure to exercise the good practice of restoring systems or components before entering an associated specified condition in the Applicability. The provisions of LCO 3.0.4 shall not prevent changes in specified conditions in the Applicability that are required to comply with ACTIONS, or that are related to the unloading of a TSC. Exceptions to LCO 3.0.4 are stated in the individual Specifications. Exceptions may apply to all the ACTIONS or to a specific Required Action of a Specification.
LCO 3.0.5	This specification is not applicable to the MAGNASTOR SYSTEM, as there is no provision for a return to service under administrative control for testing.

3.0 SURVEILLANCE REQUIREMENT (SR) APPLICABILITY

BASES

SRs

SR 3.0.1 through SR 3.0.4 establish the general requirements applicable to all Specifications and apply at all times, unless otherwise stated.

SR 3.0.1

SR 3.0.1 establishes the requirement that SRs must be met during the specified conditions in the Applicability for which the requirements of the LCO apply, unless otherwise specified in the individual SRs. This Specification is to ensure that Surveillances are performed to verify that systems and components meet the LCO and variables are within specified limits. Failure to complete Surveillance within the specified Frequency, in accordance with SR 3.0.2, constitutes a failure to meet an LCO.

Systems and components are assumed to meet the LCO when the associated SRs have been met. Nothing in this Specification, however, is to be construed as implying that systems or components meet the associated LCO when:

a. The systems or components are known to not meet the LCO, although still meeting the SRs; and,

b. The requirements of the Surveillance(s) are known to be not met between required Surveillance performances.

Surveillances do not have to be performed when the system is in a specified condition for which the requirements of the associated LCO are not applicable, unless otherwise specified.

Surveillances, including Surveillances invoked by Required Actions, do not have to be performed on equipment determined to not meet the LCO because the ACTIONS define the remedial measures that apply. Surveillances have to be met and performed in accordance with SR 3.0.2, prior to returning the equipment to service. Upon completion of maintenance, appropriate post-maintenance testing is required. This includes ensuring applicable Surveillances are not failed and their most recent performance is in accordance with SR 3.0.2.

Post-maintenance testing may not be possible in the current specified conditions in the Applicability due to the necessary system parameters not having been established. In these situations, the equipment may be considered to meet the LCO, provided testing has been satisfactorily completed to the extent possible and the equipment is not otherwise believed to be incapable of performing its function. This will allow operations to proceed to a specified condition where other necessary post-maintenance tests can be completed.

(continued)

SR 3.0.2

SR 3.0.2 establishes the requirements for meeting the specified Frequency for Surveillances and any Required Action with a Completion Time that requires the periodic performance of the Required Action on a "once per ..." interval.

SR 3.0.2 permits a 25% extension of the interval specified in the Frequency. This extension facilitates Surveillance scheduling and considers system conditions that may be suitable for conducting the Surveillance (e.g., transient conditions or other ongoing Surveillance or maintenance activities).

The 25% extension does not significantly degrade the reliability that results from performing the Surveillance at its specified Frequency. This is based on the recognition that the most probable result of any particular Surveillance being performed is the verification of conformance with the SRs. The exceptions to SR 3.0.2 are those Surveillances for which the 25% extension of the interval specified in the Frequency does not apply. These exceptions are stated in the individual Specifications as a Note in the Frequency stating, "SR 3.0.2 is not applicable."

As stated in SR 3.0.2, the 25% extension also does not apply to the initial portion of a periodic Completion Time that requires performance on a "once per ..." basis. The 25% extension applies to each performance after the initial performance. The initial performance of the Required Action, whether it is a particular Surveillance or some other remedial action, is considered a single action with a single Completion Time. One reason for not allowing the 25% extension to this Completion Time is that such an action usually verifies that no loss of function has occurred by checking the status of redundant or diverse components or accomplishes the function of the affected equipment in an alternative manner.

The provisions of SR 3.0.2 are not intended to be used repeatedly merely as an operational convenience to extend Surveillance intervals or periodic Completion Time intervals beyond those specified.

SR 3.0.3

SR 3.0.3 establishes the flexibility to defer declaring affected equipment as not meeting the LCO or an affected variable outside the specified limits when Surveillance has not been completed within the specified Frequency. A delay period of up to 24 hours or up to the limit of the specified Frequency, whichever is less, applies from the point in time that it is discovered that the Surveillance has not been performed in accordance with SR 3.0.2, and not at the time that the specified Frequency was not met.

(continued)

SR 3.0.3 (continued)

This delay period provides adequate time to complete Surveillances that have been missed. This delay period permits the completion of Surveillance before complying with Required Actions or other remedial measures that might preclude completion of the Surveillance.

The basis for this delay period includes consideration of system conditions, adequate planning, availability of personnel, the time required to perform the Surveillance, the safety significance of the delay in completing the required Surveillance, and the recognition that the most probable result of any particular Surveillance being performed is the verification of conformance with the requirements. When Surveillance with a Frequency based not on time intervals, but upon specified system conditions, is discovered not to have been performed when specified, SR 3.0.3 allows the full delay period of 24 hours to perform the Surveillance.

SR 3.0.3 also provides a time limit for completion of Surveillances that become applicable as a consequence of changes in the specified conditions in the Applicability imposed by the Required Actions.

Failure to comply with specified Frequencies for SRs is expected to be an infrequent occurrence. Use of the delay period established by SR 3.0.3 is a flexibility, which is not intended to be used as an operational convenience to extend Surveillance intervals.

If Surveillance is not complete within the allowed delay period, then the equipment is considered to not meet the LCO, or the variable is considered outside the specified limits, and the Completion Times of the Required Actions for the applicable LCO Conditions begin immediately upon expiration of the delay period. If Surveillance is failed within the delay period, then the equipment does not meet the LCO, or the variable is outside the specified limits, and the Completion Times of the Required Actions for the applicable LCO Conditions begin immediately upon the failure of the Surveillance.

Completion of the Surveillance within the delay period allowed by this Specification, or within the Completion Time of the ACTIONS, restores compliance with SR 3.0.1.

SR 3.0.4

SR 3.0.4 establishes the requirement that all applicable SRs must be met before entry into a specified condition in the Applicability.

This Specification ensures that system and component requirements and variable limits are met before entry into specified conditions in the Applicability for which these systems and components ensure safe operation of the system.

(continued)

SR 3.0.4 (continued)

The provisions of this Specification should not be interpreted as endorsing the failure to exercise the good practice of restoring systems or components before entering an associated specified condition in the Applicability.

However, in certain circumstances, failing to meet an SR will not result in SR 3.0.4 restricting a change in specified condition. When a system, subsystem, division, component, device, or variable is outside the specified limits, the associated SR(s) are not required to be performed per SR 3.0.1, which states that Surveillances do not have to be performed on equipment that has been determined to not meet the LCO. When equipment does not meet the LCO, SR 3.0.4 does not apply to the associated SR(s) since the requirement for the SR(s) to be performed is removed. Therefore, failing to perform the Surveillance(s) within the specified conditions of the Applicability. However, since the LCO is not met in this instance, LCO 3.0.4 will govern any restrictions that may (or may not) apply to specified condition changes.

