October 2023

Revision 23E

MAGNASTOR®

(**M**odular **A**dvanced **G**eneration **N**uclear **A**ll-purpose **STOR**age)

FINAL SAFETY ANALYSIS REPORT

Amendment 15
Supplement 01

NON-PROPRIETARY VERSION

Docket No. 72-1031

NAC INTERNATIONAL

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Enclosure 1

Proposed Certificate of Compliance Changes

for

MAGNASTOR® FSAR
Amendment 15 Supplement 1
Revision 23E

(Docket No 72-1031)

NAC International

October 2023

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PROPOSED APPENDIX A

TECHNICAL SPECIFICATIONS AND DESIGN FEATURES FOR THE MAGNASTOR® SYSTEM

AMENDMENT NO. 15

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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.
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	a) Assembly Average Burnup: Value calculated by averaging the burnup over the entire fuel region (UO_2) of an individual fuel assembly, including axial blankets, if present. Assembly average burnup represents the reactor record, nominal, value. The assembly average burnup is equal to the reactor record, nominal, energy production (MWd) over the life of the fuel assembly divided by the fuel assembly pre-irradiation heavy metal (U) mass in metric tons. b) Nonfuel Hardware Burnup: Equivalent accumulated irradiation exposure for activation evaluation.
COMPOSITE CLOSURE LID	A closure lid assembly, consisting of a stainless steel TRANSPORTABLE STORAGE CANISTER closure lid and a separate shield plate bolted together, that provides closure of a TRANSPORTABLE STORAGE CANISTER.
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. Closure for the CONCRETE CASK is provided by the CONCRETE CASK LID.

(continued)

CONCRETE CASK LID	The CONCRETE CASK LID is a thick concrete and steel closure for the CONCRETE CASK. The CONCRETE CASK LID precludes access to the TSC and provides radiation shielding.
DAMAGED FUEL	SPENT NUCLEAR FUEL (SNF) assembly that cannot fulfill its fuel-specific or system-related function. SNF 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 SNF assembly and the missing rods are not replaced by a solid stainless steel or zirconium 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: 3.1. Radiological and/or criticality safety is adversely affected (e.g., significantly changed rod pitch); or 3.2. The SNF assembly cannot be handled by normal means (i.e., crane and grapple); or 3.3. The SNF assembly contains fuel rods with damaged or missing grids, grid straps, and/or grid springs producing an unsupported length greater than 60 inches. Note: SNF assemblies with the following structural defects meet MAGNASTOR® system-related functional requirements and are, therefore, classified as undamaged: Assemblies with missing or damaged grids, grid straps and/or grid springs resulting in an unsupported fuel rod length not to exceed 60 inches. 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 SPENT 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. BWR fuel assemblies identified as subjected to CILC failure are not considered damaged fuel provided the fuel assemblies are channeled. 5. FUEL DEBRIS such as ruptured fuel rods, severed rods, loose fuel pellets, containers or structures that are supporting loose PWR or BWR fuel assembly parts.

(continued)

DAMAGED FUEL CAN (DFC)	A specially designed stainless steel screened can sized to hold PWR or BWR; UNDAMAGED FUEL, DAMAGED FUEL, and/or FUEL DEBRIS. The screens preclude the release of gross particulate from the DFC into the canister cavity. DFCs are only authorized for loading in specified locations of a DF Basket Assembly.
FUEL DEBRIS	FUEL DEBRIS is ruptured fuel rods, severed rods, loose fuel pellets, containers or structures that are supporting loose PWR or BWR fuel assembly parts.
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.
LOADING OPERATIONS	LOADING OPERATIONS include all licensed activities while a MAGNASTOR® SYSTEM is being loaded with fuel assemblies. LOADING OPERATIONS begin when the first assembly is placed in the TSC and end when the TSC is lowered into a CONCRETE CASK or MSO.
MAGNASTOR® SYSTEM (MAGNASTOR®)	The MAGNASTOR® (Modular Advanced Generation Nuclear All-purpose STORage) SYSTEM includes the components certified for the storage of spent fuel assemblies at an ISFSI. The MAGNASTOR® SYSTEM consists of a STORAGE CASK and a TSC. A MAGNASTOR® TRANSFER CASK (MTC), Passive MAGNASTOR® TRANSFER CASK (PMTC), or Lightweight MTC (LMTC) is provided and utilized to load and place a TSC in a CONCRETE CASK or MSO or to remove a TSC from a CONCRETE CASK or MSO.

(continued)

MSO (Metal Storage Overpack)	The MSO is the vertical storage module that receives, holds and protects the sealed TSC for storage at the ISFSI. The MSO passively provides the radiation shielding, structural protection, and heat dissipation capabilities for the safe storage of spent fuel in a TSC.
NONFUEL HARDWARE	NONFUEL HARDWARE is defined as reactor control components (RCCs), burnable poison absorber assemblies (BPAAs), guide tube plug devices (GTPDs), neutron sources/ neutron source assemblies (NSAs), hafnium absorber assemblies (HFRAs), instrument tube tie components, guide tube anchors or other similar devices, in-core instrument thimbles, steel rod inserts (used to displace water from lower section of guide tube), and components of these devices such as individual rods. All nonfuel hardware, with the exception of instrument tube tie components, guide tube anchors or other similar devices, and steel rod inserts, may be activated during in-core operations. RCCs are commonly referred to as rod cluster control assemblies (RCCAs), control rod assemblies (CRAs), or control element assemblies (CEAs). RCCs are primarily designed to provide reactor shutdown reactivity control, are inserted into the guide tubes of the assembly, and are typically employed for a significant number of operating cycles. Burnup poison absorber assemblies (BPAAs) are commonly referred to as burnup poison rod assemblies (BPRAs), but may have vendor specific nomenclature such as BPRA, Pyrex BPRA or WABA (wet annular burnable absorber). BPAAs are used to control reactivity of fresh fuel or high reactivity fuels and are commonly used for a single cycle, but may be used for multiple cycles. GTPDs are designed to block guide tube openings when no BPAA is employed and are commonly referred to as thimble plugs (TPs), thimble plug devices (TPDs), flow mixers (FMs), water displacement guide tube plugs, or vibration suppressor inserts. GTPDs may be employed for multiple cycles. NSAs are primary and secondary neutron sources used during reactor startup and may be used for multiple cycles. Integral fuel burnable absorbers, either integral to a fuel rod or as a substitution for a fuel rod, and fuel replacement rods (fueled, stainless steel, or zirconium alloy) are considered components of spent nuclear fuel (SNF) assemblies and are not considered to be nonfuel hardware.

(continued)

OPERABLE	A system, component, or device is OPERABLE when it is capable of performing its specified safety functions.
PARTIAL LENGTH SHIELD ASSEMBLIES (PLSA)	PWR fuel assemblies that contain stainless steel inserts in the bottom of each fuel rod, reducing the active fuel length, and a natural uranium blanket at the top of the active core. PLSAs are sometimes used in reactors to reduce fast neutron fluence reaching the pressure vessel wall.
SPENT NUCLEAR FUEL (SNF)	Irradiated fuel assemblies consisting of end-fittings, grids, fuel rods and integral hardware. Integral hardware for PWR assemblies primarily consists of guide/instrument tubes, but may contain integral fuel burnable absorbers, either integral to a fuel rod or as a fuel rod substitution, and fuel replacement rods (another fuel rod, stainless steel rod, or zirconium alloy rod). For BWR fuel, integral hardware may consist of water rods in various shapes, inert rods, fuel rod cluster dividers, and/or fuel assembly channels (optional). PWR SNF may contain NONFUEL HARDWARE.
STORAGE CASK	A STORAGE CASK is either a CONCRETE CASK with a CONCRETE CASK LID or an MSO.
STORAGE OPERATIONS	STORAGE OPERATIONS include all licensed activities that are performed at the ISFSI following placement of a STORAGE CASK containing a loaded TSC 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. Either an MTC, PMTC, or LMTC may be used.
TRANSFER OPERATIONS	TRANSFER OPERATIONS include all licensed activities involved in using an MTC, PMTC, or LMTC to move a loaded and sealed TSC from a CONCRETE CASK to another CONCRETE CASK or from an MSO to another MSO or from either a CONCRETE CASK or MSO to a TRANSPORT CASK.
TRANSPORT CASK	TRANSPORT CASK is the transport packaging system for the high-capacity MAGNASTOR System TSCs that consists of a MAGNATRAN transport cask body, a bolted closure lid, and energy-absorbing upper and lower (front and rear) impact limiters. The MAGNATRAN packaging is used to transport a TSC containing spent fuel assemblies or Greater Than Class C (GTCC) waste.

(continued)

TRANSPORT OPERATIONS	TRANSPORT OPERATIONS include all licensed activities performed on a loaded MAGNASTOR® STORAGE CASK when it is being moved to and from its designated location on the ISFSI. TRANSPORT OPERATIONS begin when the loaded STORAGE CASK is placed on or lifted by a transporter and end when the STORAGE CASK is set down in its storage position on the ISFSI pad.
TRANSPORTABLE STORAGE CANISTER (TSC)	The TRANSPORTABLE STORAGE CANISTER (TSC) is the welded container consisting of a basket in a weldment composed of a cylindrical shell welded to a baseplate. The TSC includes a closure lid, a shield plate (optional), a closure ring, and redundant port covers at the vent and the drain ports. The closure lid is welded to the TSC shell and the closure ring is welded to the closure lid and the TSC shell. The port covers are welded to the closure lid. 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 or MSO; 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 Part 50 facility.
UNDAMAGED FUEL	SNF that can meet all fuel specific and system-related functions. UNDAMAGED FUEL is SNF 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 cannot 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 TSC. UNLOADING OPERATIONS begin with the movement of the TSC from a CONCRETE CASK or MSO into 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 <u>not</u> 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 AND B.2 Perform Action B.2	12 hours 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 AND B.2 Complete action B.2	6 hours 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, helium backfill and TSC transfer times shall be met as appropriate to the fuel content type and heat load:

1. The time durations covering the beginning of canister draining through completion of vacuum drying and helium backfill, minimum helium backfill times, and TSC transfer times shall meet the following:

A. PWR TSC Transfer Using MTC or LMTC Reduced Helium Backfill Time

Heat Load (kW)	Maximum Vacuum Time Limit (hours)	Minimum Helium Backfill Time (hours)	Maximum TSC Transfer Time (hours)
≤ 20	No limit	0	600
≤ 25	50	7	70.5
≤ 30	19	7	8
≤ 35.5	15	7	8

B. PWR Using MTC or LMTC with Maximum TSC Transfer

Heat Load (kW)	Maximum Vacuum Time Limit (hours)	Minimum Helium Backfill Time (hours)	Maximum TSC Transfer Time (hours)
≤ 25	No limit	24	48
≤ 30	32	24	22
≤ 35.5	24	24	22

C. BWR Using MTC or LMTC with 8 Hours TSC Transfer

Heat Load (kW)	Maximum Vacuum Time Limit (hours)	Minimum Helium Backfill Time (hours)	Maximum TSC Transfer Time (hours)
≤ 25	No limit	0	8
≤ 29	34	6	8
≤ 30	31	6	8
≤ 33	26	6	8

(continued)

D. BWR Using MTC or LMTC with Maximum TSC Transfer

Heat Load (kW)	Maximum Vacuum Time Limit (hours)	Minimum Helium Backfill Time (hours)	Maximum TSC Transfer Time (hours)
≤ 25	No limit	24	65
≤ 29	No limit	24	32
≤ 30	44	24	32
≤ 33	33	24	32

E. PWR TSC Transfer Using PMTC

Heat Load (kW)	Maximum Vacuum Time Limit (hours)	Minimum Helium Backfill Time (hours)	Maximum TSC Transfer Time (hours)
≤ 20	No limit	0	600
≤ 25	54	0	600
≤ 30	32	0	600
≤ 35.5	24	0	600

Note: CE16H2 fuel type is limited to the use of the ≤ 35.5 kW operation times. Lower heat loads with increased operating times are not evaluated and are therefore not applicable to CE16H2.

F. PWR TSC Transfer Using LMTC

Heat Load (HL) (kW)	Maximum Vacuum Time Limit (hours)	Minimum Helium Backfill Time (hours)	Maximum TSC Transfer Time (hours)
35.5<HL ≤42.5	19	12	16
42.5<HL ≤53.0	27	12	22

G. BWR TSC Transfer Using LMTC

Heat Load (HL) (kW)	Maximum Vacuum Time Limit (hours)	Minimum Helium Backfill Time (hours)	Maximum TSC Transfer Time (hours)
33< HL ≤42.0	27	12	22
42.0<HL ≤46.0	40	12	22

(continued)

H. BWR DF TSC Transfer Using LMTC

Heat Load (kW)	Maximum Vacuum Time Limit (hours)	Minimum Helium Backfill Time (hours)	Maximum TSC Transfer Time (hours)
≤41.0	24	12	22
41.0<HL ≤46.0	40	12	22

2. The time duration from the end of TSC annulus cooling, either by 24 hours in the pool or by the annulus circulating water system, through completion of vacuum drying and helium backfill using a MTC shall not exceed the following:

	Heat Load (HL) kW	Time Limit (hours)
PWR	35.5	11
BWR	33	16
PWR (LMTC)	35.5<HL≤42.5	9
PWR (LMTC)	42.5<HL≤53.0	20
BWR (LMTC)	33<HL≤42.0	14
BWR (LMTC)	42<HL≤46.0	28
BWR-DF (LMTC)	≤41	13
BWR-DF (LMTC)	41<HL≤46.0	13

Note: For PWR TSC's with heat loads ≤35.5 kW using the MTC or LMTC Transfer Cask, the approved minimum helium backfill and transfer times shown in Table 1.B shall be used for operations for second and subsequent vacuum drying cycles.

For BWR TSC's with heat loads ≤33.0 kW using the MTC or LMTC Transfer Cask, the approved minimum helium backfill and transfer times shown in Table 1.D shall be used for operations for second and subsequent vacuum drying cycles.

For PWR TSCs with heat loads > 35.5 kW and ≤ 42.5kW the approved minimum helium backfill and transfer times shown in Tables 1.F are applicable for second and subsequent vacuum drying cycles.

(continued)

Note: (continued)

For PWR TSCs with heat loads > 42.5 kW and ≤ 53.0 kW the approved minimum helium backfill and transfer times shown in Tables 1.F are applicable for second and subsequent vacuum drying cycles.

For BWR and BWR-DF TSCs with heat loads > 33.0 kW and ≤ 41.0 kW the approved minimum helium backfill and transfer times shown in Tables 1.G and 1.H respectively are applicable for second and subsequent vacuum drying cycles.

For BWR and BWR-DF TSCs with heat loads > 41.0 kW and ≤ 46.0 kW the approved minimum helium backfill and transfer times shown in Tables 1.G and 1.H respectively are applicable for second and subsequent vacuum drying cycles.

3. The time duration from the end of TSC annulus cooling, either by 24 hours in the pool or by the annulus circulating water system, through completion of vacuum drying and helium backfill using a PMTC shall not exceed the following:

	Heat Load	**Time Limit (hours)**
PWR	≤ 25	34
PWR	≤ 30	17
PWR	≤ 35.5	14

Note: The helium backfill times and TSC transfer times provided in Table 1.E shall be used for operations following the second or subsequent vacuum drying cycles using the PMTC.

CE16H2 fuel type is limited to the use of the ≤ 35.5 kW operating time limit. Lower heat loads with increased operating times are not evaluated and are therefore not applicable to CE16H2.

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 A3-1, is reached.	Once, prior to TRANSPORT OPERATIONS.

Table A3-1 Helium Mass per Unit Volume for MAGNASTOR® TSCs

Fuel Type	Transfer Cask Type	Heat Load (HL) (kW)	Helium Density (g/liter)
PWR	MTC or LMTC	≤35.5	0.694 – 0.802
	LMTC	35.5<HL≤53.0	0.760 – 0.802
	PMTC	≤30.0	0.694 – 0.802
		30.0<HL≤35.5	0.760 – 0.802
BWR	MTC or LMTC	≤33.0	0.704 – 0.814
	LMTC	33.0<HL≤46.0	0.760 – 0.802

3.1 MAGNASTOR® SYSTEM Integrity

3.1.2 STORAGE CASK Heat Removal System

LCO 3.1.2 The STORAGE 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. STORAGE CASK Heat Removal System inoperable.	A.1 Ensure adequate heat removal to prevent exceeding short-term temperature limits.	Immediately
	<u>AND</u>	
	A.2 Restore STORAGE 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 STORAGE CASK air outlet temperature and ISFSI ambient temperature indicates that the STORAGE CASK Heat Removal System is operable in accordance with the FSAR thermal evaluation.	24 hours
	<u>OR</u>	
	Visually verify all STORAGE 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 B2-4. 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
	<u>AND</u>	
	A.2 Suspend positive reactivity additions.	Immediately
	<u>AND</u>	
	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, UNLOADING OPERATIONS or adding/recirculating water through the TSC. <u>AND</u> Every 72 hours thereafter while the TSC contains water and is submerged in the spent fuel pool.

3.3 MAGNASTOR® SYSTEM Radiation Protection

3.3.1 STORAGE CASK Maximum Surface Dose Rate

LCO 3.3.1 The maximum surface dose rates for the STORAGE CASK (Reference Figure A3-1) or (Reference Figure A3-2), shall not exceed the following limits:

a. PWR and BWR – 125 mrem/hour (neutron + gamma) and 5 mrem/hour neutron on the vertical surfaces (at locations specified on Figures A3-1 and A3-2); and

b. PWR and BWR – 1100 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. STORAGE CASK maximum surface dose rate limits not met	A.1 Administratively verify correct fuel loading AND	24 hours
	A.2 Perform analysis to verify compliance with the ISFSI radiation protection requirements of 10 CFR Part 20 and 10 CFR Part 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 Part 20 and 10 CFR Part 72 are not exceeded	60 days

(continued)

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.3.1.1	Verify maximum surface dose rates of STORAGE CASK loaded with a TSC containing fuel assemblies are within limits. Dose rates shall be measured at the locations shown in Figures A3-1 or A3-2.	Prior to start of STORAGE OPERATIONS of each loaded STORAGE CASK before or after placement on the ISFSI pad.

Figure A3-1 STORAGE (CONCRETE) CASK Surface Dose Rate Measurement

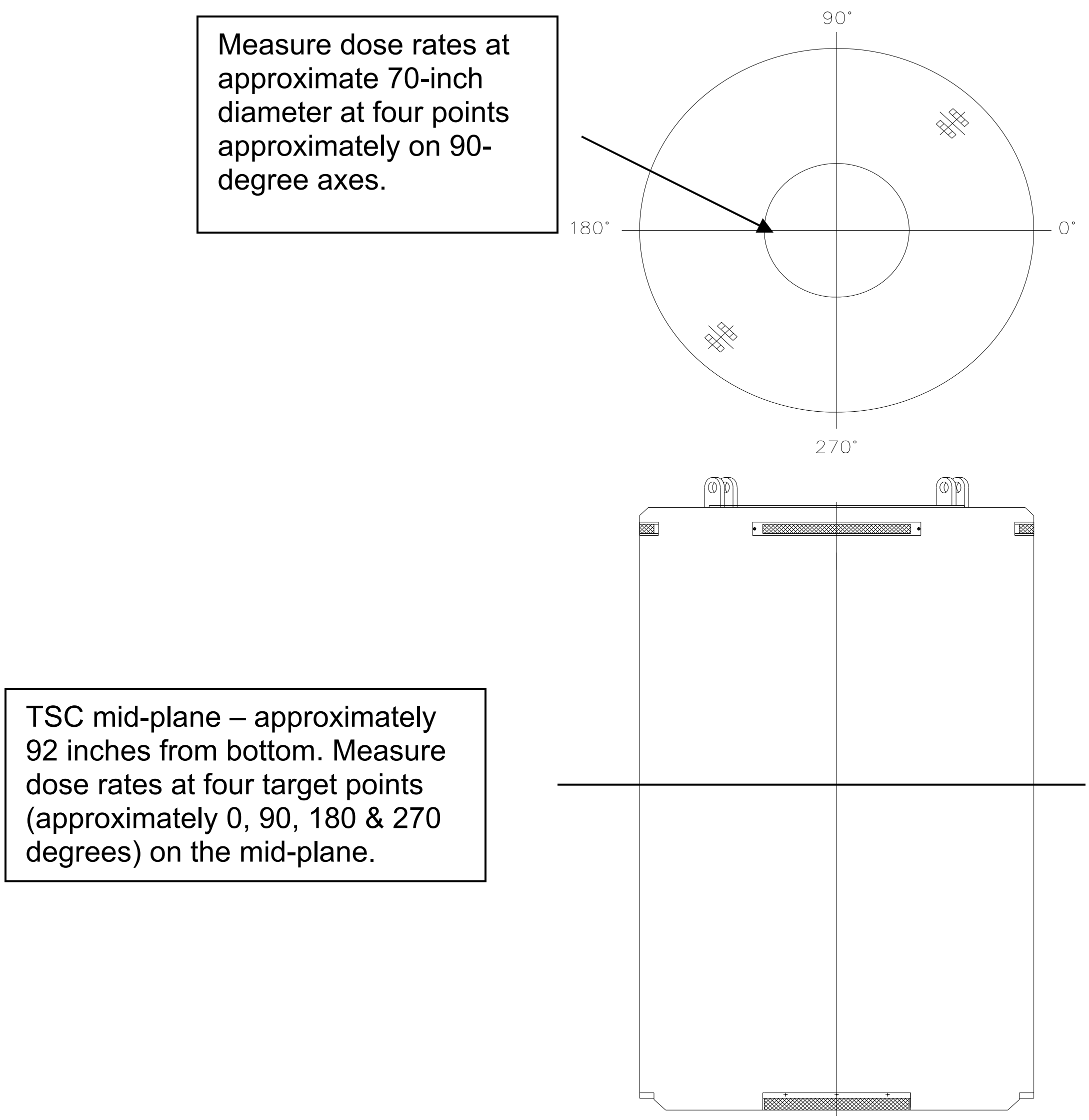
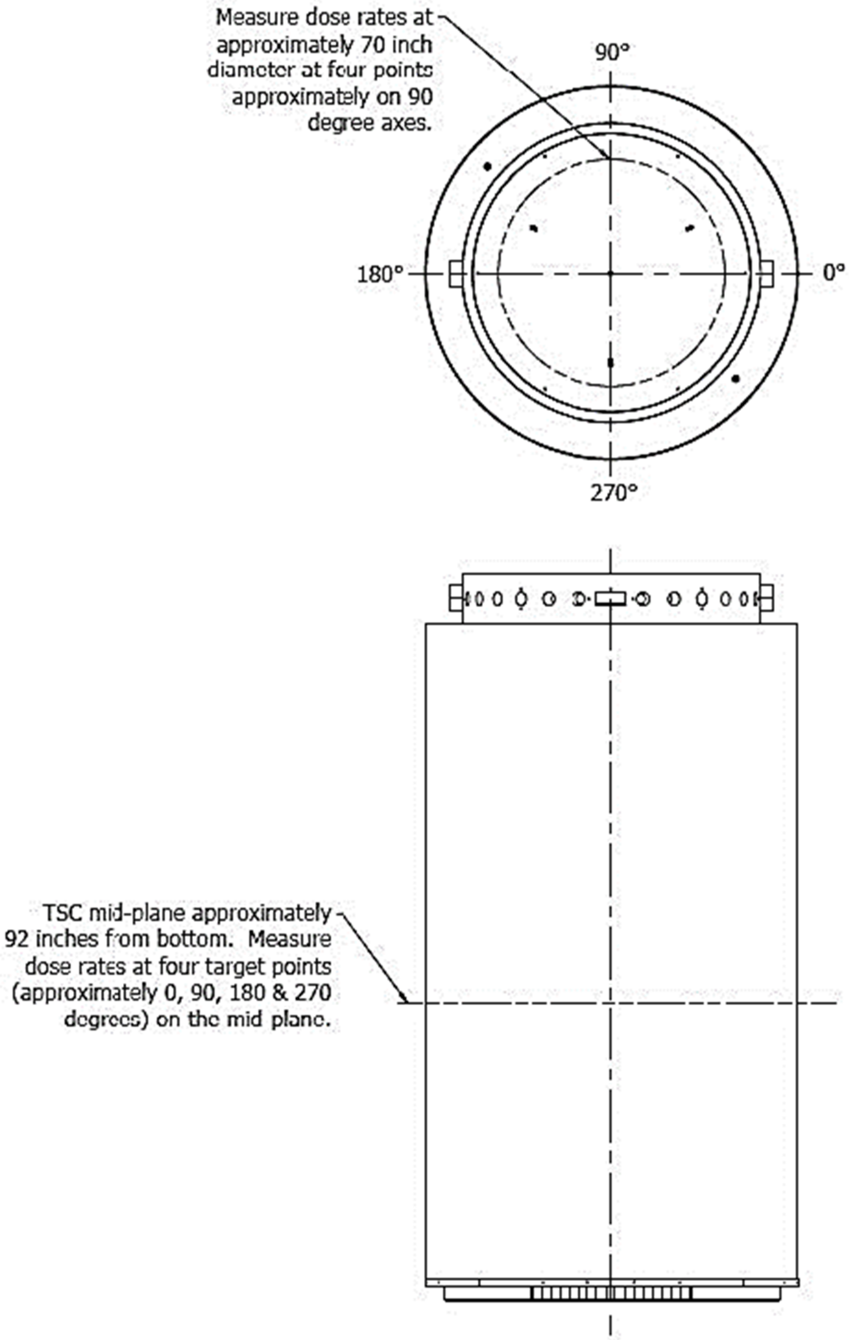


Figure A3-2 MSO Surface Dose Rate Measurement



3.3 MAGNASTOR SYSTEM Radiation Protection

3.3.2 TSC Surface Contamination

LCO 3.3.2 Removable contamination on the exterior surfaces of the TSC shall not exceed:

a. 10,000 dpm/100 cm^2 from beta and gamma sources; and

b. 100 dpm/100 cm^2 from alpha sources.

APPLICABILITY: During LOADING OPERATIONS

ACTIONS

--NOTE--
Separate Condition entry is allowed for each MAGNASTOR® SYSTEM.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. TSC removable surface contamination limits not met	A.1 Restore TSC removable surface contamination to within limits	Prior to TRANSPORT OPERATIONS

(continued)

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.3.2	Verify by either direct or indirect methods that the removable contamination on the exterior surfaces of the TSC is within limits	Once, prior to TRANSPORT OPERATIONS

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
	0.030	0.0225		0.0334	0.025
	0.027	0.020		0.03	0.0223
Borated MMC	0.036	0.027	90	0.04	0.03
	0.030	0.0225		0.0334	0.025
	0.027	0.020		0.03	0.0223
Boral	0.036	0.027	75	0.048	0.036
	0.030	0.0225		0.04	0.030
	0.027	0.020		0.036	0.0267

Enrichment/soluble boron limits for PWR systems and enrichment limits for BWR systems are incorporated in Appendix B Section 2.0.

b) Acceptance and qualification testing of borated aluminum alloy and borated MMC 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. Acceptance testing of Boral shall be in accordance with Section 10.1.6.4.8. 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 outer diagonal dimension

PWR basket — 13.08 inches
BWR basket — 8.72 inches
Note: Not applicable to DFC locations of the DF Basket Assembly.

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.

(continued)

4.1.3 Transfer Cask Shielding

For the MTC and PMTC Transfer Casks, 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 carbon steel or stainless steel and 3.2 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 (not including doors or vent shielding).

For the LMTC Transfer Cask the nominal configuration transfer cask radial bulk shielding (i.e., shielding integral to the transfer cask, excludes supplemental shielding) is variable to permit maximizing the LMTC shielding configuration to take advantage of the Site's architecture while complying with the host Site's ALARA evaluation as required in Section 5.5 - Radiation Protection Program. This design and evaluation approach permits the quantity of shielding around the body of the transfer cask to be maximized for a given length and weight of fuel specific to the host Site.

4.1.4 TSC Confinement Integrity

The TSC shell, bottom plate, all confinement welds, and the COMPOSITE CLOSURE LID shall be fabrication helium leak-tested in accordance with ANSI N14.5 to leaktight criterion.

The closure lid shall be helium leak-tested during fabrication (in accordance with ANSI N14.5 to leaktight criterion) if it is constructed with a lid thickness less than 9 inches (nominal).

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 concrete used in the construction of the CONCRETE CASK LID, at minimum, shall be of a commercial grade ready-mix type that can develop a density of 140 pcf. The mix and batching should meet the purchaser's requirement of unit weight (i.e., density) and any additional purchaser indicated attributes (e.g., air content), as allowed by ASTM C94.

The unit weight (i.e., density) of the concrete in the CONCRETE CASK LID can be verified by either test method ASTM C138 or an approved shop fabrication procedure by following the basic equation of ρ=W/V. The shop procedure shall include steps to weigh the lid before and after concrete placement and in calculating the actual volume (V) of the cavity to be filled with a record of the weight (W) of concrete placed into the cavity.

The CONCRETE CASK LID concrete placement shall be in a dry and clean cavity or form with procedures and equipment that ensure the concrete placed is thoroughly consolidated and worked around any reinforcement and/or embedded fixtures and into the corners of the cavity or form.

The CONCRETE CASK LID concrete shall be protected from the environment during curing to minimize development of cracks by one or more of various methods such as moist cure or liquid membrane forming chemicals. Type II Portland cement may be substituted by an alternate cement type for the CONCRETE CASK LID if the density requirement can be met.

The American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code), 2001 Edition with Addenda through 2003, Section III, Subsection NF, is the governing Code for the design of the MSO. The applicable standards of the American Society for Testing and Materials (ASTM) govern material procurement and the American Welding Society (AWS) D1.1 or ASME Code Section VIII govern fabrication of the MSO.

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.

(continued)

4.2.2 Construction/Fabrication Alternatives to Codes, Standards, and Criteria

Proposed alternatives to ASME Code, Section III, 2001 Edition with Addenda through 2003, other than the alternatives listed 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.

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 76ºF is the maximum average yearly temperature. The three-day average ambient temperature shall be ≤106ºF.

b. The allowed temperature extremes, averaged over a three-day period, shall be ≥–40ºF and ≤133ºF.

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(s) of the cask handling equipment used to move the loaded STORAGE CASK or MSO onto or from the ISFSI site contains a total of 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.

(Continued)

f. The TRANSFER CASK shall not be operated and used when surrounding air temperature is < 0ºF. This limit is NOT applicable to the stainless steel MTC or PMTC.

g. The STORAGE CASK shall not be lifted by the lifting lugs with surrounding air temperatures < 0ºF.

h. Loaded STORAGE CASK lifting height limit ≤24 inches.

i. The maximum design basis earthquake acceleration of 0.37g in the horizontal direction (without cask sliding) and 0.25g in the vertical direction at the ISFSI pad top surface do not result in cask tip-over.

   For design basis earthquake accelerations up to and greater than 0.37g in the horizontal direction and 0.25g in the vertical direction at the ISFSI pad top surface, site-specific cask sliding is permitted with validation by the cask user that the cask does not slide off the pad and that the g-load resulting from the collision of two sliding casks remains bounded by the cask tip-over accident condition analysis presented in Chapter 3 of the FSAR.

   An alternative to crediting site-specific cask sliding for design basis earthquake accelerations up to and greater than 0.37g in the horizontal direction and 0.25g in the vertical direction at the ISFSI pad top surface, the use of the MAGNASTOR® system is permitted provided the ISFSI pad has bollards and the cask user validates that the cask does not overturn, g-loads resulting from the cask contacting the bollard is bounded by the cask tip-over accident condition presented in Chapter 3 of the FSAR, and the ISFSI pad and bollards are designed, fabricated and installed such that they are capable of handling the combined loading of the design basis earthquake and any contact between the bollard and cask during the design basis earthquake.

j. In cases where the TRANSFER CASK or STORAGE CASK containing the loaded TSC must be tilted or down-ended to clear an obstruction (e.g., a low door opening) during on-site transport operations, a site specific safety evaluation of the system in the non-vertical orientation is required in accordance with 10 CFR 72.212 to demonstrate compliance with the thermal limits of ISG-11.

(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 Part 50 licensed facility or for utilizing an external crane structure integral to a 10 CFR Part 50 licensed facility.

Movements of the TRANSFER CASK and TSC outside of a 10 CFR Part 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 Part 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 A4-1 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 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 fuel 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”;

(Continued)

Table A4-1 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

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 The MAGNASTOR® SYSTEM does not create any radioactive materials or have any radioactive waste treatment systems. Therefore, specific operating procedures for the control of radioactive effluents are not required. LCO 3.3.2, TSC Surface Contamination, provides assurance that excessive surface contamination is not available for release as a radioactive effluent.

5.1.3 This program includes an environmental monitoring program. Each general license user may incorporate MAGNASTOR® SYSTEM operations into their environmental monitoring program for 10 CFR Part 50 operations.

5.2 TSC Loading, Unloading, and Preparation Program

A program shall be established to implement the FSAR, Chapter 9 general procedural guidance for loading fuel and components into the TSC, unloading fuel and components from the TSC, and preparing the TSC and STORAGE 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 Part 50 structure. The program requirements for UNLOADING OPERATIONS shall be maintained until all spent fuel is removed from the spent fuel pool and TRANSPORT OPERATIONS have been completed on the last STORAGE CASK. The program shall provide for evaluation and control of the following requirements during the applicable operation:

a. Verify that no TRANSFER CASK handling or STORAGE CASK handling using the lifting lugs occurs when the ambient temperature is < 0°F. This limit is NOT applicable to the stainless steel MTC or PMTC.

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, including TRANSFER OPERATIONS, and that the TSC is adequately dry. For fuel with burnup > 45 GWd/MTU, limit cooling cycles to ≤ 10 for temperature changes greater than 65ºC.

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 for the MTC or 9.4.1 for the PMTC.

(continued)

f. Verify that the time to complete the transfer of the TSC from the TRANSFER CASK to the CONCRETE CASK or MSO and from a CONCRETE CASK to another CONCRETE CASK and from an MSO to another MSO assures that the fuel cladding temperature limit of 400°C is not exceeded.

g. The surface dose rates of the STORAGE CASK are adequate to allow proper storage and to assure consistency with the offsite dose analysis.

h. The equipment used to move the loaded STORAGE CASK onto or from the ISFSI site contains no more than 50 gallons of fuel.

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 STORAGE CASK using devices that are integral to a structure governed by 10 CFR Part 50 regulations, 10 CFR Part 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 STORAGE 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 STORAGE 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 Part 50 radiation protection program appropriately addresses dry storage cask loading and unloading, and ISFSI operations, including transport of the loaded STORAGE CASK outside of facilities governed by 10 CFR Part 50 as applicable. 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)(5)(iii), 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 Each user shall establish limits on the surface contamination of the STORAGE 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 Part 50 structure. Surface contamination limits for the TSC prior to placement in STORAGE OPERATIONS shall meet the limits established in LCO 3.3.2.

5.5.5 The nominal configuration transfer cask radial bulk shielding (i.e., shielding integral to the transfer cask, excludes supplemental shielding) is variable to permit maximizing the LMTC shielding configuration to take advantage of the Site's architecture while complying with the host Site's ALARA evaluation as required in Section 5.5 - Radiation Protection Program. This design and evaluation approach permits the quantity of shielding around the body of the transfer cask to be maximized for a given length and weight of fuel specific to the host Site.

5.5.6 Supplemental shielding used, credited, or otherwise incorporated into the analysis as the basis of complying with the LMTC surface dose rate analysis in section 5.5.5 shall be referenced in the licensee's evaluation and required for use. This shall include material, thickness, specific shape and configuration and location the Supplemental Shielding was used in the evaluation.

5.5.7 Supplemental shielding used for the LMTC dose rate analysis as described in 5.5.6 shall be implemented by the licensee for the condition(s) it was evaluated for.

5.5.8 If draining the LMTC Neutron Shield is required to meet the plant architectural limits, the LMTC Neutron Shield shall be verified to be filled after completion of the critical lift. If TSC cavity draining or transfer cask/dry storage cask annulus draining operations, as applicable, are initiated after the completion of the critical lift, the LMTC Neutron Shield shall be verified to be filled before these draining operations are initiated and continually monitored during the first five minutes of the draining evolution to ensure the Neutron Shield remains filled. Observation of water level in the expansion tank or some other means can be used to verify compliance to this requirement.

5.6 [Deleted]

5.7 Training Program

A training program for the MAGNASTOR® system shall be developed under the general licensee's systematic approach to training (SAT). Training modules shall include comprehensive instructions for the operation and maintenance of the MAGNASTOR® system and the independent spent fuel storage installation (ISFSI) as applicable to the status of ISFSI operations.

(Continued)

5.8 Preoperational Testing and Training Exercises

A dry run training exercise on loading, closure, handling, unloading, and transfer of the MAGNASTOR® system shall be conducted by the licensee prior to the first use of the system to load spent fuel assemblies. The training exercise shall not be conducted with spent fuel in the TSC. The dry run may be performed in an alternate step sequence from the actual procedures, but all steps must be performed. The dry run shall include, but is not limited to, the following:

a. Moving the STORAGE CASK or MSO into its designated loading area
b. Moving the TRANSFER CASK containing the empty TSC into the spent fuel pool
c. Loading one or more dummy fuel assemblies into the TSC, including independent verification
d. Selection and verification of fuel assemblies to ensure conformance with appropriate loading configuration requirements
e. Installing the closure lid
f. Removal of the TRANSFER CASK from the spent fuel pool
g. Closing and sealing of the TSC to demonstrate pressure testing, vacuum drying, helium backfilling, welding, weld inspection and documentation, and leak testing
h. TRANSFER CASK movement through the designated load path
i. TRANSFER CASK installation on the CONCRETE CASK or MSO
j. Transfer of the TSC to the CONCRETE CASK or MSO
k. CONCRETE CASK LID or MSO lid assembly installation
l. Transport of the STOREAGE CASK to the ISFSI
m. TSC removal from the STORAGE CASK
n. TSC unloading, including reflooding and weld removal or cutting

Appropriate mock-up fixtures may be used to demonstrate and/or to qualify procedures, processes or personnel in welding, weld inspection, vacuum drying, helium backfilling, leak testing and weld removal or cutting. Previously completed and documented demonstrations of specific processes and procedures may be used, as applicable, for implementation of the MAGNASTOR® SYSTEM at a specific loading facility.

APPENDIX B

PROPOSED APPROVED CONTENTS
FOR THE MAGNASTOR SYSTEM

AMENDMENT NO. 15

Appendix B

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1.0 FUEL SPECIFICATIONS AND LOADING CONDITIONS

The MAGNASTOR SYSTEM is designed to safely store up to 37 undamaged PWR fuel assemblies in the 37 PWR Basket Assembly or up to 89 undamaged BWR fuel assemblies in the BWR Basket Assembly. The PWR DF basket has a capacity of up to 37 undamaged PWR fuel assemblies including 4 DFC locations. The BWR DF basket has a capacity of up to 81 undamaged BWR fuel assemblies including 12 DFC locations. Each DFC may contain an undamaged fuel assembly, a damaged fuel assembly, or FUEL DEBRIS equivalent to one fuel assembly. FUEL DEBRIS is included in the definition of DAMAGED FUEL (Appendix A, Section 1.1). UNDAMAGED FUEL assemblies may be placed directly in the DFC locations of a DF Basket Assembly without the use of a DFC.

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 PWR FUEL ASSEMBLIES, DAMAGED PWR FUEL ASSEMBLIES, PWR FUEL DEBRIS (PWR DAMAGED FUEL), UNDAMAGED BWR FUEL ASSEMBLIES, DAMAGED BWR FUEL ASSEMBLIES, BWR FUEL DEBRIS (BWR DAMAGED FUEL), and NONFUEL HARDWARE meeting the limits specified in this section may be stored in the MAGNASTOR SYSTEM.

Table B2-1 TSC with PWR Fuel Limits

I. TSC with PWR Basket Assembly and PWR DF Basket Assembly

A. Allowable Contents

1. Uranium PWR UNDAMAGED SNF ASSEMBLIES and DAMAGED FUEL (PWR DAMAGED SNF ASSEMBLIES or PWR FUEL DEBRIS) that meet the following specifications:

a. Cladding Type:	Zirconium-based alloy.
b. Physical Characteristics	The physical characteristics of the different PWR SNF ASSEMBLIES are defined in Table B2-3.
c. Maximum Enrichment	The fuel type specific maximum enrichments as a function of neutron absorber sheet areal density at various minimum soluble boron levels are defined in Table B2-4. For variable enrichment SNF assemblies, maximum SNF enrichments represent peak rod/pellet enrichments.
d. Decay Heat per SNF Assembly	Load pattern dependent allowed heat loads for each fuel storage location illustrated in Figure B2-1 are shown in Table B2-2. Fuel assembly and non-fuel hardware heat load to be evaluated based on discharged, or bounding, depletion and fuel assembly characteristics and total must be less than or equal to listed limit. Input into this heat load calculation is the SNF assembly average burnup (maximum for groups of assemblies) and assembly average enrichment (minimum for groups of assemblies).
e. Nominal Fresh SNF Assy: Length (in)	≤ 178.3
f. Nominal Fresh SNF Assembly Width (in.):	≤ 8.54
g. Weight Per Storage location (lbs.)	≤ 1,765, including SNF Assembly, NONFUEL HARDWARE, and fuel spacer ≤ 1,814, including SNF Assembly, NONFUEL HARDWARE, DFC and fuel spacer in a DF location
h. Non-DF Basket -Total Canister Contents Weight (lbs.)	≤ 62,160, including SNF Assemblies, NONFUEL HARDWARE, and fuel spacers
i. DF Basket – Total Canister Contents Weight (lbs.)	≤ 61,184, including SNF Assemblies, NONFUEL HARDWARE, DFCs and fuel spacers
j. Total Canister Weight including Contents (lbs.)	≤ 104,500 (nominal TSC weight plus maximum contents)

(continued)

Table B2-1 TSC with PWR Fuel Limits (continued)

B. Quantity per TSC: Up to a total of 37 PWR UNDAMAGED SNF ASSEMBLIES including up to four (4) DFCs containing PWR UNDAMAGED SNF ASSEMBLIES, PWR DAMAGED SNF ASSEMBLIES, and/or PWR FUEL DEBRIS. DFCs may only be loaded in the DFC basket and are limited to locations No. 4, 8, 30 and 34, as shown on Figure B2-1.

C. The contents of a DFC must be less than, or equivalent to, one PWR UNDAMAGED SNF ASSEMBLY. PWR SNF ASSEMBLIES loaded in a DFC shall not contain NONFUEL HARDWARE with the exception of instrument tube tie components, guide tube anchors or steel inserts, and similar devices.

D. SNF assembly lattices not containing the nominal number of fuel rods specified in Table B2-3 must contain solid filler rods that displace a volume equal to, or greater than, that of the fuel rod that the filler rod replaces. An unenriched rod may be used as a replacement rod to return a fuel assembly to an undamaged condition. SNF assemblies may have stainless steel rods inserted to displace guide tube “dashpot” water.

E. PWR UNDAMAGED SNF ASSEMBLIES not loaded in a DFC may contain NONFUEL HARDWARE. SNF assembly lattices not containing the nominal number of fuel rods specified in Table B2-3 must contain solid filler rods that displace a volume equal to, or greater than, that of the fuel rod that the filler rod replaces. SNF assemblies may have stainless steel rods inserted to displace guide tube “dashpot” water. NONFUEL HARDWARE cool times shall be in accordance with Tables B2-5, B2-6, and B2-7. Alternatively, the ^{60}Co curie limits in Tables B2-6 and B2-7 may be used to establish site-specific NONFUEL HARDWARE constraints. Alternatively, the ^{60}Co curie limits in Tables B2-6 and B2-7 may be used to establish site-specific NONFUEL HARDWARE constraints.

F. Spacers may be used in a TSC to axially position PWR UNDAMAGED SNF ASSEMBLIES, and DFCs to facilitate handling and operation.

G. Unenriched fuel assemblies and unirradiated (i.e., not inserted in-core) fuel assemblies are not authorized for loading. Unenriched end blankets are permitted, provided that the nominal length of the end blanket is not greater than six (6) inches. Low enriched and annular fuel pellet end blankets are permitted without a restriction on length.”

H. RCCs are limited to fuel cell location, minimum cool time, and maximum exposure based on load pattern and fuel type:

Minimum Cool Time (years)	Maximum Exposure (GWd/MTU)	Fuel Type	Load Pattern	Allowed Fuel Storage Locations (per Figure B2-1)
1.75	75	BW15x15	E, F, G, H	A, B, C
10	180	All	All	A
2.5		WE14x14	A, C	A
5.0		CE16x16	A, C	A
14	270	All	All	A
3.75	315	BW15x15	E, F, G, H	A, B, C
20	360	All	All	A

(continued)

Table B2-1 TSC with PWR Fuel Limits (continued)

I. One Neutron Source, or Neutron Source Assembly (NSA) is permitted to be loaded in a TSC in fuel storage locations No. 11, 12, 13, 18, 19, 20, 25, 26 or 27 (Figure B2-1). Neutron source assemblies may contain source rods attached to hardware similar in configuration to guide tube plug devices (thimble plugs) and burnable absorbers, in addition to containing burnable poison rodlets and/or thimble plug rodlets. For NSAs containing absorber rodlets, the BPAA cool time and burnup/exposure or hardware ^{60}Co curie limit listed in Table B2-6 are applied to the neutron sources. NSAs having only thimble plug rodlets require the thimble plug restriction in Table B2-7 to be applied. Combination NSAs, containing both thimble plug and burnable absorber rodlets must apply the more limiting of the two minimum cool time/curie limit.

J. Fuel assemblies may contain any number of unirradiated (i.e., not inserted in-core) nonfuel solid filler fuel replacement rods. Steel rods are limited to a 32.5 GWd/MTU maximum burnup/exposure. In-core activated stainless steel rods are limited to minimum cool time, quantity and fuel storage locations:

Fuel Storage Location (per Figure B2-1)	Number of Assemblies per Cask	Maximum number of Rods per Assembly and Minimum Cool Time
Any	1	Maximum of 5 rods

K. Fuel assemblies may contain an HFRA at a maximum burnup/exposure of 4.0 GWd/MTU and a minimum cool time of 16 years.

L. PLSA assemblies are permitted for loading provided they are limited to Region A (center 9 basket storage locations) at a maximum assembly average burnup of 40 GWd/MTU, a minimum assembly average enrichment of 1.2 wt% U-235 and a minimum cool time of 6.5 years.