The provisions of SR 3.0.4 shall not prevent changes in specified conditions in the Applicability that is required to comply with ACTIONS.

In addition, the provisions of LCO 3.0.4 shall not prevent changes in specified conditions in the Applicability that is related to the unloading of the MAGNASTOR SYSTEM.

The precise requirements of performance of SRs are specified such that exceptions to SR 3.0.4 are not necessary. The specific time frames and conditions necessary for meeting the SRs are specified in the Frequency, in the Surveillance, or both. This allows performance of Surveillances when the prerequisite condition(s) specified in a Surveillance procedure require entry into the specified condition in the Applicability of the associated LCO prior to the performance or completion of Surveillance. A Surveillance that could not be performed until after entering the LCO Applicability would have its Frequency specified such that it is not "due" until the specific conditions needed are met.

Alternately, the Surveillance may be stated in the form of a Note as not required (to be met or performed) until a particular event, condition, or time has been reached. Further, discussion of the specific formats of SRs annotation is found in Technical Specification Section 1.4, Frequency.

3.1 MAGNASTOR SYSTEM Integrity

3.1.1 Transportable Storage Canister (TSC)

BASES

BACKGROUND

A TRANSFER CASK with an empty TSC is placed into the spent fuel pool and loaded with fuel assemblies meeting the requirements of Appendix B, Approved Contents. A closure lid is then placed on the TSC and the TRANSFER CASK containing the TSC is removed from the pool and placed in the cask preparation area or prepared in a partially submerged condition. Water flow to the TRANSFER CASK annulus may be provided to assist in limiting the MAGNASTOR SYSTEM component temperatures during TSC preparation and closure activities. The closure lid is welded to the TSC shell and the weld is examined by dye penetrant examination methods (i.e., root, mid-plane and final surface). A hydrostatic pressure test of the weld is performed to 125% of maximum normal operating pressure. A closure ring is installed in the closure lid-to-TSC shell weld groove, welded to the shell and to the closure lid and examined by dye penetrant methods. The TSC cavity water is removed by pumping and/or blow down while backfilling the cavity with helium, and the free volume of the TSC is determined by measuring the volume of water removed. The final residual moisture removal is completed by vacuum drying, and the cavity is backfilled to a specified mass or pressure of high purity helium. The redundant port covers at the vent port and at the drain port are installed and welded to the closure lid, and the welds are dye penetrant examined to complete the confinement boundary. The TRANSFER CASK is then used to complete the transfer of the TSC to the CONCRETE CASK, and the loaded and closed CONCRETE CASK is moved to the ISFSI pad for long-term storage.

TSC cavity moisture removal is performed using vacuum drying following draining of the bulk cavity water. Dryness is confirmed by ensuring that any pressure rise in the isolated TSC cavity with the vacuum pump turned off is less than the acceptance criteria.

Upon verification of the dryness of the TSC cavity following vacuum drying operations, the TSC is backfilled with high purity helium until the required density is established. Drying and backfilling the TSC cavity with helium provides the capability to remove the contents decay heat and minimizes any oxidizing gases. Establishment of the inert helium atmosphere protects the fuel cladding from degradation. The backfilling

(continued)

BACKGROUND (cont.)

and resulting pressurization of the cavity with helium to an established density will provide the required helium mass and pressure to ensure the operation of the heat transfer design of the MAGNASTOR SYSTEM, and will eliminate the possibility of air in-leakage over the storage period. The TSC is designed, analyzed, and tested to meet the leaktight criteria of ANSI N14.5, and the closure lid-to-TSC shell weld is hydrostatically pressure tested following fuel loading. The closure lid, closure ring and port covers provide redundant closures to assure confinement boundary integrity. Therefore, loss of helium and possible in-leakage of air are precluded.

APPLICABLE SAFETY ANALYSIS

The confinement of the radioactive materials contents in the TSC is ensured by the multiple confinement boundaries, including the fuel pellet matrix, the fuel rod cladding, and the pressure boundary provided by the TSC. Long-term integrity of the spent fuel contents is assured by the inert helium atmosphere of the TSC, which is accomplished by the removal of free water, elimination of residual oxidizing gases, and backfilling with high purity helium. The pressurized helium atmosphere in the TSC ensures that the MAGNASTOR SYSTEM convective heat transfer thermal design will perform as analyzed. The helium backfill mass ensures that the TSC internal pressure does not exceed the vessel's design pressure under storage design operating conditions.

LCO

A dry pressurized, helium filled and sealed TSC establishes the inert environment that will ensure the integrity of the fuel cladding and proper performance of the MAGNASTOR SYSTEM thermal design, while precluding air in-leakage.

APPLICABILITY

The sealed TSC with a dry inert cavity atmosphere is required to be established prior to TRANSPORT OPERATIONS to ensure integrity of the fuel contents and the effectiveness of the heat dissipation capability during these operating phases.

(continued)

ACTIONS

A note has been added to the ACTIONS, which states that, for this LCO, separate Condition entry is allowed for each TSC. This is acceptable as the Required Actions for each Condition provide appropriate compensatory measures for each TSC not meeting the LCO. Subsequent TSCs that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

A.1

If the cavity vacuum drying pressure with the vacuum pump isolated and turned off is not met prior to TRANSPORT OPERATIONS, an engineering evaluation is necessary to determine the potential quantity of moisture left in the TSC. Since moisture remaining in the cavity during TRANSPORT and STORAGE OPERATIONS may represent a long-term degradation issue, immediate action is not required. The Completion Time is sufficient to complete an engineering evaluation of the safety significance of the Condition.

A.2

Upon determination of the mass of water potentially contained in the TSC, a corrective action plan shall be developed and actions initiated, as required, in a timely manner to return the TSC to an analyzed condition.

B.1

If a determination is made that the helium backfill mass or purity requirements are not met prior to TRANSPORT OPERATIONS, an engineering evaluation shall be performed to establish the mass of helium in the TSC. As high or low helium mass values could result in TSC over-pressurization or reduced effectiveness of the TSC heat rejection capability, respectively, the engineering evaluation shall be performed in a timely manner. The Completion Time is sufficient to complete an engineering evaluation of the safety significance of the Condition.

B.2

When the mass of helium in the TSC is determined, a corrective action plan shall be developed and actions implemented, as required, in a timely manner to return the TSC to an analyzed condition.

C.1

If the TSC cannot be returned to an analyzed safe condition, the TSC contents are required to be placed in a safe condition in the spent fuel pool. The Completion Time is reasonable based on the time required to plan, train and perform UNLOADING OPERATIONS in an orderly manner.

(continued)

SURVEILLANCE REQUIREMENTS	SR 3.1.1.1, and SR 3.1.1.2 The long-term integrity of the TSC and stored contents is dependent on a dry and pressurized helium cavity environment. The dryness of the TSC cavity is demonstrated by evacuation by a vacuum pump to a low vacuum and monitoring the rise in pressure over a specified period with the vacuum pump isolated and turned off. The establishment of the required helium backfill mass and corresponding operating pressure at operating temperature will ensure the effectiveness of the TSC capability to reject the contents decay heat to the fuel basket and TSC structure. The decay heat will subsequently be rejected by the cooling air flows provided by the CONCRETE CASK during STORAGE OPERATIONS. These two surveillances shall be performed once prior to TRANSPORT OPERATIONS. Successful completion will ensure that the appropriate conditions have been established for long-term storage in compliance with the analyzed design bases.
REFERENCES	1. FSAR Sections 4.4 and 9.1.

3.1 MAGNASTOR SYSTEM Integrity

3.1.2 CONCRETE CASK Heat Removal System

BASES

BACKGROUND

The heat removal system for the CONCRETE CASK containing a loaded TSC is a passive, convective air-cooled heat transfer system that ensures that the decay heat emitted from the TSC is transferred to the environment by the upward flow of air through the CONCRETE CASK annulus. During STORAGE OPERATIONS, ambient air is drawn into the CONCRETE CASK annulus through the four air inlets located at the base of the CONCRETE CASK. The heat from the TSC surfaces is transferred to the air flow via natural circulation. The buoyancy of the heated air creates a chimney effect forcing the heated air upward and drawing additional ambient air into the annulus through the air inlets. The heated air flows back to the ambient environment through the four air outlets located in the CONCRETE CASK lid.

APPLICABLE SAFETY ANALYSIS

The thermal analyses of the MAGNASTOR SYSTEM take credit for the decay heat from the TSC contents being transferred to the ambient environment surrounding the CONCRETE CASK. Transfer of heat from the TSC contents ensures that the fuel cladding and TSC component temperatures do not exceed established limits. During normal STORAGE OPERATIONS, the four air inlets and four air outlets are unobstructed and full natural convection heat transfer occurs (i.e., maximum heat transfer for a given ambient temperature and decay heat load).

Analyses have been performed for the complete obstruction of two and four air inlets. Blockage of two air inlets reduces the convective air flow through the CONCRETE CASK/TSC annulus and decreases the heat transfer from the TSC surfaces to the ambient environment. Under this off-normal event of blockage of two air inlets, no CONCRETE CASK or TSC components or fuel cladding exceed established short-term temperature limits, and the TSC internal pressure does not exceed the analyzed maximum pressure.

The complete blockage of all four air inlets effectively stops the transfer of the decay heat from the TSC due to the elimination of the convective air flow. The TSC will continue to radiate heat to the liner of the CONCRETE CASK. Upon loss of air cooling, the MAGNASTOR SYSTEM component temperatures will increase toward their respective established accident temperature limits. The spent fuel cladding and fuel basket and CONCRETE CASK structural component temperatures do not reach their accident limits for a time period of approximately 72 hours. The internal pressure in the TSC cavity will not reach the analyzed maximum pressure condition for approximately 58 hours after a complete blockage condition occurs.

(continued)

BASES (continued)

APPLICABLE SAFETY ANALYSIS (cont.)

Therefore, following the identification of a reduction in the heat dissipation capabilities of the CONCRETE CASK by the temperature-monitoring program or the visual inspection of the air inlet and outlet screens, actions are to be taken immediately to restore at least partial convective airflow (i.e., a minimum of 2 air inlet screens and 2 air outlets screens are unobstructed). Once partial airflow is established, the fuel cladding and the TSC and component temperatures will not exceed normal STORAGE OPERATIONS limits. Efforts to reestablish full OPERABLE status for the CONCRETE CASK can then be undertaken in a controlled manner. If necessary, the TSC may be transferred into the TRANSFER CASK to permit full access to the base of the CONCRETE CASK for repairs with minimal radiological effects.

LCO

The CONCRETE CASK heat removal system is to be verified to be OPERABLE to preserve the applicability of the design bases thermal analyses. The continued operability of the heat removal system ensures that the decay heat generated by the TSC contents is transferred to the ambient environment to maintain the fuel cladding and CONCRETE CASK and TSC temperatures within established limits.

APPLICABILITY

The LCO is applicable during TRANSPORT OPERATIONS and STORAGE OPERATIONS. Once the CONCRETE CASK lid is installed following transfer of a loaded TSC, the heat removal system is required to be OPERABLE to ensure adequate heat transfer.

ACTIONS

A Note has been added to the Actions that states for this LCO, separate condition entry is allowed for each CONCRETE CASK. This is acceptable, as the Required Actions for each Condition provide appropriate compensatory measures for each CONCRETE CASK not meeting the LCO. Other CONCRETE CASKs that do not meet the LCO are addressed by independent Condition entry and application of the associated Required Actions.

A.1

If the CONCRETE CASK heat removal system has been determined to be inoperable, full operability is to be restored, or at a minimum, adequate heat removal must be restored or verified to prevent exceeding fuel cladding and critical component temperatures for accident events. Adequate heat removal capability is defined as no more than two obstructed CONCRETE CASK air inlets and air outlets and constitutes the analyzed off-normal event. This verification must be completed immediately.

(continued)

ACTIONS (cont.)

Thermal analyses of a fully blocked CONCRETE CASK air inlet condition show that fuel cladding and critical basket material accident temperatures and internal pressure limits could be exceeded over time. As a result, requiring immediate verification, or restoration, of adequate heat removal capability will ensure that accident temperature and pressure limits are not exceeded. Once adequate heat removal has been reestablished or verified, the additional actions required to restore the CONCRETE CASK to OPERABLE status can be completed under A.2.

A.2

In addition to Required Action A.1, efforts are required to be continued to restore the CONCRETE CASK heat removal system to OPERABLE.

As long as adequate heat removal capability has been verified to exist, restoring the CONCRETE CASK heat removal system to fully OPERABLE is not an immediate concern. Therefore, restoring it to OPERABLE within 30 days is a reasonable Completion Time.

SURVEILLANCE REQUIREMENTS

SR 3.1.2.1

The long-term integrity of the stored spent fuel is dependent on the continuing ability of the CONCRETE CASK to reject decay heat from the TSC to the ambient environment. Routine verification that the four air inlets and four air outlets are unobstructed and intact ensures that convective airflow through the CONCRETE CASK/TSC annulus is occurring and performing effective heat transfer. Alternatively, the Surveillance Requirement can be fulfilled by measuring the exit air temperature from the four air outlets and determining the temperature rise over the ISFSI ambient air temperature. As long as the temperature increase of the convective airflow is less than the surveillance limits, adequate heat transfer is occurring to maintain CONCRETE CASK, TSC, and spent fuel cladding temperatures below long-term limits.

If partial or complete blockage of the CONCRETE CASK air inlets occurs, the heat rejection system will be rendered inoperable and this LCO is not meet. Immediate corrective actions are to be taken to remove the obstructions from at least two air inlets and air outlets to restore partial air flow, and additional corrective actions are to be taken to remove all air inlet and outlet obstructions and return the CONCRETE CASK to OPERABLE status.

(continued)

BASES (continued)

SURVEILLANCE REQUIREMENTS (continued)	SR 3.1.2.1 (continued) The Frequency of 24 hours is reasonable based on the time necessary for the spent fuel cladding and CONCRETE CASK and TSC component temperatures to reach their short-term temperature limits and the internal pressure to increase to the accident condition pressure limit. The Frequency will allow appropriate corrective actions to be completed in a timely manner.
REFERENCES	FSAR Section 4.4.