Table B2-2 PWR Fuel Loading Patterns

<table>
<tr><th rowspan="2">Storage Location</th><th colspan="13">Loading Pattern and Maximum Heat Load per Storage Location (W) (1)</th></tr>
<tr><th>A</th><th>B</th><th>C</th><th>E</th><th>F</th><th>G</th><th>H</th><th>I</th><th>J</th><th>K</th><th>L</th><th>M</th><th>N</th></tr>
<tr><td>A1</td><td rowspan="11">959</td><td rowspan="3">922</td><td rowspan="3">513</td><td>425</td><td>350</td><td>350</td><td>300</td><td rowspan="11">1380(3)</td><td>600</td><td>600</td><td>800</td><td>500</td><td>N/A(5)</td></tr>
<tr><td>A2</td><td>800</td><td>800</td><td>800</td><td rowspan="2">800</td><td rowspan="2">400</td><td rowspan="2">400</td><td>500</td><td>400</td><td rowspan="3">2000</td></tr>
<tr><td>A3</td><td>425</td><td>350</td><td>350</td><td>800</td><td>500</td></tr>
<tr><td>B1</td><td rowspan="3">1,200</td><td>1,800</td><td>1,300</td><td>1,000</td><td>2,500</td><td>2,000</td><td>1250</td><td>700</td><td rowspan="3">1025</td><td>1200</td></tr>
<tr><td>B2</td><td rowspan="2">1,300</td><td>1,100</td><td>900</td><td>600</td><td>800</td><td rowspan="2">800</td><td rowspan="2">1900</td><td rowspan="2">750</td><td rowspan="2">N/A(5)</td></tr>
<tr><td>B3</td><td>250</td><td>250</td><td>700</td><td>700</td></tr>
<tr><td>C1</td><td rowspan="5">800</td><td rowspan="5">830</td><td>950</td><td>1,800</td><td>800</td><td>800</td><td>1250</td><td>800</td><td rowspan="5">1800</td><td>1600</td><td>2750</td></tr>
<tr><td>C2</td><td>900</td><td rowspan="2">900</td><td>350</td><td>750</td><td>800</td><td>2500</td><td>1200</td><td>N/A(5)</td></tr>
<tr><td>C3</td><td>1,000</td><td>2,000</td><td>2,050</td><td>1250</td><td rowspan="2">800</td><td rowspan="2">2700</td><td rowspan="2">3000</td></tr>
<tr><td>C4</td><td>3,400</td><td>2,800</td><td>1,500</td><td>1,500</td><td>3250</td></tr>
<tr><td>C5</td><td>--</td><td>150</td><td>950</td><td>950</td><td>800</td><td>2500</td><td>1200</td><td>N/A(5)</td></tr>
<tr><td>Max Heat Load per Cask</td><td>35,500</td><td>35,500</td><td>35,500</td><td>35,500</td><td>35,500</td><td>35,500</td><td>35,500</td><td>42,500</td><td>42,000</td><td>42,000</td><td>48,000</td><td>48,000</td><td>53,000</td></tr>
<tr><td>Pattern Use Limits on Cask Configuration</td><td>Note (4)</td><td>Note (4)</td><td>PMTC not Permitted</td><td>MTC2 and CC6</td><td>MTC2 and CC6</td><td>MTC2 and CC6</td><td>MTC2 and CC6</td><td colspan="6">Only permitted with LMTC and CC with 3” Liner and Heat Shield.</td></tr>
<tr><td>Pattern Use Limits on Fuel Type</td><td>Note (2)</td><td>None</td><td>CE16H1 or WE14×14 Only</td><td>BW15×15</td><td>BW15×15</td><td>BW15×15</td><td>BW15×15</td><td colspan="6">Excludes CE14×14, WE14×14, and CE16H2</td></tr>
</table>

Notes for Table B2-2:

- Storage locations per Figure B2-1.
- Listed heat load is combined total of fuel assembly and nonfuel hardware, if applicable.

(1) Loading patterns are referred to in the FSAR as follows:
- A – Uniform Loading Pattern
- B – Preferential Three-Zone Loading Pattern
- C – Preferential Four-Zone Loading Pattern (with Reduced Cool Times)
- D – DELETED
- F – Loading Pattern - X
- F – Loading Pattern - Y
- G – Loading Pattern - Z
- H – Loading Pattern – Z-Prime
- I – Loading Pattern I or 37P-I
- J – Loading Pattern J or 37P-J
- K – Loading Pattern K or 37P-K
- L – Loading Pattern L or 37P-L
- M – Loading Pattern M or 37P-M
- N – Loading Pattern N or 37P-N

(2) MSO Loading Pattern Limitations:
- The MSO is only permitted for use with this pattern and fuel assembly types WE14x14, WE17x17, and CE16x16 (only Subtype CE16H1).
- The TSCs stored in the MSO shall not contain NONFUEL HARDWARE.

(3) Loading Pattern I with heat load in any storage location above 1148 W (uniform load) requires the following additional limits:

a. Assemblies with highest loads must be stored in Zone B.
b. Assemblies with lowest heat loads must be stored in Zone A, the lowest heat load in location A2.
c. Empty storage locations must be considered as zero (0) watt heat load assemblies in the context of limits (3)a. and (3)b.

(4) PMTC use limited to these patterns. PMTC may only be used with CE 16×16 fuel. TSC with lid recess for loading of neutron source rods is limited to use in the PMTC (loading/transfer) and CC5 (storage) configurations.

(5) Storage location occupied by thermal shunt.

(

Table B2-3 Bounding PWR Fuel Physical Characteristics

Assembly Type	Assembly Subtype	No. of Fuel Rods	No. of Guide Tubes [1]	Geometry [2]					
				Max Pitch (inch)	Min Clad OD (inch)	Min Clad Thick. (inch)	Max Pellet OD (inch)	Max Active Length (inch)	Max Load (MTU)
BW15x15	BW15H1	208	17	0.568	0.43	0.0265	0.3686	144.0	0.4858
	BW15H2	208	17	0.568	0.43	0.025	0.3735	144.0	0.4988
	BW15H3	208	17	0.568	0.428	0.023	0.3742	144.0	0.5006
	BW15H4	208	17	0.568	0.414	0.022	0.3622	144.0	0.4690
	BW15H5	208	17	0.568	0.422	0.0243	0.3659	144.0	0.4787
BW17x17	BW17H1	264	25	0.502	0.377	0.022	0.3252	144.0	0.4799
CE14x14	CE14H1	176	5	0.58	0.44	0.026	0.3805	137.0	0.4167
CE16x16	CE16H1	236	5	0.5063	0.382	0.025	0.3255	150.0	0.4463
	CE16H2	236	5	0.5063	0.374	0.0225	0.32225	150.0	0.4395
WE14x14	WE14H1	179	17	0.556	0.40	0.0218	0.3674	145.2	0.4188
WE15x15	WE15H1	204	21	0.563	0.422	0.0242	0.3669	144.0	0.4720
	WE15H2	204	21	0.563	0.417	0.0265	0.357	144.0	0.4469
WE17x17	WE17H1	264	25	0.496	0.372	0.0205	0.3232	144.0	0.4740
	WE17H2	264	25	0.496	0.36	0.0225	0.3088	144.0	0.4327

[1] Combined number of guide and instrument tubes.
[2] Assembly characteristics represent cold, unirradiated, nominal configurations.

Note: Assembly ID alphanumeric identifiers indicate (as applicable) vendor and/or base reactor core type forming the assembly hybrid. Loading of assemblies meeting the above limits is not restricted to the vendor(s) listed.

Table B2-4 Bounding PWR Fuel Assembly Loading Criteria – Enrichment/Soluble Boron Limits

TSC Containing only Undamaged Fuel – Max. Initial Enrichment (wt % ^{235}U)

	Absorber[1] 0.036 ^{10}B g/cm^2						Absorber[1] 0.030 ^{10}B g/cm^2					Absorber[1] 0.027 ^{10}B g/cm^2				
Soluble Boron	**1500 (ppm)**	**1750 (ppm)**	**2000 (ppm)**	**2250 (ppm)**	**2500 (ppm)**	**2650 (ppm)**	**1500 (ppm)**	**1750 (ppm)**	**2000 (ppm)**	**2250 (ppm)**	**2500 (ppm)**	**1500 (ppm)**	**1750 (ppm)**	**2000 (ppm)**	**2250 (ppm)**	**2500 (ppm)**
BW15H1	3.7%	4.1%	4.4%	4.7%	5.0%	--	3.6%	4.0%	4.2%	4.5%	4.8%	3.6%	3.9%	4.2%	4.5%	4.8%
BW15H2	3.7%	4.0%	4.3%	4.6%	4.9%	5.0%	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.8%	4.1%	4.4%	4.7%
BW15H3	3.7%	4.0%	4.3%	4.6%	4.9%	--	3.6%	3.9%	4.2%	4.4%	4.7%	3.5%	3.8%	4.1%	4.4%	4.7%
BW15H4	3.8%	4.2%	4.5%	4.8%	5.0%	--	3.7%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	5.0%
BW15H5	--	--	--	--	5.0%	--	--	--	--	--	--	--	--	--	--	--
BW17H1	3.7%	4.0%	4.3%	4.6%	4.9%	--	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.9%	4.1%	4.5%	4.7%
CE14H1	4.5%	4.8%	5.0%	5.0%	5.0%	--	4.3%	4.7%	5.0%	5.0%	5.0%	4.3%	4.6%	5.0%	5.0%	5.0%
CE16H1	4.4%	4.8%	5.0%	5.0%	5.0%	--	4.3%	4.6%	5.0%	5.0%	5.0%	4.2%	4.6%	4.9%	5.0%	5.0%
CE16H2	4.4%	4.8%	5.0%	5.0%	5.0%	----	4.3%	4.6%	5.0%	5.0%	5.0%	4.2%	4.6%	4.9%	5.0%	5.0%
WE14H1	4.7%	5.0%	5.0%	5.0%	5.0%	--	4.6%	5.0%	5.0%	5.0%	5.0%	4.5%	5.0%	5.0%	5.0%	5.0%
WE15H1	3.8%	4.2%	4.5%	4.8%	5.0%	--	3.7%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	4.9%
WE15H2	4.0%	4.4%	4.7%	5.0%	5.0%	--	3.9%	4.2%	4.6%	4.9%	5.0%	3.8%	4.2%	4.5%	4.8%	5.0%
WE17H1	3.7%	4.1%	4.4%	4.7%	5.0%	--	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.9%
WE17H2	4.0%	4.3%	4.7%	5.0%	5.0%	--	3.9%	4.3%	4.6%	4.9%	5.0%	3.8%	4.2%	4.5%	4.9%	5.0%

Table B2-4 Bounding PWR Fuel Assembly Loading Criteria – Enrichment/Soluble Boron Limits (continued)

TSC Containing Damaged Fuel – Max. Initial Enrichment (wt % ^{235}U)

	Absorber[1] 0.036 ^{10}B g/cm^2						Absorber[1] 0.030 ^{10}B g/cm^2					Absorber[1] 0.027 ^{10}B g/cm^2				
Soluble Boron	**1500 (ppm)**	**1750 (ppm)**	**2000 (ppm)**	**2250 (ppm)**	**2500 (ppm)**	**2650 (ppm)**	**1500 (ppm)**	**1750 (ppm)**	**2000 (ppm)**	**2250 (ppm)**	**2500 (ppm)**	**1500 (ppm)**	**1750 (ppm)**	**2000 (ppm)**	**2250 (ppm)**	**2500 (ppm)**
BW15H1	3.7%	4.0%	4.3%	4.6%	4.9%	--	3.6%	3.9%	4.2%	4.5%	4.7%	3.6%	3.8%	4.1%	4.4%	4.7%
BW15H2	3.6%	3.9%	4.2%	4.5%	4.8%	5.0%	3.6%	3.8%	4.1%	4.4%	4.7%	3.5%	3.8%	4.1%	4.3%	4.6%
BW15H3	3.6%	3.9%	4.2%	4.5%	4.8%	--	3.5%	3.8%	4.1%	4.4%	4.6%	3.5%	3.8%	4.0%	4.3%	4.6%
BW15H4	3.8%	4.1%	4.4%	4.7%	5.0%	--	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.8%
BW15H5	--	--	--	--	4.9%	--	--	--	--	--	--	--	--	--	--	--
BW17H1	3.6%	3.9%	4.2%	4.5%	4.8%	--	3.6%	3.9%	4.1%	4.4%	4.7%	3.5%	3.8%	4.1%	4.4%	4.6%
CE14H1	4.4%	4.8%	5.0%	5.0%	5.0%	--	4.3%	4.7%	5.0%	5.0%	5.0%	4.3%	4.6%	4.9%	5.0%	5.0%
CE16H1	4.4%	4.7%	5.0%	5.0%	5.0%	--	4.2%	4.6%	5.0%	5.0%	5.0%	4.2%	4.5%	4.9%	5.0%	5.0%
CE16H2	4.4%	4.7%	5.0%	5.0%	5.0%	----	4.2%	4.6%	5.0%	5.0%	5.0%	4.2%	4.5%	4.9%	5.0%	5.0%
WE14H1	4.6%	5.0%	5.0%	5.0%	5.0%	--	4.5%	5.0%	5.0%	5.0%	5.0%	4.5%	4.9%	5.0%	5.0%	5.0%
WE15H1	3.8%	4.1%	4.4%	4.7%	5.0%	--	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	4.0%	4.3%	4.6%	4.8%
WE15H2	3.9%	4.3%	4.6%	4.9%	5.0%	--	3.8%	4.2%	4.5%	4.8%	5.0%	3.8%	4.1%	4.4%	4.7%	5.0%
WE17H1	3.7%	4.0%	4.3%	4.6%	4.9%	--	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.9%	4.2%	4.5%	4.8%
WE17H2	3.9%	4.3%	4.6%	5.0%	5.0%	--	3.9%	4.2%	4.5%	4.9%	5.0%	3.8%	4.1%	4.5%	4.8%	5.0%

Notes for Table B2-3

- Specified soluble boron concentrations are independent of whether an assembly contains a nonfuel insert.

1 Borated aluminum neutron absorber sheet effective areal ^{10}B density

Table B2-5 Additional SNF Assembly Cool Time Required to Load NONFUEL HARDWARE

Assembly		Pattern A Storage Location A	Pattern B Storage Location A	Pattern B Storage Location B	Pattern B Storage Location C	Pattern C Storage Location A	Pattern C Storage Location B1	Pattern C Storage Location B2	Pattern C Storage Location C
CE 14x14	BPAA/HFRA	--	--	--	--	--	--	--	--
	GTPD/NSA	--	--	--	--	--	--	--	--
	RCC	0.2	0.2	0.1	0.2	--	--	--	--
WE 14x14	BPAA/HFRA	0.5	0.5	0.2	0.7	1.4	0.1	0.1	0.7
	GTPD/NSA	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1
	RCC	0.7	2.3	0.7	4.1	2.2	0.2	0.1	1.0
WE 15x15	BPAA/HFRA	0.5	0.6	0.2	0.8	--	--	--	--
	GTPD/NSA	0.1	0.1	0.1	0.1	--	--	--	--
	RCC	3.1	3.4	1.5	4.5	--	--	--	--
B&W 15x15 [2]	BPAA/HFRA	0.1	0.1	0.1	0.1	--	--	--	--
	GTPD/NSA	0.1	0.1	0.1	0.1	--	--	--	--
	RCC	0.2	0.2	0.1	0.2	--	--	--	--
	APSR	--	--	--	--	--	--	--	--
CE 16x16	BPAA/HFRA	--	--	--	--	--	--	--	--
	GTPD/NSA	--	--	--	--	--	--	--	--
	RCC	0.4[1]	0.2	0.1	0.3	0.8	0.1	0.1	0.4
WE 17x17	BPAA/HFRA	0.5	0.6	0.2	0.7	--	--	--	--
	GTPD/NSA	0.1	0.1	0.1	0.1	--	--	--	--
	RCC	2.9	3.3	1.4	4.3	--	--	--	--
B&W 17x17	BPAA/HFRA	0.1	0.1	0.1	0.1	--	--	--	--
	GTPD/NSA	0.1	0.1	0.1	0.1	--	--	--	--
	RCC	0.2	0.2	0.1	0.2	--	--	--	--

Note: Additional SNF assembly cooling time to be added to the minimum SNF assembly cool time based on SNF assembly initial enrichment and SNF assembly average burnup listed in Tables B2-15 through B2-22 and B2-25 through B2-43.

[1] 0.4 years for RCC in the PMTC (reduced storage location heat load). For all other cask types, 0.3 years for RCC with 5-year minimum cool time or 0.2 years for RCC with 10-year minimum cool time.

[2] APSRs are limited to B&W15x15 loaded in a CC6 Concrete Cask in load Patterns E, F, G, and H. Nonfuel hardware heat loads in Patterns E thru N must be added to fuel assembly heat loads when demonstrating compliance with Table B2-2 fuel storage location limits.

Table B2-6 Allowed BPAA/NSA 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[1]	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.

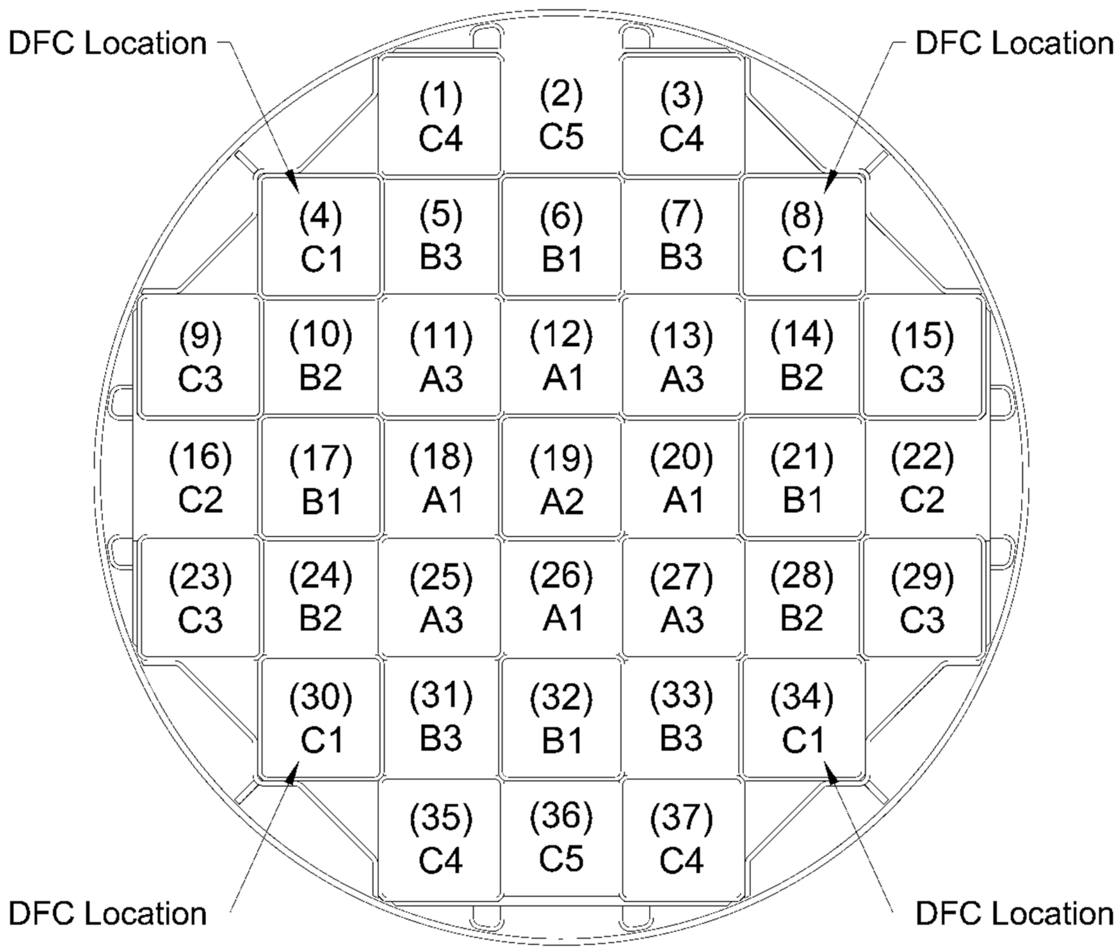
[1] For use in CC6 a minimum cool time of 1.75 years is permitted.

Table B2-7 Allowed GTPD/NSA 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.

Figure B2-1 Schematic of PWR 37-Assembly Basket



DFC designated locations may contain a loaded DFC or a PWR UNDAMAGED SNF ASSEMBLY. Figure applies to PWR Basket and PWR DF Basket.

"A1", "A2", "A3" may be referred to as storage location "A" when no differentiation of heat load is required between the various locations. Similarly, for group B and C locations.

Figure B2-2 [DELETED]

Figure B2-3 [DELETED]

Table B2-8 [DELETED]

Table B2-9 TSC with BWR Fuel Limits

I. TSC with BWR Basket Assembly and BWR DF Basket Assembly

A. Allowable Contents

1. Uranium BWR UNDAMAGED FUEL assemblies and DAMAGED FUEL (BWR DAMAGED SNF ASSEMBLIES or BWR FUEL DEBRIS) that meet the following specifications:

a. Cladding Type:	Zirconium-based alloy.
b. Physical Characteristics	The physical characteristics of the different BWR SNF ASSEMBLIES are defined in Table B2-11.
c. Maximum Enrichment	Fuel type specific enrichment limits for the BWR fuel basket configurations are defined in Table B2-12 through B2-12f as a function of neutron absorber areal density, basket type (undamaged or damaged), number of assemblies loaded, and/or preferential loading. Underload locations are defined in Table B2-12g in relation to Figures B2-4 and B2-5.
d. Decay Heat per SNF Assembly:	Load pattern dependent allowed heat loads for each fuel storage location illustrated in Figure B2-4 for the undamaged 89-Assembly basket, and Table B2-5 for the 81-Asssembly damaged basket are shown in Table B2-10a and B2-10b, respectively. Fuel assembly heat load to be evaluated based on discharged, or bounding, depletion and fuel assembly characteristics and total must be less than or equal to listed limit. Input into this heat load calculation is the SNF assembly average burnup (largest of the assembly average burnup in the group) and assembly average enrichment (lowest assembly average enrichment in the group).
e. Nominal Fresh Fuel Design SNF Assembly Length (in.):	≤ 176.2[
f. Nominal Fresh Fuel Design SNF Assembly Width (in.):	≤ 5.52
g. SNF Assembly Weight (lb):	≤ 704, including channels and spacers for non DF storage location and ≤ 804 for DF locations, including channels, the DFC and spacers.
h. Non-DF Basket - Total Canister Contents Weight (lbs.)	≤ 62,656, including SNF Assemblies, NONFUEL HARDWARE and fuel spacers
i. DF Basket -Total Canister Contents Weight (lbs.)	≤ 58,224, including SNF Assemblies, NONFUEL HARDWARE, DFCs and fuel spacers

(Continued)

Table B2-9 TSC with BWR Fuel Limits

j. Total Canister Weight including Contents (lbs.)	≤ 104,500 (nominal TSC weight plus maximum contents)

B. Quantity per TSC: Up to a total of 89 BWR UNDAMAGED SNF ASSEMBLIES in the undamaged (89-Assembly) basket or up to a total of 81 BWR UNDAMAGED SNF ASSEMBLIES in the damaged fuel (81-Assembly). The damaged fuel basket may be loaded with up to twelve (12) DFCs containing BWR UNDAMAGED SNF ASSEMBLIES, BWR DAMAGED SNF ASSEMBLIES, and/or BWR FUEL DEBRIS. DFCs may only be loaded in the DFC basket and are limited to locations No. 4, 8, 9, 15, 16, 24, 58, 66, 67, 73, 74, and 78, as shown on Figure B2-5.