3.2 MAGNASTOR SYSTEM Criticality Control for PWR Fuel

3.2.1 Dissolved Boron Concentration

BASES

BACKGROUND	A TRANSFER CASK with an empty TSC is placed into a spent fuel pool and loaded with fuel assemblies and associated nonfuel hardware meeting the requirements of Appendix B, Approved Contents for the MAGNASTOR SYSTEM. After loading the TSC, a closure lid is installed on the TSC, the closure lid is welded to the TSC shell, and the water in the cavity is drained. For those TSCs to be loaded with PWR fuel assemblies, credit is taken in the criticality analyses for boron dissolved in the water within the TSC cavity during the loading and TSC preparation up through the draining of the cavity water. To preserve the analyses bases, the dissolved boron concentration of the TSC cavity water must be verified to meet specified limits when there are fuel assemblies and water in the TSC. This may occur during LOADING OPERATIONS and UNLOADING OPERATIONS.
APPLICABLE SAFETY ANALYSIS	The spent fuel stored in the MAGNASTOR SYSTEM is required to remain subcritical ($k_{eff} < 0.95$) under all conditions of storage. The MAGNASTOR SYSTEM is analyzed to safely store a wide variety of spent fuel assembly types with differing initial enrichments and associated nonfuel hardware. For PWR fuel assemblies to be loaded in the TSCs, credit has been taken in the criticality analyses for neutron poison in the form of soluble boron in the water in the TSC cavity. Compliance with this LCO preserves the assumptions made in the criticality analyses and ensures that the stored PWR fuel assemblies will remain subcritical with a $k_{eff} < 0.95$ while water is in the TSC.
LCO	Compliance with this LCO ensures that the stored PWR fuel will remain subcritical with a $k_{eff} < 0.95$ while water is in the TSC. The LCO provides the minimum concentration of soluble boron required to be in the TSC cavity water based on the type, initial enrichment, and contained nonfuel hardware of the PWR fuel assembly. All UNDAMAGED FUEL ASSEMBLIES loaded into the TSC are limited by analysis to maximum enrichments of 5.0 wt% ^{235}U.

(continued)

BASES (continued)

APPLICABILITY	The dissolved boron concentration LCO is applicable whenever a TSC has at least one PWR fuel assembly in a storage location and water in the TSC.
ACTIONS	A Note has been added to the Actions that states for this LCO, separate condition entry is allowed for each TSC. This is acceptable since the Required Actions for each condition provide appropriate compensatory measures for each TSC not meeting the LCO. Subsequent TSCs being loaded or unloaded will be controlled by subsequent condition entry and application of associated Required Actions. A.1 and A.2 Continuation of LOADING OPERATIONS, UNLOADING OPERATIONS or positive reactivity additions (including actions to reduce dissolved boron concentration) is contingent upon maintaining the TSC in compliance with the LCO. Determination of a measurement of soluble boron below the required concentration for the limiting fuel assembly parameters, LOADING OPERATIONS, UNLOADING OPERATIONS, and any positive reactivity additions are to be immediately suspended and placed in a safe condition. A.3 Immediate actions are to be taken to restore the dissolved boron concentration in the TSC cavity water to within the established limits. One method of complying with the action is to initiate direct boration of the TSC water immediately in a controlled manner. Alternatively, the direct boration of the spent fuel pool water can be performed. Once initiated, the addition of boron to the TSC or spent fuel pool are to continue until the required soluble boron concentration is restored. The time to complete restoration will depend on the amount of boron required to be added and the capacity of the available boron addition equipment.
SURVEILLANCE REQUIREMENTS	SR 3.2.1.1 When the TSC is placed in the spent fuel pool for loading of PWR fuel assemblies requiring boron credit, the dissolved boron concentration in the TSC water must be verified by two independent measurements to be within the applicable limit within four hours prior to entering the applicability of the LCO. For LOADING OPERATIONS, this means within four hours prior to loading any approved content into the TSC.

(continued)

BASES (continued)

SURVEILLANCE REQUIREMENTS (cont.)

The use of two independent measurements provides assurance that the dissolved boron concentration limit is met and maintained. The period of four hours prior to fuel loading for the surveillance frequency is reasonable based on the potential for boron dilution to occur prior to the start of loading without limiting operational flexibility. Following the verification of the boron concentration, there is no credible unplanned event that would change the concentration. During the period between the completion of boron concentration verification and commencement of loading operations, possible methods to change the boron concentration will be administratively controlled. If actions are taken that could result in a reduction in the boron concentration within the four-hour period, the surveillance will be performed again.

While the TSC is in the spent fuel pool or while water is in the TSC, the boron concentration will be verified every 24 hours. Facility procedures will specifically ensure that any water to be added to, or recirculated through, the TSC will have a boron concentration greater than or equal to the minimum boron concentration specified by the LCO.

For UNLOADING OPERATIONS, the dissolved boron concentration in water to be used to reflood a TSC containing PWR fuel, requiring a minimum boron concentration in accordance with this LCO, will be verified within four hours of initiating TSC reflooding operations. This ensures that when the LCO is applicable the LCO will be met. The boron concentration shall be verified every 24 hours until all PWR fuel assemblies are removed from the TSC during wet unloading operations.

REFERENCES

FSAR Chapter 6

3.3 MAGNASTOR SYSTEM Radiation Protection

3.3.1 CONCRETE CASK Maximum Surface Dose Rates

BASES

BACKGROUND	The regulations governing the operation of an ISFSI set limits on the control of occupational radiation exposure and radiation doses to the general public (Ref. 1). Radiation doses to the public are limited for both normal and accident conditions in accordance with 10 CFR 72 and 10 CFR 20. Occupational radiation exposure should be kept as low as reasonably achievable (ALARA) and within the limits of 10 CFR 20. Unexpected high dose rates may also lead to the identification of a fuel misload exceeding CoC Fuel Content limitations.
APPLICABLE SAFETY ANALYSIS	The CONCRETE CASK maximum surface dose rates are not an assumption in any accident analysis, but are used to ensure compliance with regulatory limits on dose to the public and occupational dose, and to potentially identify a misloaded spent fuel assembly.
LCO	The limits on CONCRETE CASK maximum neutron and gamma surface dose rates are based on the Safety Analysis Report shielding analysis of the MAGNASTOR System (Ref. 2). The limits are selected to minimize radiation exposure to the public, as determined in accordance with 10 CFR 72 and 10 CFR 20, and to maintain occupational dose ALARA to personnel working in the vicinity of the MAGNASTOR SYSTEM. The LCO specifies sufficient locations for taking dose rate measurements to ensure the dose rates measured are indicative of the effectiveness of the shielding materials.
APPLICABILITY	The CONCRETE CASK maximum neutron and gamma surface dose rates apply immediately prior to the start of STORAGE OPERATIONS. The selected limits ensure that the CONCRETE CASK surface dose rates during STORAGE OPERATIONS are bounded by the shielding safety analyses. Radiation doses during STORAGE OPERATIONS are monitored by the MAGNASTOR SYSTEM user in accordance with the plant-specific radiation protection program as required by 10 CFR 72.212(b)(6) and 10 CFR 20 (Ref. 1).
ACTIONS	A note has been added to the ACTIONS, which states that for this LCO, separate Condition entry is allowed for each loaded CONCRETE CASK. This is acceptable since the Required Actions for each Condition provide appropriate compensatory measures for each CONCRETE CASK not meeting the LCO. Subsequent MAGNASTOR SYSTEMs that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