C. The contents of a DFC must be less than, or equivalent to, one BWR UNDAMAGED SNF ASSEMBLY.

D. BWR fuel assemblies may be unchanneled, or channeled with zirconium-based alloy channels.

E. BWR fuel assemblies with stainless steel channels are not authorized.

F. SNF Assembly lattices possessing less than the nominal number of undamaged fuel rods (see Table B2-11) must contain solid filler rods that displace a volume equal to, or greater than, that of the fuel rod that the filler rod replaces.

G. Spacers may be used in a TSC to axially position BWR SNF assemblies to facilitate handling.

H. Unirradiated (i.e., not inserted in-core) fuel assemblies are not authorized for loading. Unenriched axial blankets are permitted, provided that the nominal length of the blanket is not greater than six (6) inches.

I. Assemblies identified as subject to CILC phenomena are authorized for loading without use of DFC provided the limits in Table B2-12h are met and the fuel assembly is channeled. Should the channel not be present a DFC is required and generic BWR DF limits apply.

Table B2-10 BWR SNF Assembly Characteristics

Characteristic	Fuel Class			
	7×7	8×8	9×9	10×10
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
Min Average Enrichment (wt % ^{235}U)	0.7	0.7	0.7	0.7

- Each BWR fuel assembly may include a zirconium-based alloy channel.
- Water rods may occupy more than one fuel lattice location. Fuel assembly to contain nominal number of water rods for the specific assembly design.
- Spacers may be used to axially position fuel assemblies to facilitate handling.

[(a)] Assemblies may contain partial-length fuel rods.

Table B2-10a BWR 89-Assembly Basket Fuel Loading Patterns

<table>
<tr><th colspan="7">Loading Pattern and Maximum Heat Load per Storage Location (W)(1)</th></tr>
<tr><th>Storage Location</th><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th><th>F</th></tr>
<tr><td>A1</td><td rowspan="14">379</td><td rowspan="14">533(2)</td><td rowspan="3">200</td><td rowspan="3">200</td><td>250</td><td rowspan="2">300</td></tr>
<tr><td>A2</td><td rowspan="2">300</td></tr>
<tr><td>A3</td><td>375</td></tr>
<tr><td>B1</td><td rowspan="3">300</td><td rowspan="3">300</td><td rowspan="3">475</td><td>425</td></tr>
<tr><td>B2</td><td>375</td></tr>
<tr><td>B3</td><td>425</td></tr>
<tr><td>C1</td><td>1100</td><td>1000</td><td rowspan="4">550</td><td rowspan="2">450</td></tr>
<tr><td>C2</td><td>950</td><td>900</td></tr>
<tr><td>C3</td><td>600</td><td>600</td><td>500</td></tr>
<tr><td>C4</td><td>350</td><td>450</td><td>450</td></tr>
<tr><td>D1</td><td rowspan="4">450</td><td rowspan="4">450</td><td rowspan="4">600</td><td>550</td></tr>
<tr><td>D2</td><td>925</td></tr>
<tr><td>D3</td><td>500</td></tr>
<tr><td>D4</td><td>925</td></tr>
<tr><td>Max Heat Load per Cask</td><td>33,000</td><td>39,500</td><td>42,000</td><td>42,000</td><td>46,000</td><td>46,000</td></tr>
<tr><td>Pattern Use Limitations</td><td>None</td><td>3” Liner and Heat Shield CC / LMTC</td><td>3” Liner and Heat Shield CC / LMTC</td><td>3” Liner and Heat Shield CC / LMTC</td><td>3” Liner and Heat Shield CC / LMTC</td><td>3” Liner and Heat Shield CC / LMTC</td></tr>
</table>

Notes:

- Locations per Figure B2-4.

(1) Loading patterns are referred to in the FSAR as follows:

A – Uniform Loading Pattern
B – Loading Pattern A or 89B-A
C – Loading Pattern B or 89B-B
D – Loading Pattern C or 89B-C
E – Loading Pattern E or 89B-E
F – Loading Pattern F or 89B-F

(2) Loading Pattern B with heat load in any storage location above 444W (uniform load) requires the following additional limits:

a. Assemblies with highest loads must be stored in Zone C.
b. Assemblies with lowest heat loads must be stored in Zone A and B, with the lowest overall heat load in the center of Zone A and progressively increasing heat loads in the surrounding rings.
c. Empty storage locations must be considered as zero (0) watt heat load assemblies in the context of limits (2)a and (2)b

Table B2-10b BWR 81-Assembly (DF) Basket Fuel Loading Patterns

<table>
<tr><td colspan="6">Loading Pattern and Maximum Heat Load per Storage Location (W)(3)</td></tr>
<tr><td>Storage Location</td><td>A</td><td>B</td><td>C</td><td>D</td><td>E</td></tr>
<tr><td>A</td><td rowspan="11">585(4)</td><td>300</td><td>300</td><td>300</td><td>300</td></tr>
<tr><td>B1</td><td rowspan="2">400</td><td rowspan="2">400</td><td rowspan="2">475</td><td>425</td></tr>
<tr><td>B2</td><td>500</td></tr>
<tr><td>C1</td><td>1100</td><td>1000</td><td rowspan="2">675</td><td rowspan="2">600</td></tr>
<tr><td>C2</td><td>900</td><td rowspan="2">600</td></tr>
<tr><td>C3</td><td>500</td><td>600</td><td>500</td></tr>
<tr><td>C4</td><td>475</td><td rowspan="3">525</td><td rowspan="4">675</td><td rowspan="2">600</td></tr>
<tr><td>D1</td><td>425</td></tr>
<tr><td>D2</td><td>475</td><td>1175</td></tr>
<tr><td>D3</td><td>500</td><td>600</td><td>600</td></tr>
<tr><td>D4</td><td>475</td><td>525</td><td></td><td></td></tr>
<tr><td>Max Heat Load per Cask</td><td>39,500</td><td>41,000</td><td>41,000</td><td>46,000</td><td>46,000</td></tr>
<tr><td>Pattern Use Limitations</td><td colspan="5">3” Liner and Heat Shield CC / LMTC</td></tr>
</table>

Notes:

- Locations per Figure B2-5.

(3) Loading patterns are referred to in the FSAR as follows:
A – Loading Pattern A or 81B-A
B – Loading Pattern B or 81B-B
C – Loading Pattern C or 81B-C
D – Loading Pattern D or 81B-D
E – Loading Pattern E or 81B-E

(4) Loading Pattern A with heat load in any storage location above 488W (uniform load) requires the following additional limits:

a. Assemblies with highest loads must be stored in Zone C.
b. Assemblies with lowest heat loads must be stored in Zone A and B, with the lowest overall heat load in the center of Zone A and progressively increasing heat loads in the surrounding rings.
c. Empty storage locations must be considered as zero (0) watt heat load assemblies in the context of limits (4)a. and (4)b

Table B2-10c [DELETED]

Table B2-10d [DELETED]

Table B2-11 BWR SNF Assembly Loading Criteria

Assembly Type	Number of Fuel Rods	Number of Partial Length Rods [1]	Geometry [3,4] Max Pitch (inch)	Min Clad OD (inch)	Min Clad Thick. (inch)	Max Pellet OD (inch)	Max Active Length (inch)	Max Loading (MTU)
B7_48A	48	N/A	0.7380	0.5700	0.03600	0.4900	144.0	0.1981
B7_49A	49	N/A	0.7380	0.5630	0.03200	0.4880	146.0	0.2034
B7_49B	49	N/A	0.7380	0.5630	0.03200	0.4910	150.0	0.2115
B8_59A	59	N/A	0.6400	0.4930	0.03400	0.4160	150.0	0.1828
B8_60A	60	N/A	0.6417	0.4840	0.03150	0.4110	150.0	0.1815
B8_60B	60	N/A	0.6400	0.4830	0.03000	0.4140	150.0	0.1841
B8_61B	61	N/A	0.6400	0.4830	0.03000	0.4140	150.0	0.1872
B8_62A	62	N/A	0.6417	0.4830	0.02900	0.4160	150.0	0.1921
B8_63A	63	N/A	0.6420	0.4840	0.02725	0.4195	150.0	0.1985
B8_64A	64	N/A	0.6420	0.4840	0.02725	0.4195	150.0	0.2017
B8_64B[5]	64	N/A	0.6090	0.4576	0.02900	0.3913	150.0	0.1755
B9_72A	72	N/A	0.5720	0.4330	0.02600	0.3740	150.0	0.1803
B9_74A	74[2]	8	0.5720	0.4240	0.02390	0.3760	150.0	0.1873
B9_76A	76	N/A	0.5720	0.4170	0.02090	0.3750	150.0	0.1914
B9_79A	79	N/A	0.5720	0.4240	0.02390	0.3760	150.0	0.2000
B9_80A	80	N/A	0.5720	0.4230	0.02950	0.3565	150.0	0.1821
B10_91A	91[2]	8	0.5100	0.3957	0.02385	0.3420	150.0	0.1906
B10_92A	92[2]	14	0.5100	0.4040	0.02600	0.3455	150.0	0.1966
B10_96A[5]	96[2]	12	0.4880	0.3780	0.02430	0.3224	150.0	0.1787
B10_100A[5]	100	N/A	0.4880	0.3780	0.02430	0.3224	150.0	0.1861

[1] Location of the partial length rods is illustrated in Figure B2-6.
[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.

Table B2-12 BWR 89-Assembly Basket SNF Assembly Loading Criteria – Enrichment Limits

	Max. Initial Enrichment[a] (wt % ^{235}U) Absorber[b] 0.027 ^{10}B g/cm^2						
	89-Assy	87-Assy	86-Assy	85-Assy	84-Assy	83-Assy	82-Assy
B7_48A	4.0%	4.5%	4.7%	5.0%	5.0%	5.0%	5.0%
B7_49A	3.8%	4.3%	4.5%	4.8%	5.0%	5.0%	5.0%
B7_49B	3.8%	4.3%	4.5%	4.8%	5.0%	5.0%	5.0%
B8_59A	3.9%	4.4%	4.6%	4.8%	5.0%	5.0%	5.0%
B8_60A	3.8%	4.3%	4.4%	4.7%	4.9%	5.0%	5.0%
B8_60B	3.8%	4.3%	4.4%	4.7%	4.9%	5.0%	5.0%
B8_61B	3.8%	4.3%	4.4%	4.7%	4.9%	4.9%	5.0%
B8_62A	3.8%	4.2%	4.4%	4.6%	4.8%	4.9%	5.0%
B8_63A	3.8%	4.2%	4.4%	4.6%	4.8%	4.9%	5.0%
B8_64A	3.8%	4.3%	4.4%	4.7%	4.9%	4.9%	5.0%
B8_64B	3.6%	4.0%	4.2%	4.4%	4.5%	4.6%	4.9%
B9_72A	3.8%	4.2%	4.4%	4.6%	4.8%	4.8%	5.0%
B9_74A	3.7% c	4.1%	4.2%	4.4%	4.6%	4.6%	4.8%
B9_76A	3.5%	3.9%	4.1%	4.3%	4.5%	4.5%	4.8%
B9_79A	3.7%	4.1%	4.3%	4.5%	4.7%	4.7%	5.0%
B9_80A	3.8%	4.3%	4.4%	4.7%	4.9%	4.9%	5.0%
B10_91A	3.7%	4.2%	4.3%	4.6%	4.8%	4.8%	5.0%
B10_92A	3.8%	4.2%	4.3%	4.6%	4.7%	4.8%	5.0%
B10_96A	3.7%	4.1%	4.2%	4.4%	4.6%	4.6%	4.8%
B10_100A	3.6%	4.1%	4.2%	4.4%	4.6	4.7%	4.9%

[a] Maximum planar average.

[b] Borated aluminum neutron absorber sheet effective areal ^{10}B density.

[c] 3.85% in the 88-assembly configuration

Table B2-12a BWR 89-Assembly Basket SNF Assembly Loading Criteria – Reduced Neutron Absorber Content - Enrichment Limits

	Max. Initial Enrichment[a] (wt % 235U)			
	Absorber 0.0225 ^{10}B g/cm^2		Absorber 0.02 ^{10}B g/cm^2	
	84-Assy	84-Assy	84-Assy	84-Assy
B7_48A	3.7%	4.5%	3.6%	4.4%
B7_49A	3.6%	4.4%	3.5%	4.3%
B7_49B	3.6%	4.4%	3.5%	4.2%
B8_59A	3.7%	4.5%	3.6%	4.3%
B8_60A	3.7%	4.4%	3.5%	4.2%
B8_60B	3.6%	4.3%	3.5%	4.2%
B8_61B	3.6%	4.3%	3.5%	4.2%
B8_62A	3.6%	4.3%	3.5%	4.1%
B8_63A	3.6%	4.3%	3.4%	4.2%
B8_64A	3.6%	4.3%	3.5%	4.2%
B8_64B	3.4%	4.1%	3.3%	4.0%
B9_72A	3.6%	4.3%	3.4%	4.1%
B9_74A	3.4%	4.1%	3.4%	4.0%
B9_76A	3.4%	4.0%	3.3%	3.9%
B9_79A	3.4%	4.2%	3.3%	4.0%
B9_80A	3.6%	4.3%	3.5%	4.2%
B10_91A	3.6%	4.3%	3.5%	4.1%
B10_92A	3.6%	4.3%	3.5%	4.1%
B10_96A	3.5%	4.1%	3.4%	4.0%
B10_100A	3.5%	4.1%	3.4%	4.0%

[a] Maximum planar average.

Table B2-12b BWR 89-Assembly Basket SNF Assembly Loading Criteria – 89- Assembly Load - Absorber 0.027 ^{10}B g/cm^2 – Preferential Loading Enrichment Limits

Outer Assembly[a] Enrichment Limit[b] (wt % 235U)	4.6%	4.7%	4.8%
Assembly	**Inner Assembly[c] Enrichment Limit[b] (wt % ^{235}U)**		
B9_72	3.6	3.5	3.5
B9_74	3.4	3.3	3.2
B9_76	3.2	3.2	3.1
B9_79	3.4	3.4	3.3
B9_80A	3.7	3.6	3.6
B10_91A	3.5	3.5	3.5
B10_92A	3.5	3.5	3.5
B10_96A	3.4	3.4	3.3
B10_100A	3.4	3.3	3.2

[a] Locations C1, C2, C4, D1, D2, 12, 18, 72, 78 in Figure B2-4.

[b] Maximum planar average.

[c] Locations A, B, C3 (except for Locations 12, 18, 72, 78) in Figure B2-4.

Table B2-12c BWR 89-Assembly Basket SNF Assembly Loading Criteria – Absorber 0.027 ^{10}B g/cm^2 – Preferential Load/Underload Combination Enrichment Limits

# Assy Loaded / Pattern ID	**87-Assembly Under Load**			**86-Assembly Under Load**			**85-Assembly Under Load**		
Outer Assembly[a] Enrichment Limit[b] (wt% ^{235}U)	4.6%	4.7%	4.8%	4.6%	4.7%	4.8%	4.6%	4.7%	4.8%
	Inner Assembly[c] Enrichment Limit[b] (wt% ^{235}U)								
B9_72A	4.0%	3.9%	3.8%	4.2%	4.2%	4.1%	4.6%	4.5%	4.4%
B9_74A	3.7%	3.6%	3.5%	3.9%	3.9%	3.8%	4.3%	4.2%	4.1%
B9_76A	3.5%	3.4%	3.3%	3.8%	3.7%	3.6%	4.1%	4.0%	3.9%
B9_79A	3.8%	3.7%	3.6%	4.1%	4.0%	4.0%	4.4%	4.4%	4.3%
B9_80A	4.1%	4.1%	4.0%	4.4%	4.3%	4.2%	4.8%	4.7%	4.7%
B10_91A	4.0%	3.9%	3.8%	4.2%	4.1%	4.1%	4.6%	4.5%	4.4%
B10_92A	3.9%	3.9%	3.8%	4.2%	4.1%	4.1%	4.6%	4.5%	4.4%
B10_96A	3.7%	3.7%	3.6%	4.0%	3.9%	3.8%	4.3%	4.2%	4.1%
B10_100A	3.7%	3.7%	3.6%	4.0%	3.9%	3.8%	4.4%	4.3%	4.2%

[a] Locations C1, C2, C4, D1, D2, 12, 18, 72, 78 in Figure B2-4.

[b] Maximum planar average.

[c] Locations A, B, C3 (except for Locations 12, 18, 72, 78) in Figure B2-4.

Table B2-12d BWR 81-Assembly Basket SNF Assembly Loading Criteria – Enrichment Limits

	Max. Initial Enrichment[a] (wt % ^{235}U)						
Max # Assy in Basket	**81-Assy**	**80-Assy**	**79-Assy**	**78-Assy**	**77-Assy**	**76-Assy**	**75-Assy**
B7_48A	4.0%	4.3%	4.5%	5.0%	5.0%	5.0%	5.0%
B7_49A	3.9%	4.2%	4.4%	4.8%	4.9%	5.0%	5.0%
B7_49B	3.9%	4.2%	4.4%	4.8%	4.9%	5.0%	5.0%
B8_59A	4.0%	4.3%	4.5%	4.8%	5.0%	5.0%	5.0%
B8_60A	3.9%	4.2%	4.4%	4.7%	4.9%	5.0%	5.0%
B8_60B	3.9%	4.2%	4.4%	4.7%	4.9%	5.0%	5.0%
B8_61B	3.9%	4.2%	4.4%	4.7%	4.9%	5.0%	5.0%
B8_62A	3.8%	4.1%	4.3%	4.6%	4.8%	5.0%	5.0%
B8_63A	3.8%	4.1%	4.3%	4.6%	4.8%	5.0%	5.0%
B8_64A	3.9%	4.1%	4.3%	4.7%	4.8%	5.0%	5.0%
B8_64B	3.7%	4.0%	4.1%	4.4%	4.6%	4.7%	4.8%
B9_72A	3.8%	4.1%	4.3%	4.6%	4.8%	5.0%	5.0%
B9_74A	3.7%	4.0%	4.1%	4.4%	4.6%	4.8%	4.9%
B9_76A	3.6%	3.9%	4.0%	4.3%	4.5%	4.7%	4.8%
B9_79A	3.7%	4.0%	4.1%	4.5%	4.7%	4.8%	4.9%
B9_80A	3.9%	4.2%	4.4%	4.7%	4.8%	5.0%	5.0%
B10_91A	3.8%	4.1%	4.3%	4.6%	4.8%	4.9%	5.0%
B10_92A	3.8%	4.1%	4.3%	4.6%	4.8%	4.9%	5.0%
B10_96A	3.7%	4.0%	4.2%	4.4%	4.6%	4.8%	4.9%
B10_100A	3.7%	4.0%	4.1%	4.4%	4.6%	4.8%	4.9%

[a] Maximum planar average.

**Table B2-12e BWR 81-Assembly Basket SNF Assembly Loading Criteria –
81 - Assembly Load - Preferential Loading Enrichment Limits**

Outer Assembly[a] Enrichment Limit[b] (wt % 235U)	**4.6%**	**4.7%**	**4.8%**
Assembly	**Inner Assembly[c] Enrichment Limit[b] (wt % ^{235}U)**		
B9_72	3.7	3.7	3.6
B9_74	3.5	3.5	3.4
B9_76	3.4	3.3	3.3
B9_79	3.5	3.4	3.4
B9_80A	3.7	3.7	3.6
B10_91A	3.7	3.7	3.6
B10_92A	3.7	3.6	3.6
B10_96A	3.4	3.4	3.3
B10_100A	3.5	3.4	3.4

[a] Locations C, D, F, G, H, I in Figure B2-5.

[b] Maximum planar average.

[c] Locations A, B, E in Figure B2-4.

Table B2-12f BWR 81-Assembly Basket SNF Assembly Loading Criteria - Preferential Load/Underload Combination Enrichment Limits

# Assy Loaded / Pattern ID	80-Assembly Under Load			79-Assembly Under Load			78-Assembly Under Load		
Outer Assembly[a] Enrichment Limit[b] (wt% ^{235}U)	4.6%	4.7%	4.8%	4.6%	4.7%	4.8%	4.6%	4.7%	4.8%
	Inner Assembly[c] Enrichment Limit[b] (wt% ^{235}U)								
B9_72A	4.0%	3.9%	3.9%	4.2%	4.1%	4.1%	4.5%	4.4%	4.3%
B9_74A	3.7%	3.7%	3.7%	4.0%	3.9%	3.8%	4.2%	4.1%	4.1%
B9_76A	3.6%	3.5%	3.5%	3.8%	3.7%	3.6%	4.0%	3.9%	3.9%
B9_79A	3.7%	3.7%	3.6%	3.9%	3.9%	3.8%	4.2%	4.1%	4.3%
B9_80A	4.0%	3.9%	3.9%	4.3%	4.2%	4.1%	4.5%	4.5%	4.4%
B10_91A	3.9%	3.9%	3.8%	4.2%	4.1%	4.1%	4.4%	4.4%	4.3%
B10_92A	3.9%	3.9%	3.8%	4.1%	4.1%	4.1%	4.4%	4.4%	4.3%
B10_96A	3.7%	3.6%	3.6%	3.9%	3.8%	3.7%	4.2%	4.1%	4.0%
B10_100A	3.7%	3.6%	3.6%	3.9%	3.8%	3.8%	4.2%	4.1%	4.0%

[a] Locations C, D, F, G, H, I in Figure B2-5.

[b] Maximum planar average.

[c] Locations A, B, E in Figure B2-5.

Table B2-12g BWR Load Pattern Identifier Underload/Empty Location Key

Basket	Load Pattern Identifier	Evaluation Type[a]	Underload/Empty Basket Locations[b]
89	88	Uniform	45
	87	Uniform/Preferential	33, 57
	86	Uniform/Preferential	25, 43, 67
	85	Uniform/Preferential	25, 32, 58, 65
	84	Uniform	25, 32, 45, 58, 65
	83	Uniform	15, 31, 37, 45, 64, 76
	82	Uniform	14, 26, 31, 45, 59, 64, 76
81-DF	80	Uniform/Preferential	41
	79	Uniform/Preferential	29, 53
	78	Uniform/Preferential	28, 31, 62
	77	Uniform	20, 39, 43, 62
	76	Uniform	21, 28, 41, 54, 61
	75	Uniform	21, 28, 41, 50, 54, 62

a Analysis type that this load pattern is identified with.
b Locations identified in Figure B2-4 (BWR 89-Assembly) and Figure B2-5 (BWR-DF 81-Assembly).

Table B2-12h BWR CILC Fuel Assembly Enrichment Limits

Basket Configuration	89 Assembly	89 Assembly	81 Assembly DF
Load Definition	Full Load - 89 Assembly	Underload - 87 Assembly	Full Load - 81 Assembly
Assembly Type	Enrichment (wt% 235U) Maximum Planar Average		
B8_59A	3.3%	3.6%	3.4%
B8_60A	3.3%	3.6%	3.4%
B8_60B	3.3%	3.6%	3.3%
B8_61B	3.3%	3.6%	3.3%
B8_62A	3.2%	3.5%	3.3%
B8_63A	3.2%	3.5%	3.3%
B8_64A	3.2%	3.5%	3.3%
B8_64B	3.2%	3.5%	3.3%

Figure B2-4 Schematic of BWR 89-Assembly Basket

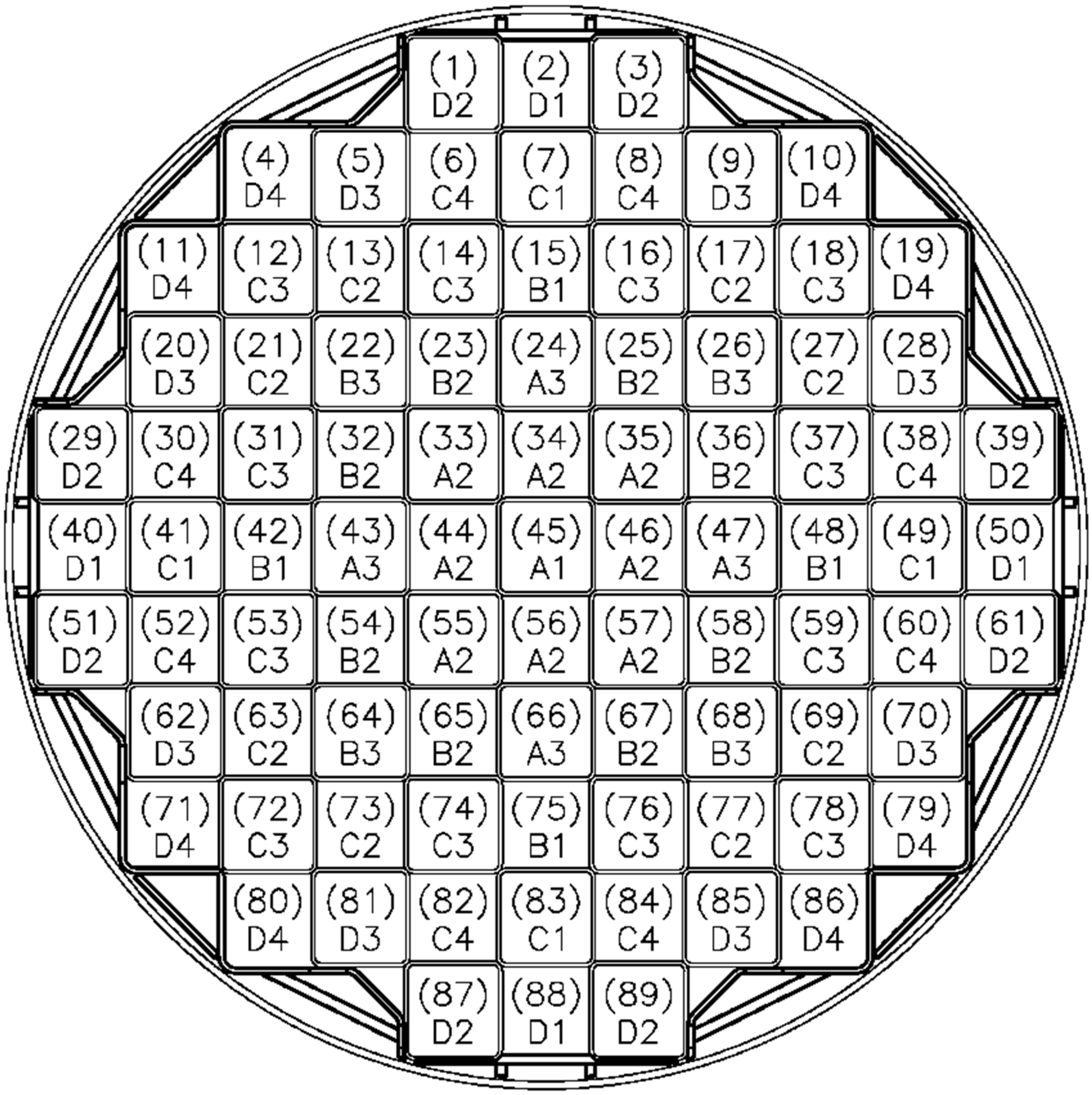


Figure B2-5 Schematic of BWR 81-Assembly Basket

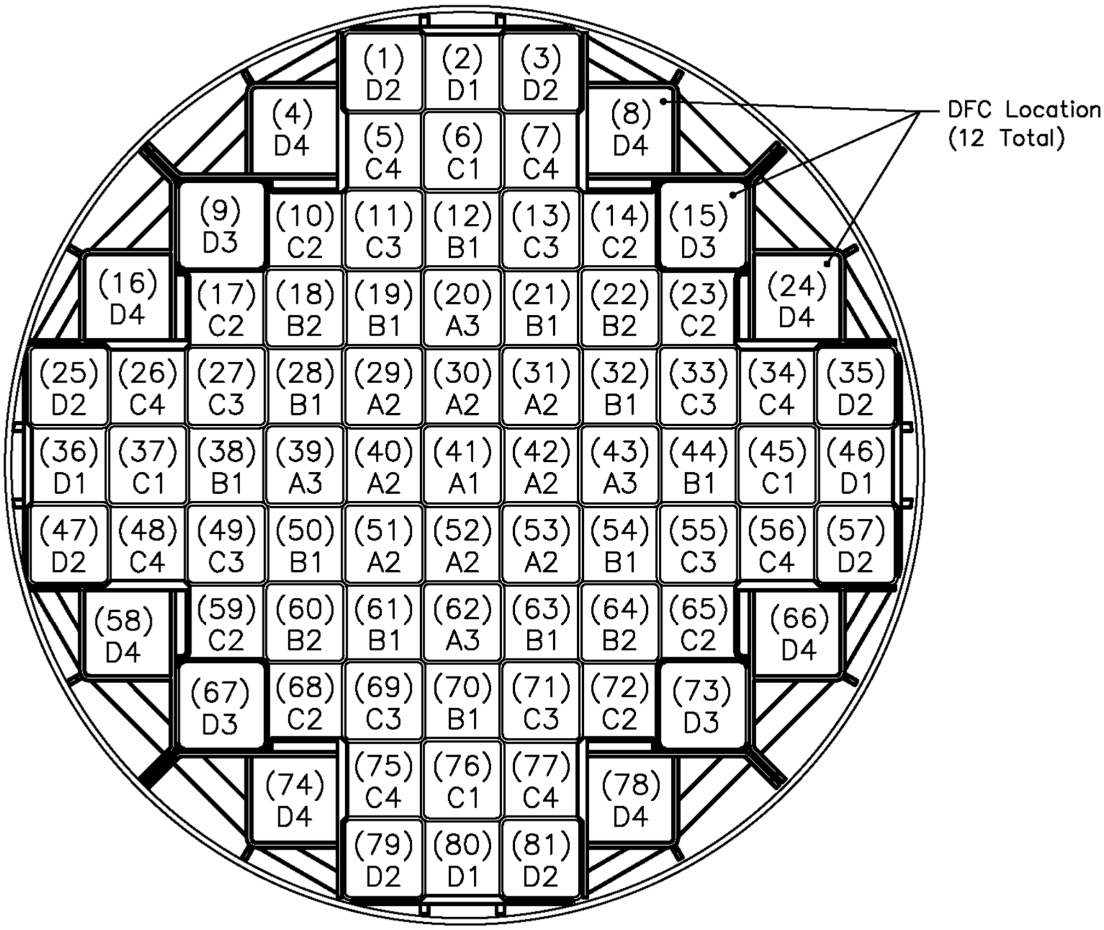
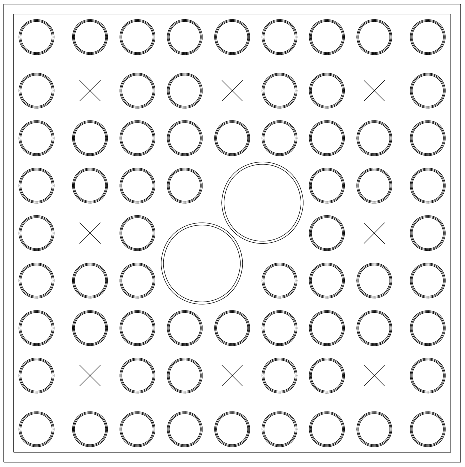


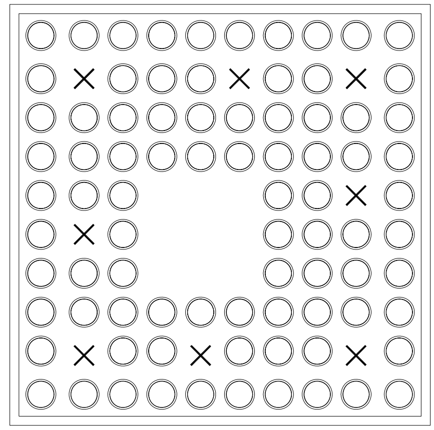
Figure B2-6 BWR Partial Length Fuel Rod Location Sketches



= Fuel Rod Location

= Partial Rod Location

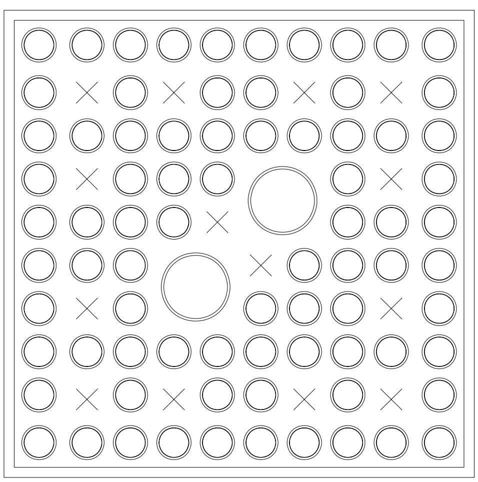
B9_74A 8 Partial Length Rods



= Fuel Rod Location

= Partial Rod Location

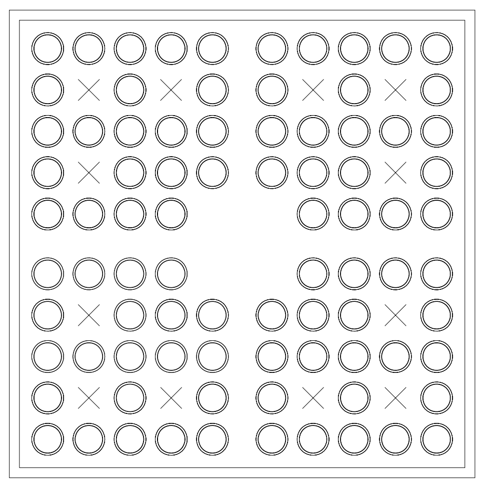
B10_91A 8 Partial Length Rods



= 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 B2-13 thru Table B2-43 [DELETED]

Enclosure 2

Supporting Calculations

for

MAGNASTOR® FSAR, Amendment 15 Supplement 1 Revision 23E

(Docket No 72-1031)

NAC International

October 2023

List of Calculations:

<u>Structural</u>

- 71160-2054 R0, MAGNASTOR Structural Evaluation of the CE16-NGF and CE16-HTP Fuel

<u>Thermal</u>

- 71160-3151 R2, Steady State Thermal Evaluation for the Passive MAGNASTOR Transfer Cask (PMTC) with 35.5 kW PWR Canister
- 71160-3152 R0, MAGNASTOR Thermal Evaluation CE16-NGF and CE16-HTP Fuel
- 71160-3156 R2, Transient Thermal Evaluation for the Passive MAGNASTOR Transfer Cask (PMTC) with 35.5 kW PWR Canister

<u>Shielding</u>

- 30032-5003 R1, Evaluation of Closure Lid Recess Effect on Top Dose Rates (LMTC and CC5)

<u>Criticality</u>

- 30032-6001 R0, MAGNASTOR Criticality Evaluation of CE16H2 Fuel Type

CALCULATIONS WITHHELD IN THEIR ENTIRETY PER 10 CFR 2.390

Enclosure 3

List of Changes

for

MAGNASTOR® FSAR
Amendment 15 Supplement 1
Revision 23E

(Docket No 72-1031)

NAC International

October 2023

List of Changes for the MAGNASTOR® FSAR, Revision 23E

Note: The List of Effective Pages and the Chapter Table of Contents, List of Figures, and List of Tables have been revised accordingly to reflect the list of changes detailed below.

Chapter 1

- Pages 1.1-6, revised Thermal Shunt definition
- Pages 1.3-8, revised Section 1.3.1.5 where indicated
- Pages 1.8-1 thru 1.8-2, drawing revisions where indicated

Chapter 2

- Page 2.2-2, revised Section 2.2.1 where indicated

Chapter 3

- Pages 3.1-5, revised Section 3.1.2 where indicated
- Pages 3.1-6 thru 3.1-7, text flow

Chapter 4

- Pages 4.10.3-2, revised Section 4.10.3.4 where indicated
- Pages 4.10.4-1, revised Section 4.10.4.2 where indicated
- Pages 4.10.4-2, revised Section 4.10.4.3 where indicated
- Pages 4.10.4-4, replaced Figure 4.10-6
- Pages 4.10.4-5, replaced Figure 4.10-7
- Pages 4.10.4-6, revised Tables 4.10-1 and 4.10-2 where indicated

Chapter 5

- Pages 5.17-1 thru 5.17.3-2, added new Section 5.17

Chapter 6

- Page 6.1-3, revised first full paragraph on page where indicated
- Page 6.1-10, added row in Table 6.1.1-1, where indicated and revised text in Footnote b, where indicated
- Page 6.1-11, added row in Table 6.1.1-2, where indicated
- Page 6.1-19, added row in Table 6.1.1-10, where indicated
- Page 6.2-3, added column 6 in Table 6.2.1-1, where indicated
- Page 6.4-8, added row in Table 6.4.3-1, where indicated
- Page 6.4-9, added row in Table 6.4.3-2, where indicated
- Page 6.4-11, added row in Table 6.4.3-4, where indicated
- Page 6.6-1, added reference 11
- Page 6.7.2-1, added sentence in Section 6.7.2, where indicated
- Page 6.7.2-2 thru 6.7.2-3, text flow changes
- Page 6.7.3-1, revised text in section 6.7.3.1, were indicated

- Page 6.7.3-23, added row in Table 6.7.3-9, where indicated
- Page 6.7.3-24, added row in Table 6.7.3-10, where indicated
- Page 6.7.3-25, added row in Table 6.7.3-11, where indicated
- Page 6.7.3-27, added row in Table 6.7.3-14, where indicated
- Page 6.7.8-83, added row in Table 6.7.8-2, where indicated and revised Note 1
- Page 6.7.8-87, added three rows in Table 6.7.8-6, where indicated
- Page 6.7.8-88, added three rows in Table 6.7.8-7, where indicated
- Page 6.7.8-91, added row in Table 6.7.8-10, where indicated

Chapter 7

- No changes.

Chapter 8

- No changes.

Chapter 9

- Pages 9.3-1, revised Section 9.3 where indicated
- Pages 9.3-4, added Note to Step 15 where indicated, and revised Step 16 where indicated
- Pages 9.3-5, text flow

Chapter 10

- Pages 10.1-6, revised Section 10.1.2.5 where indicated
- Pages 10.1-7 thru 10.1-8, revised Section 10.1.2.6 where indicated and added Section10.1.2.7
- Pages 10.1-9 thru 10.1-25, text flow

Chapter 11

- No changes.

Chapter 12

- No changes.

Chapter 13

- No changes.

Chapter 14

- No changes

Chapter 15

- No changes

<u>Enclosure 4</u>

List of Drawing Changes

for

MAGNASTOR® FSAR, Amendment 15 Supplement 1 Revision 23E

(Docket No 72-1031)

NAC International

October 2023

NAC PROPRIETARY INFORMATION REMOVED

[redacted]

NAC PROPRIETARY INFORMATIONREMOVED

[redacted]

NAC PROPRIETARY INFORMATION REMOVED

[redacted]

Enclosure 5

FSAR LOEP and Changed Pages

for

MAGNASTOR® FSAR,
Amendment 15 Supplement 1
Revision 23E

(Docket No 72-1031)

NAC International

October 2023

October 2023

Revision 23E

MAGNASTOR®

(**M**odular **A**dvanced **G**eneration **N**uclear **A**ll-purpose **STOR**age)

FINAL SAFETY ANALYSIS REPORT

NON-PROPRIETARY VERSION

Docket No. 72-1031

NAC INTERNATIONAL

Atlanta Corporate Headquarters: 3930 East Jones Bridge Road, Norcross, Georgia 30092 USA
Phone 770-447-1144, Fax 770-447-1797, www.nacintl.com

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Page 6.7.3-26 .... Revision 5
Page 6.7.3-27 ....Revision 23E
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Page 6.7.8-4 .... Revision 7
Page 6.7.8-5 thru 6.7.8-6............. Revision 5
Page 6.7.8-7 thru 6.7.8-82.......... Revision 11
Page 6.7.8-83 ....Revision 23E
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Page 6.7.8-87 thru 6.7.8-88......Revision 23E
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Page 7.1-6 .... Revision 2
Page 7.2-1 .... Revision 8
Page 7.2-2 .... Revision 0
Page 7.3-1 .... Revision 0
Page 7.4-1 .... Revision 0

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Page 8.12-1 thru 8.12-2................ Revision 0
Page 8.12-3 .... Revision 11
Page 8.13-1 .... Revision 8

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Lid

A thick carbon steel closure with encapsulated NS-3 shielding material for the MSO. The lid precludes access to the TSC and provides radiation shielding.

Inner and Outer Liners

Carbon steel shells that form the inside and outside diameters of the MSO. The annulus formed by the inner and outer liners serves to encapsulate NS-3 shielding material. The liners and NS-3 provide radiation shielding and structural protection for the TSC.

Standoffs (Channels)

Carbon steel weldments attached to the liner that assist in centering the TSC in the MSO and supporting the TSC and its contents in a nonmechanistic tip-over event.

Nonfuel Hardware

Nonfuel hardware is defined as reactor control components (RCCs), burnable poison absorber assemblies (BPAAs), guide tube plug devices (GTPDs), neutron sources/neutron source assemblies (NSAs), hafnium absorber assemblies (HFRAs), instrument tube tie components, in-core instrument thimbles, and steel rod inserts (used to displace water from lower section of guide tube), and components of these devices such as individual rods. All nonfuel hardware, with the exception of instrument tube tie components and steel rod inserts, may be activated during in-core operations.

RCCs are commonly referred to as rod cluster control assemblies (RCCAs), control rod assemblies (CRAs), or control element assemblies (CEAs). RCCs are primarily designed to provide reactor shutdown reactivity control, are inserted into the guide tubes of the assembly, and are typically employed for a significant number of operating cycles. Burnup poison absorber assemblies (BPAAs) are commonly referred to as burnup poison rod assemblies (BPRAs), but may have vendor specific nomenclature such as BPRA, Pyrex BPRA or WABA (wet annular burnable absorber). BPAAs are used to control reactivity of fresh fuel or high reactivity fuels and are commonly used for a single cycle, but may be used for multiple cycles. GTPDs are designed to block guide tube openings when no BPAA is employed and are commonly referred to as thimble plugs (TPs), thimble plug devices (TPDs), flow mixers (FMs), water displacement guide tube plugs, or vibration suppressor inserts. GTPDs may be employed for multiple cycles. NSAs are primary and secondary neutron sources used during reactor startup and may be used for multiple cycles.

Integral fuel burnable absorbers, either integral to a fuel rod or as a substitution for a fuel rod, and fuel replacement rods (fueled, stainless steel, or zirconium alloy) are considered components of spent nuclear fuel (SNF) assemblies and are not considered to be nonfuel hardware.

Part Length Shield Assemblies (PLSAs)

PWR fuel assemblies that contain stainless steel inserts in the bottom of each fuel rod, reducing the active fuel length, and a natural uranium blanket at the top of the active core. PLSAs are sometimes used in reactors to reduce fast neutron fluence reaching the pressure vessel wall.

Spent Nuclear Fuel (SNF), Spent Fuel

Irradiated fuel assemblies consisting of end-fittings, grids, fuel rods and integral hardware. Integral hardware for PWR assemblies primarily consists of guide/instrument tubes, but may contain integral fuel burnable absorbers, either integral to a fuel rod or as a fuel rod substitution, and fuel replacement rods (fueled, stainless steel, or zirconium alloy). For BWR fuel, integral hardware may consist of water rods in various shapes, inert rods, fuel rod cluster dividers, and/or fuel assembly channels (optional). PWR SNF may contain nonfuel hardware.

Storage Cask

A storage cask is either a Concrete Cask or a Metal Storage Overpack.

Thermal Shunt

A specially designed aluminum block encased within a stainless steel weldment designed to occupy specific storage locations in a fuel basket for certain short-loaded preferential loading patterns. Thermal shunts prevent fuel assemblies from being inadvertently loaded into storage locations that are not intended for fuel. In addition, thermal shunts provide a heat transfer function.

Transfer Cask

A shielded device used to lift and handle the TSC during fuel loading and closure operations, as well as to transfer the TSC in/out of the storage cask during storage or in/out of a transport cask. The transfer cask includes two lifting trunnions and two shield doors that can be opened to permit the vertical transfer of the loaded TSC into the CC. There are three types of transfer cask, the first is the standard MAGNASTOR Transfer Cask (MTC) with solid neutron shielding. The MTC structural components are fabricated from either high-strength carbon steel (MTC1) or stainless steel (MTC2). The second type is the Passive MTC (PMTC) with demineralized water filled neutron shield tank. The PMTC is specifically designed for use in a high ambient temperature environment (≤ 104°F) and to passively cool the loaded TSC during transfer operations by convective air cooling equivalent to that provided by the storage cask. The PMTC is fabricated from stainless steel. The third type is the Lightweight MTC (LMTC), intended for use at facilities with limited crane capacity and for TSCs with high-heat loads. The LMTC includes a demineralized water-filled neutron shield tank that can be drained for pool loading operations to reduce the hook wet weight, then refilled to restore neutron shielding prior to performing canister draining, drying, and closure operations. The LTMC structural components are all fabricated from stainless steel.

Lifting Trunnions

Two low-alloy steel components used to lift the transfer cask in a vertical orientation via a lifting assembly.

TSC (Transportable Storage Canister)

The stainless steel cylindrical shell, bottom-end plate, closure lid, closure ring, and redundant port covers that contain the fuel basket structure and the spent fuel contents.