(continued)

ACTIONS (continued)

A.1

If the CONCRETE CASK maximum surface dose rates are not within limits, it could be an indication that a fuel assembly that did not meet the Approved Contents Limits in Section B2.0 of Appendix B was inadvertently loaded into the TSC. Administrative verification of the TSC fuel loading, by means such as review of video recordings and records of the loaded fuel assembly serial numbers, can establish whether a misloaded fuel assembly is the cause of the out-of-limit condition. The Completion time is based on the time required to perform verification.

A.2

If the CONCRETE CASK maximum surface dose rates are not within limits and it is determined that the CONCRETE CASK was loaded with the correct fuel assemblies, an analysis may be performed. This analysis will determine if the CONCRETE CASK would result in the ISFSI offsite or occupational calculated doses exceeding regulatory limits in 10 CFR 72 or 10 CFR 20, respectively. If it is determined that the measured maximum surface dose rates do not result in the regulatory limits being exceeded, STORAGE OPERATIONS may proceed.

B.1

If it is verified that the fuel was misloaded, or that the ISFSI offsite radiation protection requirements of 10 CFR 20 or 10 CFR 72 will not be met with the CONCRETE CASK maximum surface dose rates above the LCO limit, the performance of the CONCRETE CASK shall be assessed and a safe configuration established. The Completion Time is reasonable, based on the time required to perform an engineering evaluation and safety assessment of the CONCRETE CASK, to implement corrective actions such as augmented shielding applied to the CONCRETE CASK, repositioning the CONCRETE CASK in the cask array at the ISFSI to reduce the offsite dose impact of the CONCRETE CASK, or to off-load the affected TSC.

(continued)

BASES (continued)

SURVEILLANCE REQUIREMENTS	SR 3.3.1.1 This SR ensures that the CONCRETE CASK maximum neutron and gamma surface dose rates are within the LCO limits after transfer of the TSC into the CONCRETE CASK and prior to the beginning of STORAGE OPERATIONS. This Frequency is acceptable, as corrective actions can be taken before offsite dose limits are compromised. The surface dose rates are measured approximately at the locations indicated on Figure 3-1 of Appendix A of the Technical Specifications Technical Specifications.
REFERENCES	1. 10 CFR Parts 20 and 72 2. SAR Section 5.1

Chapter 14
Quality Assurance

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14 QUALITY ASSURANCE

The NAC International (NAC) Quality Assurance (QA) Program is designed and administered to meet all Quality Assurance criteria of 10 CFR 72, Subpart G [1], 10 CFR 50, Appendix B [2], 10 CFR 71, Subpart H [3], and NQA-1 (Basic and Supplemental Requirements) [4]. The Nuclear Regulatory Commission (NRC) has reviewed and approved (Approval No. 0018) NAC's Quality Assurance Program description.

The NAC Quality Assurance Manual (as approved by the company's President) describes the policy NAC follows to comply with the applicable regulatory quality assurance criteria. The policy described in the NAC Quality Assurance Manual is implemented by detailed procedures presented in the Quality Procedures Manual.

Employing a graded methodology, as described in NRC Regulatory Guide 7.10 [5], NAC applies quality controls to items and activities consistent with their safety significance. Table 14-1 identifies the NAC Quality Assurance Manual sections that address the applicable quality criteria.

Table 14-1 Correlation of Regulatory Quality Assurance Criteria to NAC Quality Assurance Program

Regulatory Quality Assurance Criteria[a]	Corresponding NAC QA Manual Section Number
Organization	1.0
Quality Assurance Program	2.0
Design Control	3.0
Procurement Document Control	4.0
Procedures, Instructions, and Drawings	5.0
Document Control	6.0
Control of Purchased Items and Services	7.0
Identification and Control of Material, Parts and Components	8.0
Control of Special Processes	9.0
Inspection	10.0
Test Control	11.0
Control of Measuring and Test Equipment	12.0
Handling, Storage and Shipping	13.0
Inspection, Test and Operating Status	14.0
Control of Nonconforming Items	15.0
Corrective Action	16.0
Records	17.0
Audits	18.0

[a] The criteria are obtained from 10 CFR 50, Appendix B; 10 CFR 71, Subpart H; and 10 CFR 72, Subpart G

14.1 NAC Quality Assurance Program Synopsis

Eighteen applicable Quality Assurance criteria are identified in 10 CFR 72, Subpart G; 10 CFR 50, Appendix B; 10 CFR 71, Subpart H; and ASME NQA-1 (Basic and Supplemental Requirements). Refer to the following sections for NAC's compliance with each of these criteria.

14.1.1 Organization

The President of NAC has the ultimate authority and responsibility over all organizations and their functions within the corporation. However, the President delegates and empowers qualified personnel with the authority and responsibility over selected key areas, as identified in the NAC Organization Chart (see Figure 14.1-1).

The Vice President, Quality, is responsible for definition, development, implementation, and administration of the NAC Quality Assurance Program. The Quality Assurance organization is independent from other organizations within NAC and has complete authority to assure adequate and effective program execution, including problem identification, satisfactory corrective action implementation and the authority to stop work, if necessary. The Vice President, Quality, reports directly to the President of NAC. The Vice President, Quality, has sufficient expertise in the field of quality to direct the quality function and will be capable of qualifying as a lead auditor.

Strategic Business Unit (SBU) Vice Presidents direct operations and use project teams as appropriate for a particular work scope. SBU Vice Presidents are responsible to the President for the proper implementation of the NAC Quality Assurance Program.

14.1.2 Quality Assurance Program

Employing a grading methodology consistent with NRC Regulatory Guide 7.10, the Quality Assurance Program provides control over activities affecting quality from the design to fabrication, operation, and maintenance of nuclear products and services for nuclear applications. The Quality Assurance Program is documented in the Quality Assurance Manual and implemented via Quality Procedures. These documents are approved by the Vice President, Quality, and the applicable Vice President from each SBU performing activities within the scope of the NAC Quality Assurance Manual.

Personnel assigned responsibilities by the Quality Assurance Program may delegate performance of activities associated with that responsibility to other personnel in their group when those individuals are qualified to perform those activities by virtue of their education, experience, and training. Such delegations need not be in writing. The person assigned responsibility by the Quality Assurance Program retains full accountability for the activities.

14.1.3 Design Control

The established Quality Procedures covering design control ensure that the design activity is planned, controlled, verified, and documented so that applicable regulatory and design basis requirements are correctly translated into specifications, drawings, and procedures with appropriate acceptance criteria for inspection and test delineated.