The MSO provides an annular air passage to allow natural circulation of air around the TSC to remove the decay heat from the contents. The lower air inlets and upper air outlets are carbon steel penetrations in the bottom weldment and inner liner respectively. Each air inlet/outlet is covered with a screen. The weldment baffle directs the air upward and around the pedestal that supports the TSC. Decay heat is transferred from the fuel assemblies to the TSC wall by conduction, convection, and radiation. Heat is removed by convection and radiation from the TSC shell to the air flowing upward through the annular air passage and to the MSO inner liner, respectively. Heat radiated to the inner liner can be transferred to the air annulus and by conduction through the NS-3 shielding and outer liner wall. The heated air in the annulus exhausts through the air outlets. The passive cooling system is designed to maintain the peak fuel cladding temperature below acceptable limits during long-term storage [10]. The inner liner of the MSO incorporates standoffs that provide lateral support to the TSC in side impact accident events.

A carbon steel lid with encapsulated NS-3 shielding is bolted to the top of the MSO. The lid reduces skyshine radiation and provides a cover to protect the TSC from the environment and postulated tornado missiles.

Fabrication of the MSO requires no unique or unusual forming. The NS-3 shielding is placed between the inner and outer liner of the MSO prior to welding the annulus top plate.

Daily visual inspection of the air inlet and outlet screens for blockage assures that airflow through the cask meets licensed requirements. A description of the visual inspection is included in the Technical Specifications, Chapter 13. As an alternative to daily visual inspections, the loaded MSO in storage may include the capability to measure air temperature at the four outlets. Each air outlet may be equipped with a remote temperature detector mounted in the outlet air plenum. The air temperature-monitoring system, designed to provide verification of heat dissipation capabilities, can be designed for remote or local read-out capabilities at the option of the licensee. The temperature-monitoring system can be installed on all or several MSOs at the Independent Spent Fuel Storage Installation (ISFSI) facility.

1.3.1.5 Transfer Cask

The transfer cask is designed, fabricated, and tested to meet the requirements of ANSI N14.6 [11] as a special lifting device. The transfer cask provides biological shielding and structural protection for a loaded TSC, and is used to lift and move the TSC between workstations. The transfer cask is also used to shield the vertical transfer of a TSC into a storage cask or a transport cask.

The transfer cask is available in multiple configurations. The first is the standard MAGNASTOR Transfer Cask (MTC) with solid neutron shielding. The MTC can be supplied fabricated from high-strength carbon steel (MTC1) or a shortened stainless steel version (MTC2). The second configuration is the Passive MTC (PMTC) with demineralized water filled shield tank. The PMTC is specifically designed for use in a high ambient temperature environment (≤ 104°F) and to passively cool the loaded TSC during transfer operations by convective air cooling equivalent to that provided by the storage cask. The PMTC is fabricated from stainless steel. The third configuration is the Lightweight MTC (LMTC), intended for use at facilities with limited crane capacity and for TSCs with high-heat loads. The LMTC includes a demineralized water-filled neutron shield tank that can be drained for pool loading operations to reduce the hook wet weight, then refilled to restore neutron shielding prior to performing canister draining, drying, and closure operations. The LTMC structural components are all fabricated from stainless steel. The Reduced Width LMTC is a configuration that is designed to satisfy site-specific requirements for crane capacity and cask loading pit size limits. It is like the standard LMTC in nearly all respects, except that its gamma shield thickness is set to 2.5-inches, its lifting trunnions are rotated 45° from the door rail axis, and flats are added to the neutron shield to maintain an 86.5-inch width on the short axis. The principal dimensions and materials of fabrication of the transfer cask are provided in Table 1.3-1.

The transfer cask designs incorporate a retaining ring or three retaining blocks, pin-locked in place, or a bolted retaining ring, to prevent a loaded TSC from being inadvertently lifted through its top opening. The transfer cask has retractable bottom shield doors. During TSC loading and handling operations, the shield doors are closed and secured by lock pins. After placement of the transfer cask on the storage cask, the lock pins are removed and the doors are retracted using hydraulic cylinders and a hydraulic supply. The TSC is then lowered into a storage cask for storage. Refer to Figure 1.3-1 for the general arrangement of the transfer cask, TSC, and storage cask during loading.

The MTC and LMTC both have sixteen penetrations, eight at the top and eight at the bottom, are available to provide a water supply to the transfer cask annulus. Penetrations not used for water supply or draining are capped. The transfer cask annulus is isolated using inflatable seals located between the transfer cask inner shell and the TSC near the upper and lower ends of the transfer cask.

The PMTC has eight upper penetrations available to provide a water supply to the transfer cask annulus. The upper PMTC annulus is isolated from the spent fuel pool water by a shield/seal insert ring which inflates against both the PMTC inside diameter and the outside diameter of the TSC. The bottom end of the PMTC annulus is enclosed inside an isolated volume created by the PMTC skirt and Catch Basin with the aid of an inflatable seal. The Catch Basin includes features to facilitate the circulation of cooling water through the PMTC annulus (ACWS/R-ACWS) while isolating the annulus from contaminated spent fuel pool water.

During TSC closure, clean (e.g., filtered) borated or demineralized spent fuel pool water is circulated through these penetrations into the annulus region to minimize component temperatures and improve canister preparation time limits. The annulus circulating water system (ACWS) can be utilized through completion of TSC activities. The ACWS is turned off and

1.8 License Drawings

This section presents the list of License Drawings for MAGNASTOR.

Drawing Number	Title	Revision No.
71160-551	Fuel Tube Assembly, MAGNASTOR – 37 PWR	13NP*
71160-556	Assembly, MAGNASTOR Transfer Cask (MTC), Stainless Steel	6
71160-560	Assembly, Standard Transfer Cask, MAGNASTOR	2
71160-561	Structure, Weldment, Concrete Cask, MAGNASTOR	11
71160-562	Reinforcing Bar and Concrete Placement, Concrete Cask, MAGNASTOR	11
71160-565	Body, Lid and Details, Metal Storage Overpack (MSO), MAGNASTOR	0NP*
71160-567	Loaded Metal Storage Overpack (MSO), MAGNASTOR	1NP*
71160-571	Details, Neutron Absorber, Retainer, MAGNASTOR – 37 PWR	11NP*
71160-572	Details, Neutron Absorber, Retainer, MAGNASTOR – 87 BWR	9NP*
71160-574	Basket Support Weldments, MAGNASTOR – 37 PWR	9
71160-575	Basket Assembly, MAGNASTOR – 37 PWR	13NP*
71160-581	Shell Weldment, PWR TSC, MAGNASTOR	8
71160-584	Details, PWR TSC, MAGNASTOR	11
71160-585	TSC Assembly, PWR, MAGNASTOR	15
71160-590	Loaded Concrete Cask, MAGNASTOR	10
71160-591	Fuel Tube Assembly, MAGNASTOR – 87 BWR	8NP*
71160-598	Basket Support Weldments, MAGNASTOR – 87 BWR	7NP*
71160-599	Basket Assembly, MAGNASTOR – 87 BWR	8NP*
71160-600	Basket Assembly, MAGNASTOR – 82 BWR	5NP*
71160-601	Damaged Fuel Can (DFC), Assembly, MAGNASTOR	4NP*
71160-602	Damaged Fuel Can (DFC), Details, MAGNASTOR	5NP*
71160-603	Damaged Fuel Can (DFC), Assembly, MAGNASTOR	0NP*
71160-656	Cask Body Weldment, Passive Transfer Cask, MAGNASTOR	3NP*
71160-657	Passive Transfer Cask, Assembly, MAGNASTOR	2NP*
71160-661	Structure, Weldment, Concrete Cask, MAGNASTOR	0NP*
71160-662	Reinforcing Bar and Concrete Placement, Concrete Cask, MAGNASTOR	0NP*
71160-663	Lift Lug and Details, Concrete Cask, MAGNASTOR	0NP*
71160-664	Upper Segment Assembly, Concrete Cask, MAGNASTOR	0NP*

*Proprietary drawing replaced by nonproprietary version.

Drawing Number	Title	Revision No.
71160-671	Details, Neutron Absorber, Retainer, For DF Corner Weldment, MAGNASTOR – 37 PWR	3NP*
71160-673	Damaged Fuel Can (DFC), Spacer, MAGNASTOR	0
71160-674	DF Corner Weldment, MAGNASTOR	6NP*
71160-675	DF Basket Assembly, 37 Assembly PWR, MAGNASTOR	7NP*
71160-681	DF, Shell Weldment, TSC, MAGNASTOR	4
71160-684	Details, DF Closure Lid, MAGNASTOR	4
71160-685	DF, TSC Assembly, MAGNASTOR	10NP*
71160-690	Loaded Concrete Cask Assembly, MAGNASTOR	0NP*
71160-L104	Damaged Fuel Can (DFC) BWR, MAGNASTOR	0NP*
71160-L178	Corner Weldment, BWR DF Basket, MAGNASTOR	0NP*
71160-L180	Basket Assembly, BWR DF, MAGNASTOR	0NP*
71160-L186	TSC Assembly, BWR DF, MAGNASTOR	0NP*
71160-L257	Cask Assembly, Lightweight MAGNASTOR Transfer Cask (LMTC)	0NP*
71160-L258	Cask Body Weldment, Lightweight MAGNASTOR Transfer Cask (LMTC)	0NP*
71160-L261	Structure, Weldment, Concrete Cask, MAGNASTOR	0NP*
71160-L262	Reinforcing Bar and Concrete Placement, Concrete Cask, MAGNASTOR	0NP*
71160-L272	Details, Neutron Absorber, Retainer, BWR, MAGNASTOR	0NP*
71160-L290	Loaded Concrete Cask, MAGNASTOR	0NP*
71160-L291	Fuel Tube Assembly, BWR, MAGNASTOR	0NP*
71160-L297	Side Support Weldment, BWR, MAGNASTOR	0NP*
71160-L298	Corner Support Weldment, BWR, MAGNASTOR	0NP*
71160-L361	Structure, Weldment, Concrete Cask, MAGNASTOR	0NP*
71160-L362	Reinforcing Bar and Concrete Placement, Concrete Cask MAGNASTOR	0NP*
71160-L363	Lift Lug and Details, Concrete Cask, MAGNASTOR	0NP*
71160-L364	Upper Segment Assembly, Concrete Cask, MAGNASTOR	0NP*
71160-L381	Shell Weldment, BWR TSC, MAGNASTOR	0NP*
71160-L384	Details, Closure Lid, BWR TSC, MAGNASTOR	0NP*
71160-L385	TSC Assembly, BWR, MAGNASTOR	0NP*
71160-L390	Loaded Concrete Cask, MAGNASTOR	0NP*
71160-L399	Basket Assembly, BWR TSC, MAGNASTOR	0NP*

* Proprietary drawing replaced by nonproprietary version.

2.2 Spent Fuel To Be Stored

MAGNASTOR is designed to safely store up to 37 PWR fuel assemblies or up to 89 BWR fuel assemblies. PWR assemblies are stored in either standard or damaged fuel basket each having a 37-assembly maximum capacity. The BWR undamaged basket has an 89-assembly capacity while the BWR damaged basket is limited to 81 assemblies. The PWR system is designed to store up to four damaged fuel cans (DFCs) in the DF Basket assembly while the BWR DF Basket assemblies are designed to store up to twelve DFCs. Each DFC may contain an undamaged fuel assembly, a damaged fuel assembly, or fuel debris equivalent to one undamaged fuel assembly. Undamaged fuel assemblies may be placed directly in the DFC locations of a DF Basket Assembly. PWR fuel assemblies may be stored with nonfuel hardware. PWR fuel assemblies loaded into a DFC shall not contain nonfuel hardware, with the exception of instrument tube tie components and steel inserts.

The fuel assemblies are assigned to two groups of PWR and two groups of BWR fuel assemblies on the basis of fuel assembly length. Refer to Chapter 1 for the fuel assembly length groupings.

PWR and BWR fuel assemblies having parameters as shown in Table 2.2-1 and Table 2.2-2, respectively, may be stored in MAGNASTOR.

The minimum initial enrichment limits are shown in Table 2.2-1 and Table 2.2-2 for PWR and BWR fuel, respectively. Fuel assemblies with low enriched, unenriched, and/or annular axial end-blankets may be loaded into MAGNASTOR.

2.2.1 PWR Fuel Evaluation

MAGNASTOR evaluations are based on bounding PWR fuel assembly parameters that maximize the source terms for the shielding evaluations, the reactivity for criticality evaluations, the decay heat load for the thermal evaluations, and the fuel weight for the structural evaluations. These bounding parameters are selected from the various spent fuel assemblies that are candidates for storage in MAGNASTOR. The bounding fuel assembly values are established based primarily on how the principal parameters are combined, and on the loading conditions (or restrictions) established for a group of fuel assemblies based on its parameters.

The limiting parameters of the PWR fuel assemblies authorized for loading in MAGNASTOR are shown in Table 2.2-1. The maximum initial enrichments listed are based on maximum neutron absorber content (g $^{10}B/cm^2$) and maximum soluble absorber levels (ppm Boron). Lower absorber sheet areal densities and/or soluble boron concentrations are allowed in water for fuel assemblies with lower maximum enrichments. The maximum initial enrichment authorized represents the peak fuel rod enrichment for variably enriched PWR fuel assemblies. The PWR fuel assembly characteristics are summarized by fuel assembly type in Table 6.4.3-1, with maximum initial enrichment/ minimum soluble boron content as a function of absorber sheet loading listed in Table 6.4.3-2. Table 2.2-1 assembly physical information is limited to the criticality analysis input of fuel mass, array configuration, and number of fuel rods. These analysis values are key inputs to the shielding and criticality evaluations in Chapters 5 and 6. Lattice parameters dictating system reactivity are detailed in Chapter 6. Enrichment limits are set for each fuel type to produce reactivities at the upper subcritical limit (USL).

The maximum TSC decay heat load for the storage of PWR fuel assemblies varies depending on maximum fuel assembly heat load, transfer cask used, zoning preference and minimum cool-time needed. Figure 2.2-1 shows the fuel storage locations for each loading pattern allowed in the PWR basket and in the DF Basket Assembly. The heat loads are a combined total of the fuel assembly and non-fuel hardware (if applicable). Each of the loading patterns and their associated fuel storage maximum heat loads are described below. Note, Figure 2.2-1 is a consolidated view of all the following patterns for both the PWR and PWR DF baskets. Designations for each pattern (e.g., A through H) is used for simplicity but are referred to within the FSAR evaluations by their description instead of the pattern designation. The exceptions are Patterns E, F, G and H which are referred to as X, Y, Z and Z-Prime within the FSAR evaluation sections.

Pattern A is a uniform loading pattern that permits assemblies with a peak heat load of 0.96 kW/assembly. Pattern B is the preferential three-zone loading pattern permitting peak heat loads of 1.20 kW/assembly. Pattern C is the preferential four-zone loading pattern limited to Combustion Engineering (CE) 16×16 or Westinghouse (WE) 14×14 permitting peak heat loads of 1.80 kW/assembly. Pattern D been removed as an optional loading pattern. Loading patterns E, F, G, and H are micro-zoned patterns only to be utilized with Babcock and Wilcox (BW) 15×15 fuel and the CC6 overpack. The micro-zoning of fuel assembly maximum heat loads allows patterns E, F, G, and H to achieve peak heat loads of 3.4, 2.8, 2.5, and 2.05 kW/assembly respectively. Loading patterns I through N are high heat load patterns, i.e., greater than 35.5 kW. These patterns are also designated as patterns 37P-I through 37P-N in the thermal evaluation. Heat load patterns above 35.5 kW are not applicable to the 14×14 fuel types (i.e., CE14 and WE14).

The fuel basket configuration for PWR fuel with damaged fuel cans is shown in Figure 2.2-1. The bounding thermal evaluations for the baseline 35.5 kW heat load are based on the WE 17×17 fuel assembly. The fuel assemblies and source terms that produce the maximum storage and transfer cask dose rates are summarized in Section 5.1 for the 35.5 kW maximum heat load cases.

spent fuel assemblies. The TSC shell is fabricated from dual-certified SA240 Type 304/304L stainless steel. The TSC closure lid is fabricated from Type 304 or 304L stainless steel, with material yield and ultimate strengths equal to, or greater than, those of Type 304. The TSC shell is a 0.5-inch thick plate formed into a 72-inch outer diameter cylinder. The TSC closure lid assembly is provided as either a single-piece stainless steel plate (i.e., 9-inch thick lid for the TSC1 and TSC2 configurations and 8-inch thick lid for the TSC5 configuration) or a two-piece composite lid assembly (i.e., the TSC3 and TSC4 configurations). The TSC3 and TSC4 composite lid assembly design consists of a 4-inch thick closure lid and a 5-inch thick shield plate. Note that an optional pocket recess (5 inches in diameter and 3 inches deep) may be provided near the center of the 9-inch closure lid for TSC1/TSC2 configurations to accommodate a neutron source. The recessed lid is only permitted for storage of CE16 fuel using the PMTC and the CC5 storage cask. The structural evaluation of this lid configuration with recess is bounded by that of the 4-inch closure lid for the TSC3/TSC4 configurations. The closure lid forms the TSC confinement boundary and provides radiation shielding. The shield plate, which is fabricated from A36 carbon steel that is coated with electroless nickel plating, provides radiation shielding and structural support for the closure lid. The shield plate is attached to the closure lid by ten 1-½ inch diameter A193, Grade B6 bolts.

The fuel basket assembly is provided in two configurations – one for up to 37 PWR fuel assemblies and one for up to 89 BWR fuel assemblies. The PWR configuration includes a DF basket design to store up to 4 PWR damaged fuel cans at corner locations. The BWR configuration includes a DF basket design to store up to 81 BWR fuel assemblies and up to 12 BWR damaged fuel cans. The baskets are manufactured from SA537 Class 1 Carbon Steel. For both the PWR basket and BWR basket, the basic components are the same. The baskets are assembled from three major components – fuel tube assemblies, corner support weldments, and side support weldments. The fuel tube assemblies are equipped with neutron absorbers and stainless steel covers on up to four interior surfaces of the fuel tubes. When neutron absorbers are not needed, they may be replaced by aluminum sheets. The geometric integrity of the fuel tube array (21 fuel tubes – PWR, 45 fuel tubes – BWR) is maintained by the corner and side support weldments, which are bolted to the fuel tube array. The nominal inner dimension of the PWR fuel tubes is 8.86-inches square. The nominal inner dimension of the BWR fuel tubes is 5.86-inches square. The nominal inner dimension of the BWR DF tubes/weldments is 6.52-inches square (to accommodate a BWR damaged fuel can).

Transfer Cask

The transfer cask, with its lifting yoke, is primarily a shielded lifting device used to handle the TSC. It provides biological shielding for a loaded TSC. The transfer cask is used for the vertical transfer of the TSC between workstations and the storage cask, or transport cask. The transfer cask is available in multiple configurations. The first is the standard MAGNASTOR Transfer Cask (MTC) with solid neutron shielding. The MTC can be supplied fabricated from high-strength carbon steel (MTC1) or a shortened stainless steel version (MTC2). The second configuration is the Passive MTC (PMTC) with demineralized water filled shield tank. The PMTC has a larger cavity diameter (inner diameter of the cask inner shell) than the MTC, resulting in a larger gap between the loaded TSC and the cask inner shell, which allows passive air cooling for the system during the transfer operations. The third configuration is the Lightweight MTC (LMTC), intended for use at facilities with limited crane capacity and for TSCs with high-heat loads. The LMTC includes a demineralized water-filled neutron shield tank that can be drained for pool loading operations to reduce the hook wet weight, then refilled to restore neutron shielding prior to performing canister draining, drying, and closure operations. The LTMC structural components are all fabricated from stainless steel. The transfer cask is a heavy lifting device that is designed, fabricated, and load-tested to the requirements of ANSI–N14.6 [2] and NUREG–0612 [3]. All of the transfer cask configurations include TSC retainers that are designed to prevent a loaded TSC from being inadvertently lifted through the top of the transfer cask. The MTC1 TSC retainer consists of three retractable retainer assemblies attached to the top of the transfer cask. The MTC2 TSC retainer for the MTC2 and PMTC consists of an annular plate that is bolted to the transfer cask top ring. The MTC2 TSC retainer also has an optional configuration of three retainer assemblies, which is similar to those for the MTC1 cask. The transfer cask has retractable bottom shield doors. During loading operations, the doors are closed and secured by bolts/pins so they cannot inadvertently open. During unloading, the doors are retracted using hydraulic cylinders to allow the TSC to be lowered into the storage cask or transport cask.

Component Evaluation

The following components are evaluated in this chapter.

- TSC lifting devices
- TSC shell, bottom plate, and closure lid assembly
- Fuel basket assembly
- Transfer cask trunnions, shells, retainer, shield doors, and support rails
- Storage cask body
- Storage cask steel components (reinforcement, inner shell, lid assembly, bottom weldment, etc.)

Other MAGNASTOR components shown on the license drawings in Chapter 1 are included as loads in these component evaluations.

The structural evaluations in this chapter demonstrate that MAGNASTOR components meet their respective structural design criteria and are capable of safely storing the design basis PWR or BWR spent fuel assemblies.

[redacted]

4.10.3 Thermal Models for the PMTC Thermal Evaluation - 35.5 kW

For the PMTC containing a loaded PWR TSC with a maximum heat load of 35.5 kW, thermal evaluation is performed using the thermal models described in Section 4.10.1 with the following modifications to remove conservatism:

1. The effective thermal properties for the fuel assembly or the loaded basket region correspond to the fuel type of CE16×16 fuel.
2. For TSC backfilled with helium, the average helium density is changed to 0.76 g/L from 0.69 g/L.
3. Turbulence flow is modeled for the helium or water regions inside the TSC.
4. The emissivity of basket wall facing the canister shell is changed to 0.32 from 0.2.
5. The canister shell inner and outer surface emissivity is changed to 0.5 from 0.36. The PMTC inner and outer surface emissivity is also changed to 0.5 from 0.36.

The heat generation rate is defined in the active fuel region of the models based on the axial power profile for the PWR fuel as shown in Figure 4.4-3. Heat load distribution in the radial direction in the models is based on loading pattern as presented in Figure 4.1-1. For the evaluation of water, vacuum and helium backfill phases, the analyses are performed considering the ACWS in operation with a water flow rate of 40 gpm and a cooling water temperature of ≤125°F. Note that the sensitivity analyses discussed in Section 4.10 show insignificant differences in using ACWS or R-ACWS for the annulus cooling.

The additional modifications which are unique to each model, if any, are described in the respective model description below.

4.10.3.1 Two-Dimensional Axisymmetry FLUENT Model for the Transfer Condition

A two-dimensional axisymmetric FLUENT model is used to perform a steady state analysis for the transfer condition of the TSC inside the PMTC. The model is identical to the model presented in Section 4.10.1.1 with applicable modifications described in Section 4.10.3. In addition, the bottom surface of the PMTC door is changed to a convective surface from an adiabatic surface. The convective heat transfer coefficient for a horizontal plate facing downward (Kreith) [13] is applied on this surface.

$$Nu_L = 0.27\, Ra_L^{1/4} \qquad (10^5 \le Ra_L \le 10^{10})$$

$$h_{bottom} = \mathrm{Nu}_L \times k_f / L$$

Ra_L ----------------- $Gr_L \times Pr$, is the Rayleigh numbe

L	------------	surface area/perimeter, is the characteristic length, meter
Nu_L	------------	Nusselt number at the bottom surface
k_f	------------	Conductivity calculated at the film temperature, W/m-K
h_{bottom}	------------	heat transfer coefficient at the bottom surface, W/m^2-K

4.10.3.2 Two-Dimensional Axisymmetric FLUENT Model for Water Phase

A two-dimensional axisymmetric FLUENT model is used to perform a steady state analysis for PMTC containing the loaded TSC with water inside the TSC. The model is identical to the model presented in Section 4.10.1.2, with applicable changes described in Section 4.10.3.

4.10.3.3 Two-Dimensional Axisymmetry FLUENT model for vacuum drying condition

A two-dimensional axisymmetric FLUENT model is used to perform a steady state analysis to provide boundary conditions for the vacuum drying analysis. The model is identical to the model presented in Section 4.10.1.3, with applicable changes described in Section 4.10.3.

4.10.3.4 Two-Dimensional Axisymmetric FLUENT Model for Helium Cool Down Condition

A two-dimensional axisymmetric FLUENT model is used to perform a transient analysis for helium cooldown condition. The model is identical to the model presented in Section 4.10.1.4, with applicable changes described in Section 4.10.3. In addition, the top surface of canister lid is modified from adiabatic surface to a convective surface with radiation. The convection heat transfer coefficient for top surface is applied as described in Section 4.4.1.1. The emissivity of 0.36 is applied for radiation. The ambient temperature for convection and radiation heat transfer is 104°F.

The initial conditions for the transient cooling simulation using this model are:

1. The temperature field with peak temperature of 690°F is applied in the canister which is the peak temperature at the end of the vacuum drying phase.

2. A pressure of 90.6 psig is applied inside the TSC resulting in the average helium density of 0.76 g/L.

3. Zero helium velocity in the canister.

4.10.4 Evaluation of Transfer Operations Using PMTC - 35.5 kW

Thermal evaluations are performed for the Transfer Cask (PMTC) containing the TSC with PWR fuel with heat load of 35.5 kW for the water, vacuum drying, helium and transfer conditions.

4.10.4.1 Evaluation of the Water Phase

The two-dimensional axisymmetric FLUENT model as described in 4.10.3.2 is used to evaluate the condition when the TSC is filled with water with ACWS in operation. A steady state analysis is performed for heat load of 35.5 kW. The maximum fuel temperature is computed to be 149°F.

4.10.4.2 Evaluation of the Vacuum Drying Phase

Thermal transient analysis for the vacuum drying phase is performed using the quarter-symmetry three-dimensional ANSYS model as described in Section 4.10.3.5. The initial condition is based on analysis results of water phase described in Section 4.10.4.1. A bounding boundary condition (TSC shell outer surface temperature profile) is obtained by steady state analyses using two-dimensional axisymmetric FLUENT model described in Section 4.10.3.3.
The transient analyses are performed for 24 hours for the total heat load of 35.5 kW. The maximum temperatures of the fuel cladding and basket are presented in Table 4.10-1. The maximum fuel temperature as a function of time for the vacuum drying phase is shown in Figure 4.10-6.

As described in 4.10.2.2, the system thermal performance for an additional 4 hours is performed under vacuum condition to allow for removal of the shield/seal insert. This is conservative since the TSC has been backfilled with helium with the required helium mass per Table 3A-1 of LCO 3.1.1. For this analysis, the canister shell surface is conservatively changed to adiabatic while the convection and radiation heat transfer is maintained at canister top surface. The maximum fuel temperature is calculated to be 736°F after an additional 4 hours of vacuum condition.

If dryness is not met within the first vacuum drying cycle time limits, the TSC shall be backfilled with helium to 91 psig (-0, +10 psi) and cooled by ACWS or R-ACWS with minimum flowrate of 40 gpm and cooling water temperature of ≤ 125°F. The peak fuel temperature reduces to 435°F in 24 hours of cooling. By using the temperature history for the first vacuum drying cycle, the time limit for the second (or subsequent) vacuum drying after the cooling period is determined to be 14 hours, as shown in Table 4.10-2.

4.10.4.3 Evaluation of the Helium Backfill Phase (24 hour cooling)

The evaluation of helium backfill phase is performed by a transient analysis and is discussed in Section 4.10.2.3 for heat loads ≤ 30 kW. For heat load of 35.5 kW, the transient analysis considers that the TSC is initially backfilled with helium with a pressure of 91 psig, corresponding to a density of 0.76 g/L. The analysis is performed for 24 hours with the ACWS in operation. The two-dimensional FLUENT model described in Section 4.10.3.4 is used for the analysis. The analysis considers an initial condition with a maximum fuel cladding temperature of 690°F. The maximum fuel temperature history for 24 hours period for is shown in Figure 4.10-7. After 24 hours of cooling, the maximum fuel temperature is 435°F.

4.10.4.4 Evaluation of Transfer Condition (Moving the TSC into the Concrete Cask)

A steady state analysis is performed for the PMTC containing the loaded TSC for 35.5 kW using the two-dimensional FLUENT model described in Section 4.10.3.1. There is no time limit for this operation since the maximum fuel temperature for the steady state for this condition is 708°F, which is below the temperature limit of 752°F.

Figure 4.10-5 Temperature Distribution of the Canister Outer Surface (ºF) – Vacuum Drying Condition (35.5 kW)

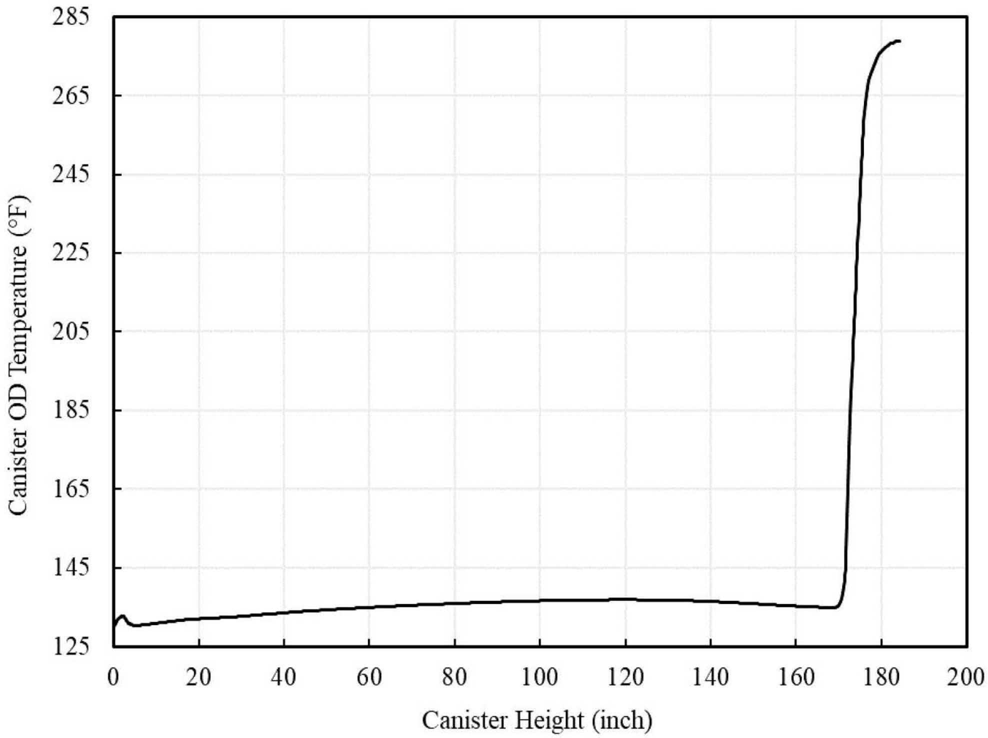

Figure 4.10-6 Maximum Fuel Temperature vs. Time for Vacuum Drying – 35.5 kW

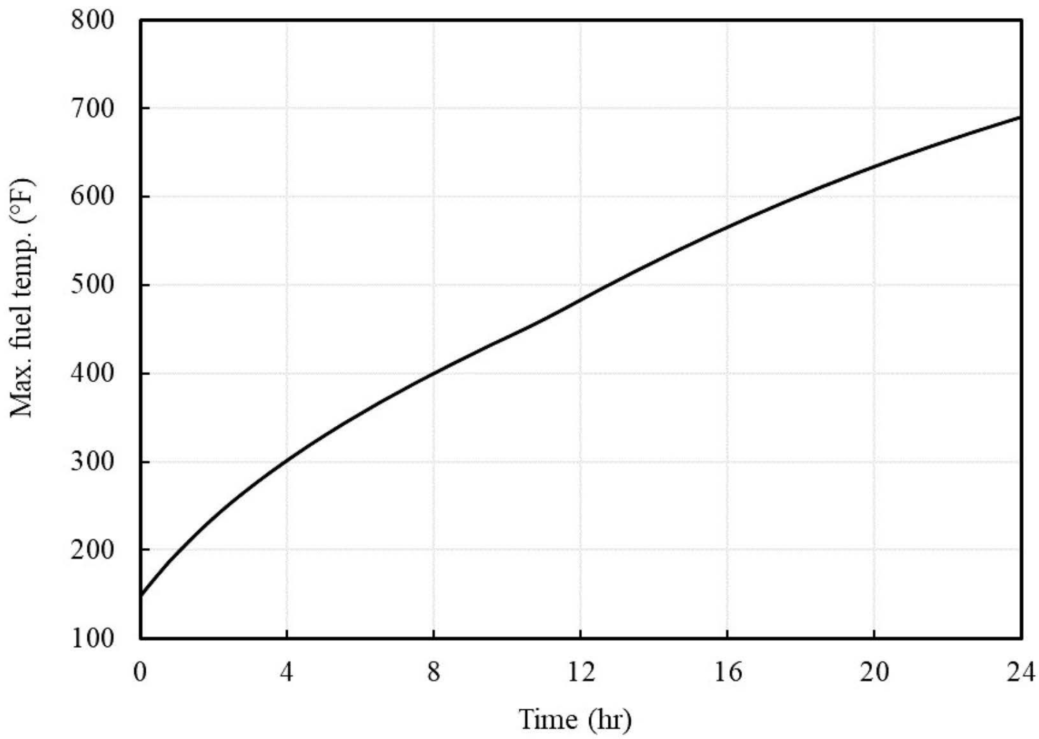

Figure 4.10-7 Maximum Fuel Temperature vs. Time for Cool-down Condition – 35.5 kW

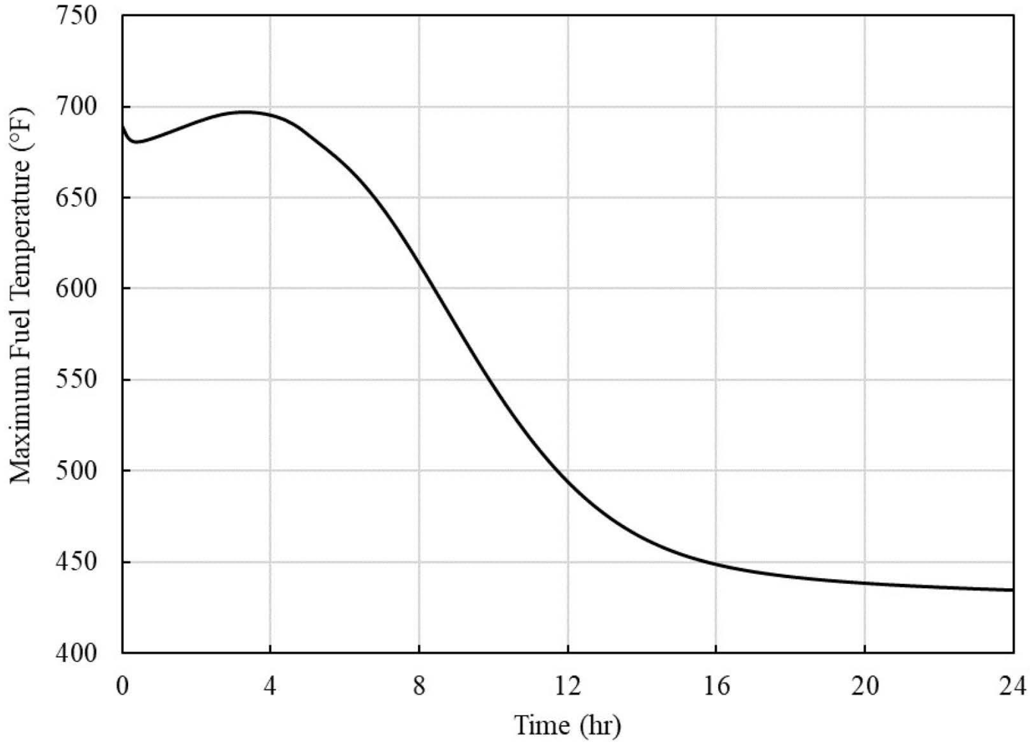

Table 4.10-1 Durations and Temperatures at the End of the First Vacuum Stage for PMTC Configuration

Heat Load (kW)	Vacuum Duration (hours)	T_{max} at the End of the Duration (°F)	
		Fuel	Basket
35.5	24	690	661
30	32	715	687
25	54	715	688
20	No Limit	651	625

Table 4.10-2 Durations and Temperatures at the End of the Second Vacuum Stage for PMTC Configuration

Heat Load (kW)	Helium Backfill Duration (hours)	T_{max} of Fuel at the End of the Helium Backfill (°F)	Second Vacuum Duration (hours)	T_{max} of Fuel at the End of the Second Vacuum (°F)
35.5	24	435	14	690
30	24	446	17	715
25	24	446	34	715

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5.17 Closure Lid Recess Effect on Top Dose Rates (PMTC and CC5)

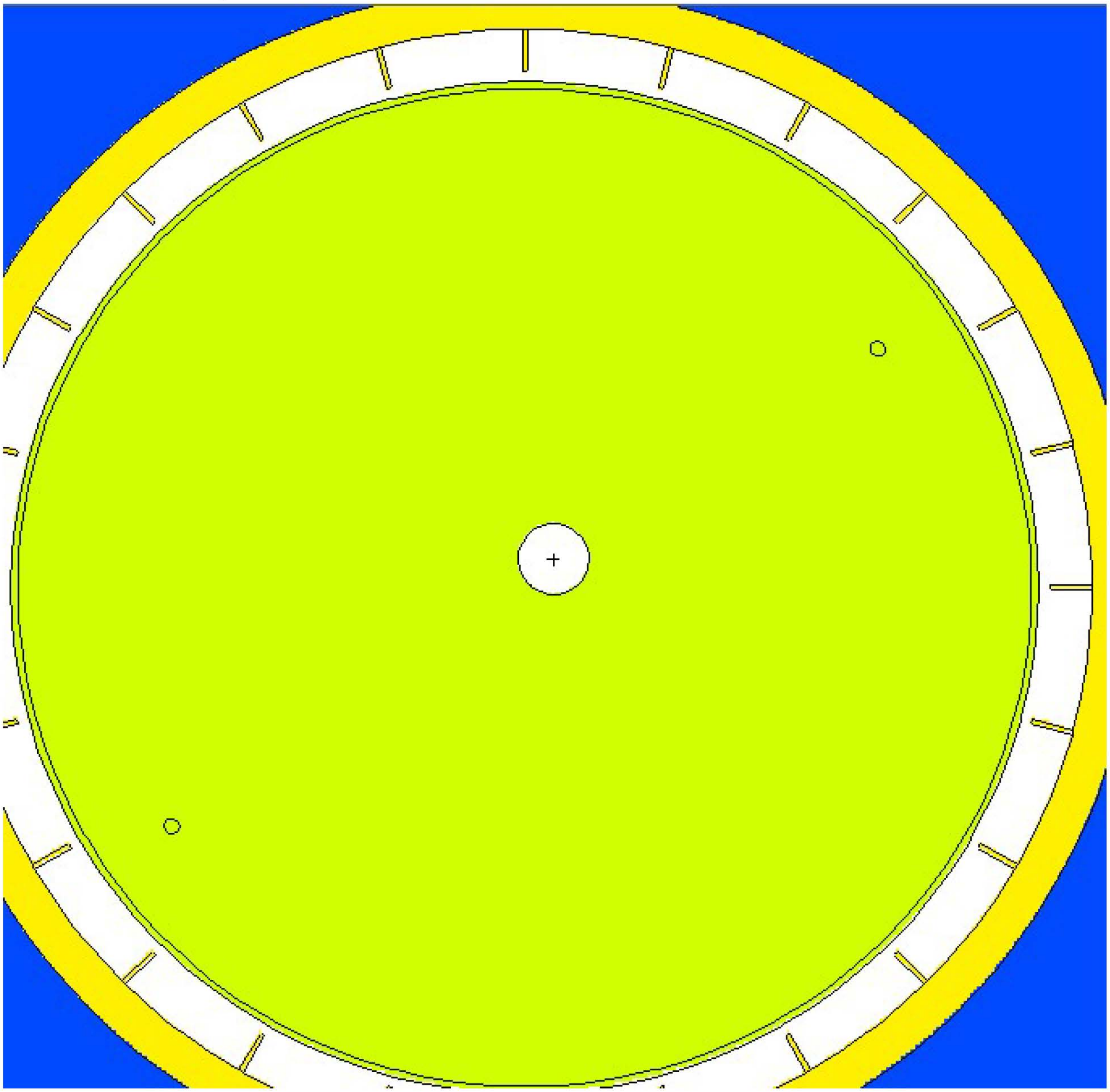
In order to accommodate the loading of neutron source assemblies longer than the TSC cavity height, a recess in the TSC closure lid has been included in the storage system design. This section documents the effect on top dose rates for the PMTC and CC5 for a uniform cask heat load of 35.5 kW. The results are applicable to allowable preferential loadings of these casks.

The effect of the recess on the top dose rates is governed by the contribution from fuel assemblies, not the neutron source contribution. This is based on the neutron source being effectively a near point source recessed into the middle of the active fuel region (~90 inches from the top of the assembly). Fuel will self-shield the neutron source with the exception of a very small focus angle. Furthermore, adjacent fuel assemblies contribute to the top dose rates at the center of the basket, not just the assembly under the recess.

5.17.1 Model Description

Other than the recess in the TSC closure lid, no changes are required to the previously-developed models of the PMTC and CC5. The closure lid recess is 3 inches deep with a 5-inch OD, slightly offset from the center of the basket as shown in Figure 5.17.1-1.

Figure 5.17.1-1 Modeled TSC Closure Lid Recess Location



5.17.2 PMTC Results

Two configurations are evaluated for the PMTC at the bounding 35.5 kW source terms:

- Configuration 1 models the vacuum drying and sealing process. This configuration leaves out the port covers and installs a weld shield to the top of the TSC. Also included in this configuration is the shield/seal insert assembly (shield ring) which provides shielding in the annulus between the TSC and the passive transfer cask. Configuration 1 is evaluated with a burnup of 40 GWd/MTU, initial enrichment of 2.5 wt% ^{235}U, and a cool time of 5.6 years.
- Configuration 2 models the transfer of the TSC to the concrete cask. This configuration removes the shield/seal insert assembly and the weld shield from the previous configuration and inserts the TSC port covers and a 3-inch retaining ring. Configuration 2 is evaluated with a burnup of 35 GWd/MTU, initial enrichment of 2.3 wt% ^{235}U, and a cool time of 4.7 years.

Results for the PMTC are shown in Figure 5.17.2-1 and Figure 5.17.2-2. In the figures, “Baseline” denotes the no recess results and “Void for NSA” denotes the lid recess results. As expected, dose rates increase at the cask centerline for both models. Dose rates at the TSC-to-cask annulus and over the entire surface decrease for the Configuration 1 model and increase for the Configuration 2 model. The TSC-to-cask annulus peak for the Configuration 2 model is within 2σ of the no recess dose rate. Due to the very small uncertainties over the entire surface, a greater than 2σ increase in the average is observed. However, an increase of 2% is deemed as not significant based on typical uncertainties, which often exceed 1%. As the peak locations are within 2σ, and this location is bounding for occupational exposures, occupational exposures will not significantly increase.

Based on the rationale above, the recess in the TSC closure lid is acceptable for the PMTC.