All software used to perform engineering calculations is verified for computational accuracy and error tracking, and is controlled in accordance with approved Quality Procedures.

Design interface control is established and adequate to ensure that the review, approval, release, distribution, and revision of design documents involving interfaces are performed by appropriately trained, cognizant design personnel using approved procedures.

Design verification is performed by individuals other than those who performed the original design. These verifications may include design reviews, alternate calculations, or qualification tests. Selection of the design verification method is based on regulatory, contractual, or design complexity requirements. When qualification testing is selected, the "worst case" scenario will be used. The verification may be performed by the originator's supervisor, provided the supervisor did not specify a singular design approach, rule out certain design considerations, or establish the design inputs used in the design, or unless the supervisor is the only individual in the organization competent to perform the verification. When verification is provided by the supervisor, the need and basis shall be so documented in advance and evaluated after performance by internal audit.

Design changes are controlled and require the same review and approvals as the original design.

14.1.4 Procurement Document Control

Procurement documents and their authorized changes are generated, reviewed, and approved in accordance with the Quality Procedures. These procedures ensure that all purchased material, components, equipment, and services adhere to design specification, regulatory, and contractual requirements including Quality Assurance Program and documentation requirements.

NAC Quality Assurance personnel review and approve all purchase orders invoking compliance with the Quality Assurance Program for inclusion of quality-related requirements in the procurement documents.

14.1.5 Procedures, Instructions and Drawings

All activities affecting quality are delineated in the Quality Procedures, Specifications, Inspection/Verification Plans, or on appropriate drawings. These documents are developed via approved Quality Procedures and include appropriate quantitative and qualitative acceptance criteria. These documents are reviewed and approved by Quality Assurance personnel prior to use.

14.1.6 Document Control

All documents affecting quality, including revisions, are reviewed and approved by authorized personnel, and are issued and controlled in accordance with Quality Procedures by those responsible persons or groups. Transmittal forms, with provisions for receipt acknowledgment, are used and controlled document distribution logs are maintained.

All required support documentation for prescribed activities is available at the work location prior to initiation of the work effort.

14.1.7 Control of Purchased Items and Services

Items and services affecting quality are procured from qualified suppliers. These suppliers have been evaluated and selected in accordance with the Quality Procedures based on their capability to comply with applicable regulatory and contractual requirements.

Objective evidence attesting to the quality of items and services furnished by NAC suppliers is provided with the delivered item or service, and is based on contract requirements and item or service complexity. This vendor documentation requirement is delineated in the procurement documents.

Source inspection, receipt inspection, vendor audits, and vendor surveillance are performed as required to assure product quality, documentation integrity, and supplier compliance to the procurement, regulatory and contractual requirements.

14.1.8 Identification and Control of Material, Parts and Components

Identification is maintained either on the item or in quality records traceable to the item throughout fabrication and construction to prevent the use of incorrect or defective items.

Identification, in accordance with drawings and inspection plans, is verified by Quality Assurance personnel prior to releasing the item for further processing or delivery.

14.1.9 Control of Special Processes

Special processes, such as welding, heat treating, and nondestructive testing, are performed in accordance with applicable codes, standards, specifications, and contract requirements by qualified personnel. NAC and NAC suppliers' special process procedures and personnel certifications are reviewed and approved by NAC Quality Assurance prior to their use.

14.1.10 Inspection

NAC has an established and documented inspection program that identifies activities affecting quality and verifies their conformance with documented instructions, plans, procedures, and drawings.

Inspections are performed by individuals other than those who performed the activity being inspected. Inspection personnel report directly to the Vice President, Quality.

Process monitoring may also be used in conjunction with identified inspections, if beneficial to achieve required quality.

Mandatory inspection hold points assure verification of critical characteristics. Such hold points are delineated in appropriate process control documents.

14.1.11 Test Control

NAC testing requirements are developed and applied in order to demonstrate satisfactory performance of the tested items to design/contract requirements.

The NAC test program is established to ensure that preoperational or operational tests are performed in accordance with written test procedures. Test procedures developed in accordance with approved Quality Procedures identify test prerequisites, test equipment and instrumentation, and suitable environmental test conditions. Test procedures are reviewed and approved by NAC Quality Assurance personnel.

Test results are documented, evaluated, and accepted by qualified personnel as required by the Quality Assurance inspection instructions prepared for the test, as approved by cognizant quality personnel.

14.1.12 Control of Measuring and Testing Equipment

Control of measuring and testing equipment/instrumentation is established to assure that devices used in activities affecting quality are calibrated and properly adjusted at specified time intervals to maintain their accuracy.

Calibrated equipment is identified and traceable to calibration records, which are maintained. Calibration accuracy is traceable to national standards when such standards exist. The basis of calibration shall always be documented.

Whenever measuring and testing equipment is found to be out of calibration, an evaluation shall be made and documented of the validity of inspection or test results performed and of the acceptability of items inspected or tested since the previous calibration.

14.1.13 Handling, Storage and Shipping

Requirements for handling, storage and shipping are documented in specifications and applicable procedures or instructions. These requirements are designed to prevent damage or deterioration to items and materials.

Information pertaining to shelf life, environment, packaging, temperature, cleaning and preservation are also delineated as required.

Quality Assurance Surveillance/Inspection personnel are responsible for verifying that approved handling, storage and shipping requirements are met.

14.1.14 Inspection, Test and Operating Status

Procedures are established to indicate the means of identifying inspection and test status on the item and/or on records traceable to the item. These procedures assure identification of items that have satisfactorily passed required inspections and/or tests to preclude inadvertent bypassing of the inspection/test.

Inspection, test and operating status indicators may only be applied or modified by Quality Assurance personnel or with formal Quality Assurance concurrence.

14.1.15 Control of Nonconforming Items

NAC has established and implemented procedures that assure appropriate identification, segregation, documentation, notification and disposition of items that do not conform to specified requirements. These measures prevent inadvertent usage of the item and assure appropriate authorization or approval of the item's disposition.

All nonconformances are reviewed and accepted, rejected, repaired or reworked in accordance with documented approved procedures. If necessary, a Review Board is convened, consisting of engineering, licensing, quality, operations and testing personnel, as applicable, to provide disposition of nonconforming conditions.

NAC procurement documents provide for control, review and approval of nonconformances noted on NAC items, including associated dispositions.

14.1.16 Corrective Action

Conditions adverse to quality, such as failures, malfunctions, deficiencies, defective material/equipment and nonconformances, are promptly identified, documented and corrected.

Significant conditions adverse to quality will have their cause determined and sufficient corrective action taken to preclude recurrence. These conditions are documented and reported to the Vice President, Quality, who assures awareness by the President.

14.1.17 Records

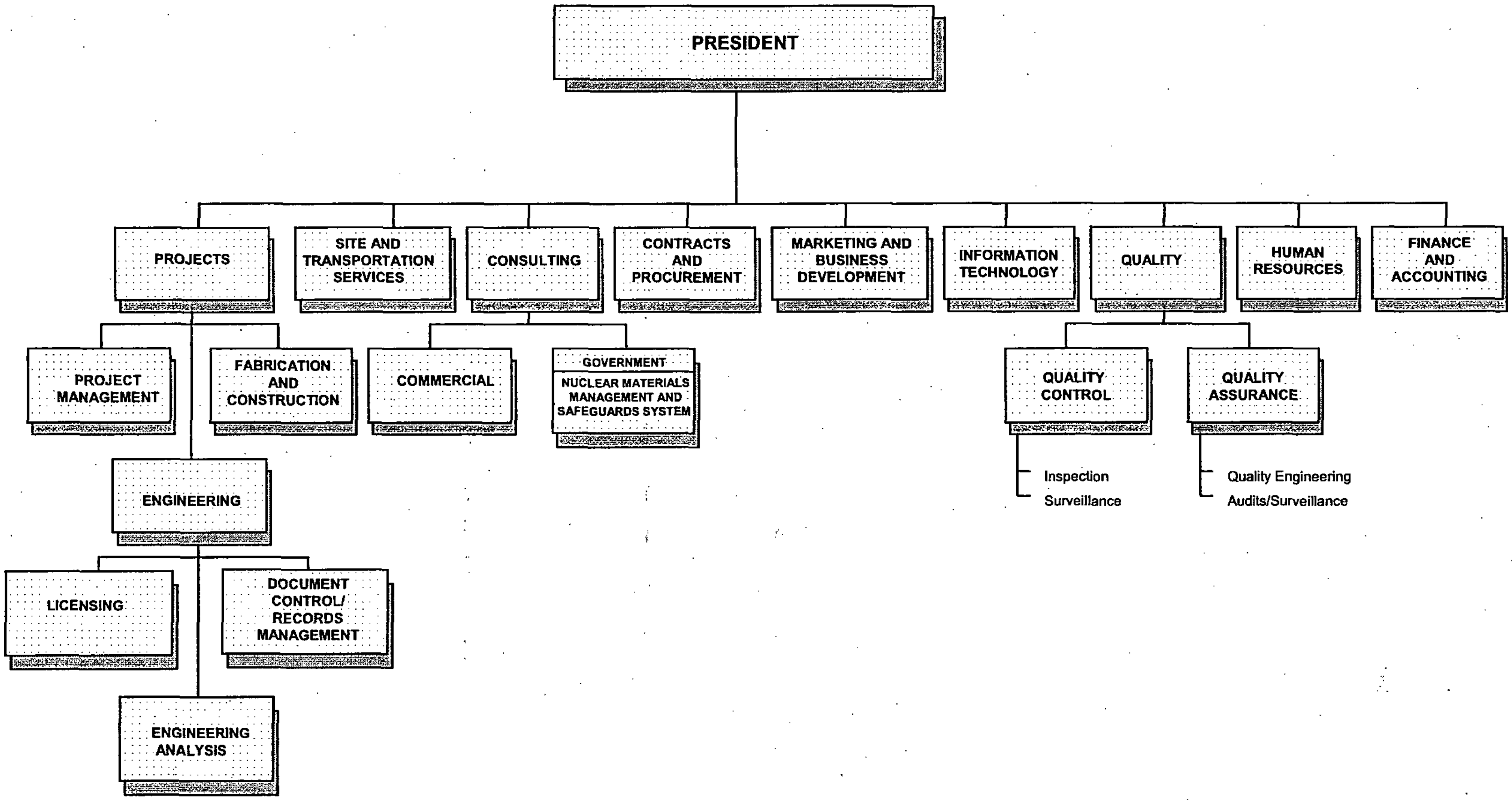
NAC maintains a records system in accordance with approved procedures to ensure that documented objective evidence pertaining to quality-related activities is identifiable, retrievable and retained to meet regulatory and contract requirements, including retention duration, location and responsibility.

Quality records include, but are not limited to, inspection and test reports, audit reports, quality personnel qualifications, design documents, purchase orders, supplier evaluations, fabrication documents, nonconformance reports, drawings, specifications, and so forth. Quality Assurance maintains a complete list of records and provides for record storage and disposition to meet regulatory and contractual requirements.

14.1.18 Audits

Approved Quality Procedures provide for a comprehensive system of planned and periodic audits performed by qualified personnel, independent of activities being audited. These audits are performed in accordance with written procedures and are intended to verify program adequacy and its effective implementation and compliance, both internally and at approved-supplier locations. Internal audits are conducted annually, and approved suppliers are audited on a triennial basis, as a minimum.

Figure 14.1-1 NAC Functional Organization Chart



14.2 References

1. 10 CFR 72, Code of Federal Regulations, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste and Reactor-Related Greater than Class C Waste," Subpart G, "Quality Assurance Requirements," US Government, Washington, DC.
2. 10 CFR 50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," Code of Federal Regulations, US Government, Washington, DC.
3. 10 CFR 71, Code of Federal Regulations, "Packaging and Transportation of Radioactive Material," Subpart H, "Quality Assurance," US Government, Washington, DC.
4. ASME NQA-1, Part 1, Basic and Supplemental Requirements (as referenced by the ASME Code, including latest accepted addenda), Quality Assurance Requirements for Nuclear Facility Applications.
5. Regulatory Guide 7.10, "Establishing Quality Assurance Programs for Packaging Used in Transport of Radioactive Material," US Nuclear Regulatory Commission, Washington, DC.

Chapter 15
Decommissioning

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15 DECOMMISSIONING

The principal elements of MAGNASTOR that may require decommissioning are the concrete cask and the TSC. The TSC is designed and fabricated to be suitable for use as part of the waste package for permanent disposal in a deep Mined Geological Disposal System [1] and is not expected to require onsite decommissioning. The concrete cask is not expected to become surface contaminated during use as it does not come in direct contact with radioactive materials. Surface contamination may be removed by standard decontamination techniques, including washing and surface abrasion. The activity concentrations from activation of concrete cask and TSC components are listed in Table 15.2-1, Table 15.2-2, and Table 15.2-3. The analysis conservatively assumes that the neutron flux is constant for 60 years and is based on a source description that bounds both BWR and PWR fuel. The tables only include the radiologically significant isotopes. The isotope contributing the majority of the carbon steel curie activity is ^{55}Fe, which decays following electron capture and is not of radiological concern.

The design of the concrete cask and TSC precludes the release of contamination from the contents to the environment over the period of use of the system. Consequently, the storage pad, fence, and supporting utility fixtures are not expected to require decontamination as a result of use of MAGNASTOR. These items may be reused or disposed of as locally generated clean waste.

Decommissioning of the concrete cask, TSC, and storage pad will be accomplished by the licensee using either licensee personnel or contract personnel working in accordance with a site license and decommissioning plan.

15.1 Decommissioning the Concrete Cask

The concrete cask is not expected to become surface contaminated during use, except through incidental contact with other contaminated surfaces. Incidental contact could occur at the interior surface (liner) of the concrete cask and the base plate of the concrete cask that supports the TSC. All of these surfaces are made of carbon steel, and it is anticipated that these surfaces could be decontaminated as necessary for decommissioning. The concrete that provides biological shielding is not expected to become contaminated during the period of use, as it does not come into contact with other contaminated objects or surfaces.

Activation of the carbon steel liner, concrete, support plates, and reinforcing bar could occur due to neutron flux from the stored fuel. As shown in Table 15.2-1 and Table 15.2-2, only minimal activation of concrete and carbon steel in the concrete cask is expected to occur. Activation data is provided at one day after removal of the TSC. Individual isotopes listed are limited to those exceeding a 1 $\mu Ci/cm^3$ threshold at one year after removal of the TSC.

Decommissioning of the concrete cask will involve the removal of the TSC and the subsequent disassembly of the concrete cask. It is expected that the concrete will be broken up and the steel components segmented to reduce volume. Any contaminated or activated items are expected to qualify for near-surface disposal as Surface Contaminated Objects (SCO) or Low Specific Activity (LSA) material.

15.2 Decommissioning the TSC

The TSC is designed and fabricated to ensure its retrievability for use as a component of the waste package for permanent disposal in accordance with the guidance of ISG-2 [2] and the requirements of 10 CFR 72 [3]. The TSC is fabricated from materials having high long-term corrosion resistance, and it contains no paints or coatings that could adversely affect its permanent disposal. Decommissioning of the TSC will occur only if the fuel contained in the TSC is removed, or if the current requirements for disposal change. Decommissioning will require that the welds at the TSC closure lid and the vent and drain port covers be cut, so that the spent fuel can be removed. Removal of the contents will occur in a spent fuel pool or dry unloading facility, such as a hot cell. Closure welds can be cut either manually, or with automated equipment, using the unloading procedures of Chapter 9, Section 9.3, for wet unloading, or modified as required for dry unloading.

Following removal of its contents, the TSC interior is expected to have significant fixed and removable surface contamination. Additionally, in cases where the TSC has been exposed to accident loading conditions such as a tip-over or drop, fuel particulate materials may have been released into the TSC from damaged fuel rods.

Some effort may be required to remove the fixed and removable surface contamination prior to disposal; however, in practice, it will likely not be absolutely necessary to decontaminate the TSC internals. Since the TSC internal contamination will consist only of by-product materials, any contaminated TSC and internal components are expected to qualify for near-surface disposal as SCO or LSA waste. Any required internal decontamination is facilitated by the smooth surfaces of the TSC and the basket, and by the design that precludes the presence of crud traps. Since the neutron flux rate from the stored fuel is low, as shown in Table 15.2-3, only minimal activation of the TSC is expected to occur. Isotope and total curie concentrations are provided at one day after fuel removal. Only isotopes that meet a 1 $\mu Ci/cm^3$ threshold at one year after fuel removal are listed.

In cases where fuel particulate release is suspected, the interior of the unloaded TSC should be surveyed for fuel particulates, which will require removal prior to final disposition of the empty TSC and lid components. Residual fuel material will be removed, packaged and disposed of in accordance with the appropriate regulations. Similar surveys for, and removal of, fuel particulate materials have routinely been performed on spent fuel racks prior to their removal and off-site shipment.

The unloaded TSC can also qualify as a strong, tight container for other waste. In this case, the TSC can be filled, within weight limits, with other qualified waste, closed, and transported to a near-surface disposal site. Use of the TSC for this purpose can reduce decommissioning costs by avoiding decontamination, segmenting, and repackaging.

Table 15.2-1 Activity Concentration in the Concrete Cask Reinforcing Bar and Concrete

Isotope	Concentration (Ci/m³)			
	Concrete	Rebar	Lid Concrete	Lid Rebar
^{39}Ar [a]	1.53E-06	--	--	--
^{40}K [b]	3.76E-05	--	3.76E-05	--
^{41}Ca	1.00E-06	--	--	--
^{45}Ca	1.34E-04	--	5.65E-06	--
^{54}Mn	--	7.41E-05	--	--
^{55}Fe	9.01E-05	2.45E-02	3.79E-06	1.02E-03
^{59}Fe	--	6.37E-04	--	--
^{60}Co	6.83E-05	9.39E-04	3.07E-06	4.18E-05
^{63}Ni	--	3.97E-05	--	1.66E-06
^{65}Zn	6.81E-06	1.08E-05	--	--
^{133}Ba	1.41E-06	--	--	--
^{152}Eu	1.70E-04	--	7.06E-06	--
^{154}Eu	1.65E-05	--	--	--
Total	1.34E-03	2.71E-02	9.20E-05	1.14E-03

Table 15.2-2 Activity Concentration in the Concrete Cask Carbon Steel

Isotope	Concentration (Ci/m³)				
	Standoffs	Pedestal	Lid	Outlets	Liner
^{54}Mn	3.91E-03	1.71E-04	2.07E-05	1.36E-05	1.49E-03
^{55}Fe	2.75E-02	3.82E-03	3.05E-03	1.27E-03	2.26E-02
^{59}Fe	1.28E-03	--	--	--	8.37E-04
^{60}Co	1.08E-02	1.39E-03	6.56E-04	3.32E-04	6.03E-03
^{63}Ni	3.87E-06	--	--	--	1.48E-06
Total	4.47E-02	5.67E-03	3.89E-03	1.69E-03	3.17E-02

[a] Argon is a noble gas so this radionuclide will probably have escaped the concrete.

[b] Potassium-40 is a naturally occurring radionuclide. It is present in the concrete due to the inclusion of potassium as a trace constituent of the ordinary concrete; it is not present as a result of activation.

Table 15.2-3 Activity Concentration in the TSC/Basket

Isotope	Concentration (Ci/m^3)		
	TSC	Basket	Absorber
^{14}C	2.62E-06	--	--
^{46}Sc	--	--	2.43E-05
^{51}Cr	1.70E-02	--	--
^{54}Mn	2.08E-03	1.35E-01	3.55E-04
^{55}Fe	1.28E-02	6.38E-01	1.64E-03
^{58}Co	5.60E-03	--	--
^{59}Fe	5.98E-04	3.11E-02	--
^{59}Ni	2.11E-05	--	--
^{60}Co	4.12E-02	2.66E-01	2.31E-05
^{63}Ni	2.11E-03	1.34E-04	9.82E-05
^{65}Zn	2.91E-04	--	4.87E-03
^{75}Se	5.32E-05	--	--
^{87}Rb	1.93E-06	--	--
^{110m}Ag	9.53E-06	--	--
^{124}Sb	1.01E-04	--	--
^{134}Cs	8.18E-06	--	--
^{142}Ce	1.18E-05	--	--
^{152}Eu	1.75E-06	--	--
^{154}Eu	1.37E-06	--	--
^{181}W	8.97E-06	--	--
^{185}W	1.48E-04	--	--
Total	9.29E-02	1.11E+00	2.80E-02

15.3 References

1. 10 CFR 61, Code of Federal Regulations, "Licensing Requirements for Land Disposal of Radioactive Waste," US Government, Washington, DC.
2. ISG-2, "Fuel Retrievability," US Nuclear Regulatory Commission, Washington, DC, October 1998.
3. 10 CFR 72, Code of Federal Regulations, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste and Reactor-Related Greater Than Class C Waste," US Government, Washington, DC.