Figure 5.17.2-1 PMTC Configuration 1 Model Top Dose Rate Profile Comparison

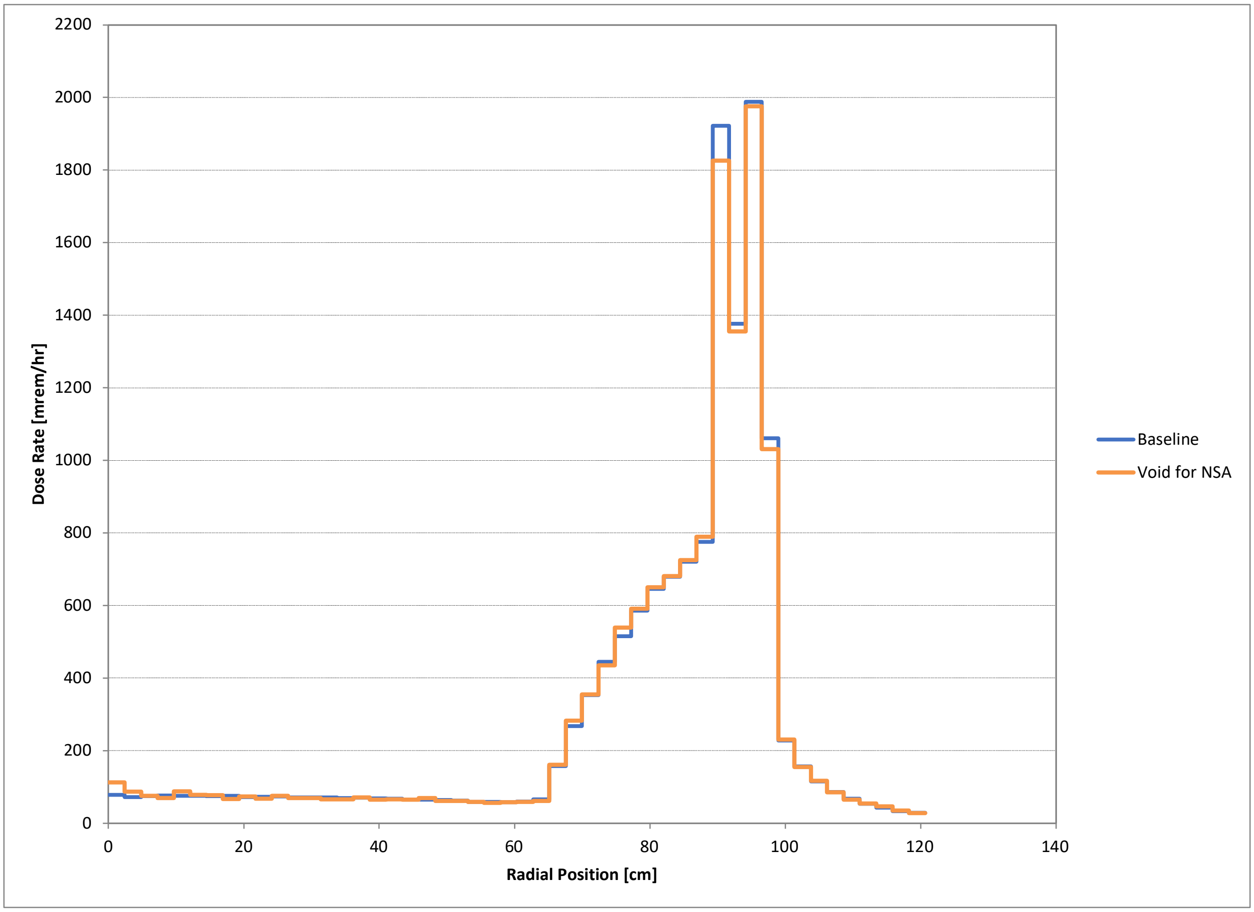
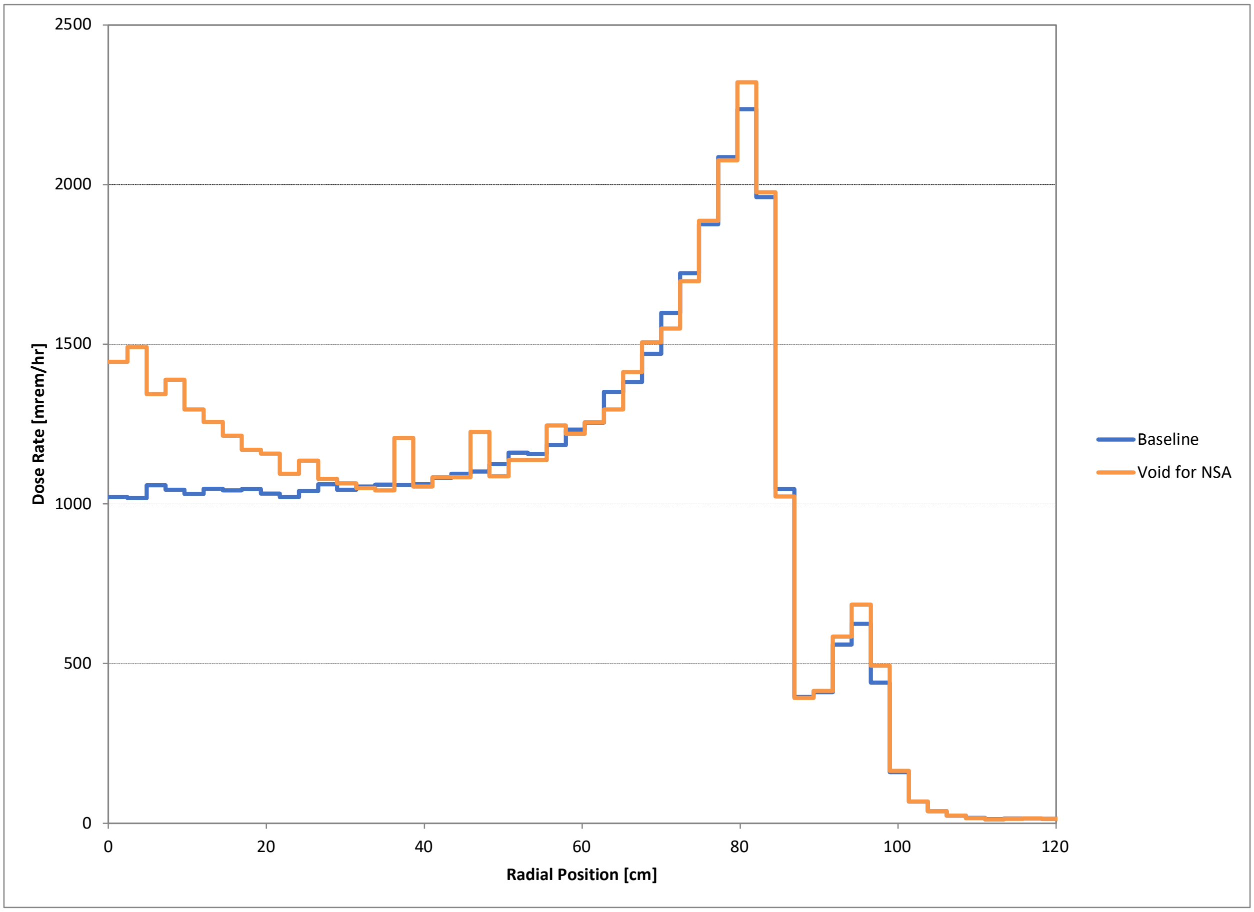


Figure 5.17.2-2 PMTC Configuration 2 Model Top Dose Rate Profile Comparison



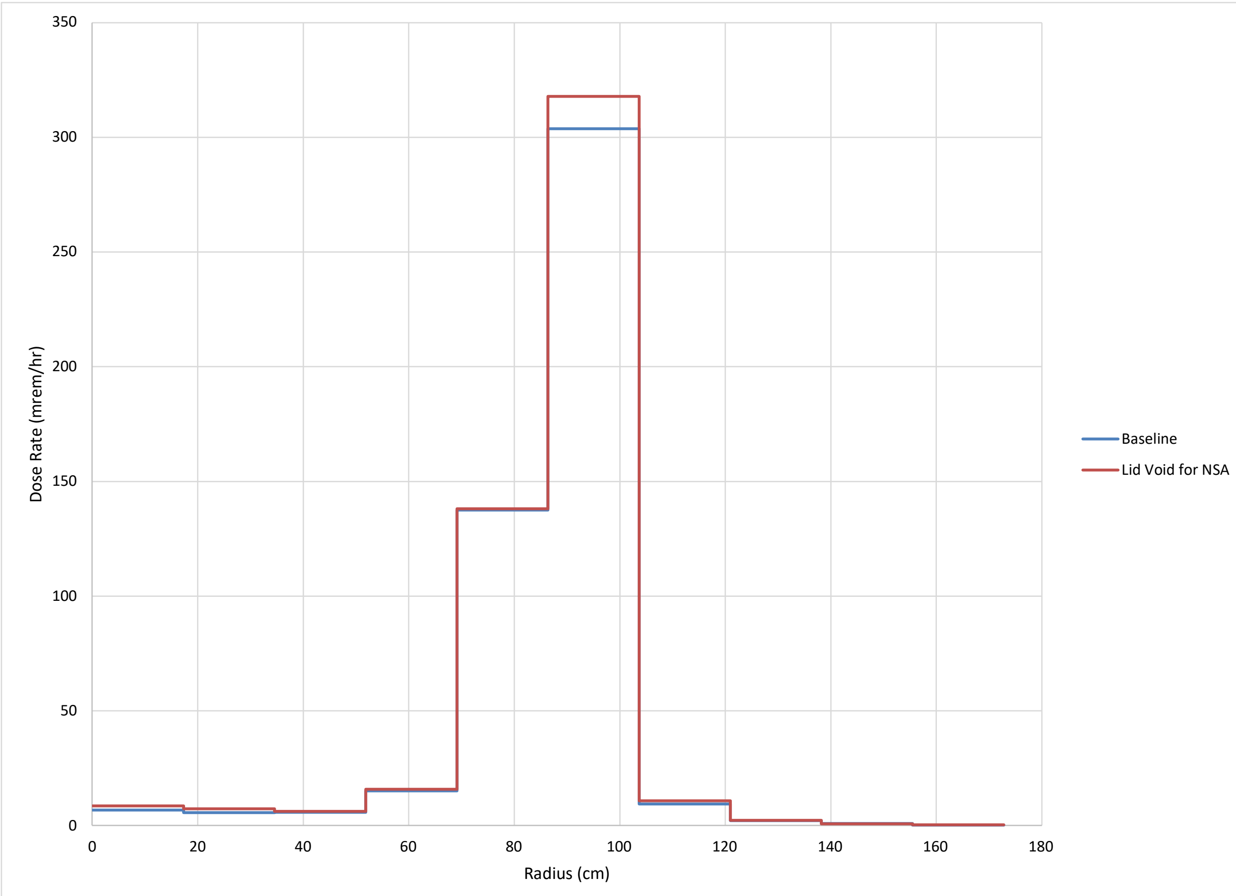
5.17.3 CC5 Results

The CC5 is evaluated with the bounding 35.5 kW source term which is a burnup of 32.5 GWd/MTU, initial enrichment of 2.1 wt% ^{235}U, and a cool time of 4.4 years.

Results for the CC5 are shown in Figure 5.17.3-1. As expected, the dose rate increases at the cask centerline. This increase is greater than 2σ of the no recess dose rate. Increases are also observed at the peak over the TSC-to-cask annulus and over the entire surface. The increase at the peak is within 2σ of the no recess dose rate. The increase over the entire surface is within 0.1% of 2σ. This is deemed as a non-significant effect on site boundary dose rates, which are governed by average surface dose rates.

Based on the rationale above, the recess in the TSC lid is acceptable for the CC5.

Figure 5.17.3-1 CC5 Top Dose Rate Profile Comparison



creates effective flux traps between fuel assemblies, the configuration will be bounded by 37-assembly evaluations. No 21-assembly specific criticality evaluations were performed. 37-assembly enrichment/soluble boron limits are applicable to the underload configuration.

MCNP5, a three-dimensional Monte Carlo code, is used in the baseline PWR and BWR system criticality analysis. The evaluations are primarily based on the ENDF/B-VI continuous energy neutron cross-section library [4 and 11] available in the MCNP distribution. Nuclides for which no ENDF/B-VI data is available are set to the latest cross-section sets available in the code distribution. The code and cross-section libraries are benchmarked by comparison to a range of critical experiments relevant to light water reactor fuel in storage and transport casks. An upper subcritical limit (USL) for the system is determined based on guidance given in NUREG/CR-6361 [10]. Later evaluations, for example BWR-DF and preferential load evaluations, apply MCNP6 with primarily ENDF/B-VII continuous energy cross-sections. Identical to the MCNP5 evaluations a USL and area of applicability is established consistent with NUREG/CR-6361. Detail of the MCNP6 validation/bias calculations is included in Section 6.5 and Section 6.7.7.

Key assembly physical characteristics, maximum initial enrichment, and soluble boron requirements (PWR only) for each PWR and BWR fuel assembly type are shown in Table 6.1.1-1, Table 6.1.1-2 and Table 6.1.1-10 for the PWR system and Table 6.1.1-3 through Table 6.1.1-8 for the BWR system. PWR results represent the bounding values for fuel assemblies with and without nonfuel inserts in the guide tubes. Maximum enrichment is defined as peak rod enrichment for PWR assemblies and the maximum peak planar-average enrichment for BWR assemblies. The maximum initial peak planar-average enrichment is the maximum planar-average enrichment at any height along the axis of the fuel assembly.

Assemblies are evaluated with a full, nominal set of fuel rods. Fuel rod (lattice) locations may contain filler rods. A filler rod must occupy, at a minimum, a volume equivalent to the fuel rod it displaces. Filler rods may be placed into the lattice after assembly in-core use or be designed to replace fuel rods prior to use, such as integral burnable absorber rods.

The assembly must contain its nominal set of guide and instrument tubes (PWR), and water rods (BWR). Analysis demonstrated that variations in the guide/instrument tube and water rod thickness and diameter have no significant effect on system reactivity.

6.1.1.1 Undamaged Fuel Criticality Results

The maximum multiplication factors ($k_{eff}+2\sigma$) are calculated, using conservative assumptions, for the transfer and concrete cask. The USL applied to the analysis results is 0.9376 per Section 6.5.2. The results of the analyses are presented in detail in Sections 6.4.3 and 6.7. Summary of key results for the MCNP5 baseline evaluations are summarized as follows.

Cask Body	Gap Condition	Operating Condition	Water Density (g/cc) Interior	Exterior	PWR $k_{eff} + 2\sigma$	BWR $k_{eff} + 2\sigma$
Transfer	Dry	Normal	0.9982	0.0001	0.93183	0.92900
Transfer	Wet	Normal	0.9982	0.0001	0.93712	0.93679
Transfer	Dry	Normal	0.9982	0.9982	0.92975	0.92839
Transfer	Wet	Normal	0.9982	0.9982	0.93615	0.93674
Storage	Dry	Normal	0.0001	0.0001	0.48145	0.43685
Storage	Dry	Accident	0.0001	0.9982	0.47104	0.42991

Analysis of simultaneous moderator density variation inside and outside either the transfer or concrete cask shows a monotonic decrease in reactivity with decreasing moderator density. For the BWR system, there is a statistically significant increase in reactivity when moving from void to full moderator density. In the PWR system, reactivity increases as moderator density rises from void conditions, but there is no significant reactivity difference at water densities above 0.9 g/cm^3. The use of soluble boron in PWR systems, specified in parts per million of moderator, flattens out the reactivity curve by increasing absorber quantity in conjunction with increasing moderator. The full moderator density TSC interior condition bounds any off-normal or accident condition. Analysis of moderator intrusion into the concrete cask heat transfer annulus with the dry TSC shows a slight decrease in reactivity from the completely dry condition.

Additional evaluations such as BWR damaged fuel evaluations and underload/preferential load evaluations for the BWR system were performed with MCNP6, which while producing slightly higher keff values also has a higher USL (see section 6.5). Results for these calculations are included in their respective detail section (Section 6.7) and are below the USL.

BWR fuel assemblies subject to CILC damage are evaluated in the 89-Assembly Basket under the assumption that the assembly includes the channel and does not require a DFC for other damage that includes gross fuel failure or fuel debris. Evaluations and limits for this condition are included in Section 6.7.10.

6.1.1.2 Damaged PWR Fuel Criticality Results

The PWR system is designed to safely store up to 37 PWR fuel assemblies of which up to 4 may be classified as damaged and be placed into damaged fuel cans (DFCs) in the four corner basket locations. The DFC provides a screened container to prevent gross fissile material release into the TSC cavity from failed fuel rod cladding. The results of the analyses are presented in detail in Section 6.7.8 and are summarized as follows. All results are below the USL of 0.9376.

Figure 6.1.1-3 BWR DF Basket Configuration – Basket Cell Location Identification

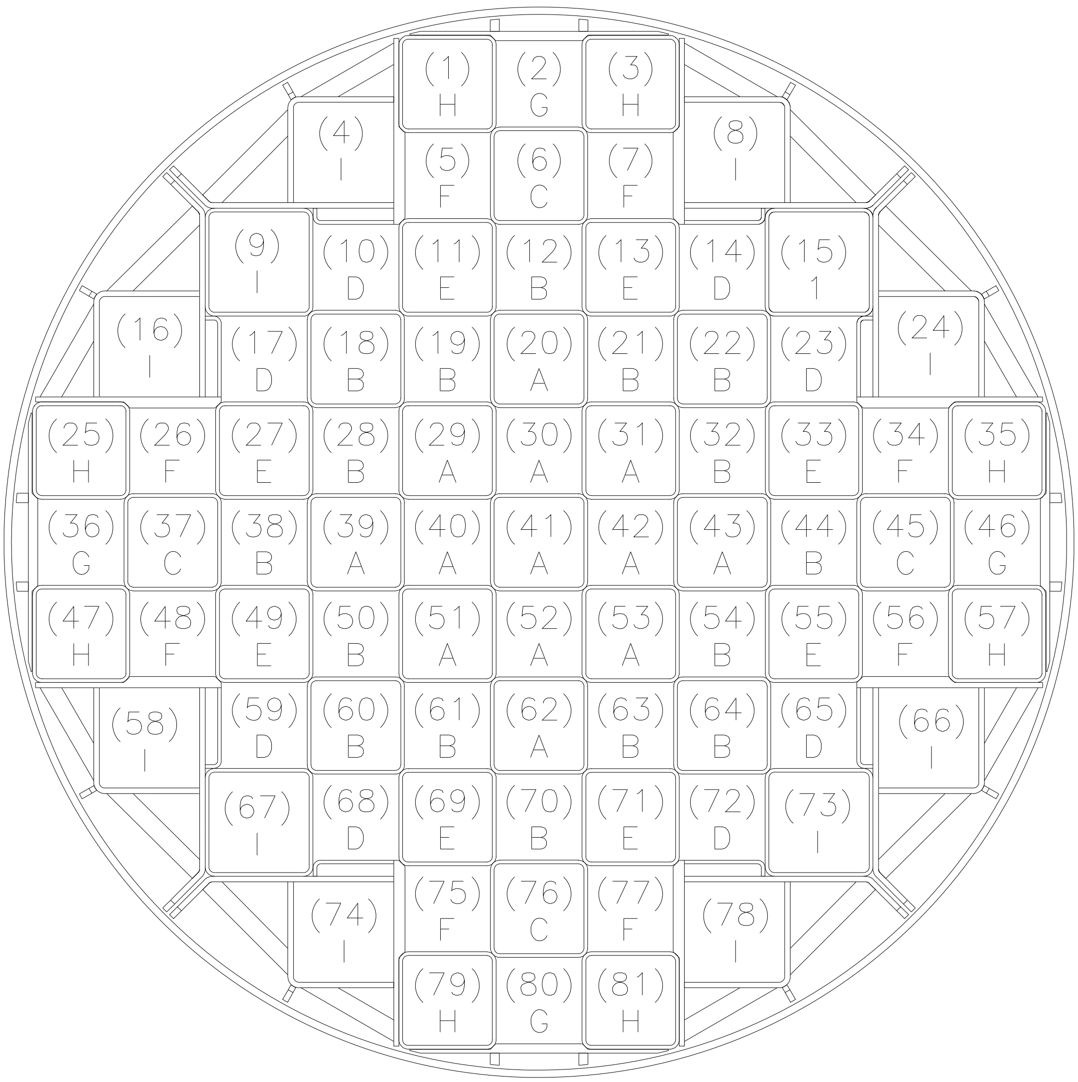


Table 6.1.1-1 Bounding PWR Fuel Assembly Loading Criteria (Assembly Description)

Assembly Type	No. of Fuel Rods	No. of Guide Tubes[a]	Max Pitch (inch)	Min Clad OD (inch)	Min Clad Thick. (inch)	Max Pellet OD (inch)	Max Active Length (inch)	Max Load (MTU)
BW15H1	208	17	0.568	0.43	0.0265	0.3686	144.0	0.4858
BW15H2	208	17	0.568	0.43	0.025	0.3735	144.0	0.4988
BW15H3	208	17	0.568	0.428	0.023	0.3742	144.0	0.5006
BW15H4	208	17	0.568	0.414	0.022	0.3622	144.0	0.4690
BW15H5	208	17	0.568	0.422	0.0243	0.3659	144.0	0.4787
BW17H1	264	25	0.502	0.377	0.022	0.3252	144.0	0.4799
CE14H1	176	5	0.58	0.44	0.026	0.3805	137.0	0.4167
CE16H1[b]	236	5	0.5063	0.382	0.025	0.3255	150.0	0.4463
CE16H2	236	5	0.5063	0.374	0.0225	0.3225	150.0	0.4395
WE14H1	179	17	0.556	0.40	0.0162[(1)]	0.3674	145.2	0.4188
WE15H1	204	21	0.563	0.422	0.0242	0.3669	144.0	0.4720
WE15H2	204	21	0.563	0.417	0.0265	0.357	144.0	0.4469
WE17H1	264	25	0.496	0.372	0.0205	0.3232	144.0	0.4740
WE17H2	264	25	0.496	0.36	0.0225	0.3088	144.0	0.4327

- Assembly characteristics represent cold, unirradiated, nominal configurations.

(1) The 0.0162 inch clad thickness is below typical values for this fuel type. Clad was reduced to this thickness to maintain the maximum listed pellet diameter and minimum clad OD and not produce a clad overlap with the pellet. Documented lower bound clad thickness is 0.0218 inch for this fuel type.

[a] Combined number of guide and instrument tubes.

[b] The baseline value for analysis of the CE16H1 assembly type Maximum Pellet Outside Diameter is 0.325 inch. The increase to 0.3255 inch was evaluated in section 6.7.2 and does not impact the safety conclusion of the system, i.e., $k_{eff} \leq 0.95$.

Table 6.1.1-2 Undamaged Fuel Basket Bounding PWR Fuel Assembly Loading Criteria (Enrichment/Soluble Boron Limits)

	Max. Initial Enrichment (wt % ^{235}U)															
	Absorber[a] 0.036 ^{10}B g/cm^2						Absorber 0.030 ^{10}B g/cm^2					Absorber 0.027 ^{10}B g/cm^2				
Soluble Boron	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	2600 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)
BW15H1	3.7%	4.1%	4.4%	4.7%	5.0%	--	3.6%	4.0%	4.2%	4.5%	4.8%	3.6%	3.9%	4.2%	4.5%	4.8%
BW15H2	3.7%	4.0%	4.3%	4.6%	4.9%	5.0%	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.8%	4.1%	4.4%	4.7%
BW15H3	3.7%	4.0%	4.3%	4.6%	4.9%	--	3.6%	3.9%	4.2%	4.4%	4.7%	3.5%	3.8%	4.1%	4.4%	4.7%
BW15H4	3.8%	4.2%	4.5%	4.8%	5.0%	--	3.7%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	5.0%
BW15H5	--	--	--	--	5.0%	--	--	--	--	--	--	--	--	--	--	--
BW17H1	3.7%	4.0%	4.3%	4.6%	4.9%	--	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.9%	4.1%	4.5%	4.7%
CE14H1	4.5%	4.8%	5.0%	5.0%	5.0%	--	4.3%	4.7%	5.0%	5.0%	5.0%	4.3%	4.6%	5.0%	5.0%	5.0%
CE16H1	4.4%	4.8%	5.0%	5.0%	5.0%	--	4.3%	4.6%	5.0%	5.0%	5.0%	4.2%	4.6%	4.9%	5.0%	5.0%
CE16H2	4.4%	4.8%	5.0%	5.0%	5.0%	--	4.3%	4.6%	5.0%	5.0%	5.0%	4.2%	4.6%	4.9%	5.0%	5.0%
WE14H1	4.7%	5.0%	5.0%	5.0%	5.0%	--	4.6%	5.0%	5.0%	5.0%	5.0%	4.5%	5.0%	5.0%	5.0%	5.0%
WE15H1	3.8%	4.2%	4.5%	4.8%	5.0%	--	3.7%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	4.9%
WE15H2	4.0%	4.4%	4.7%	5.0%	5.0%	--	3.9%	4.2%	4.6%	4.9%	5.0%	3.8%	4.2%	4.5%	4.8%	5.0%
WE17H1	3.7%	4.1%	4.4%	4.7%	5.0%	--	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.9%
WE17H2	4.0%	4.3%	4.7%	5.0%	5.0%	--	3.9%	4.3%	4.6%	4.9%	5.0%	3.8%	4.2%	4.5%	4.9%	5.0%

- Specified soluble boron concentrations are independent of whether a fuel assembly contains a nonfuel insert.

[a] Borated aluminum neutron absorber sheet effective areal ^{10}B density.

Table 6.1.1-3 BWR Fuel Assembly Loading Criteria
(Assembly Description)

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)
B7_48A	48	N/A	0.7380	0.5700	0.03600	0.4900	144.0	0.1981
B7_49A	49	N/A	0.7380	0.5630	0.03200	0.4880	146.0	0.2034
B7_49B	49	N/A	0.7380	0.5630	0.03200	0.4910	150.0	0.2115
B8_59A	59	N/A	0.6400	0.4930	0.03400	0.4160	150.0	0.1828
B8_60A	60	N/A	0.6417	0.4840	0.03150	0.4110	150.0	0.1815
B8_60B	60	N/A	0.6400	0.4830	0.03000	0.4140	150.0	0.1841
B8_61B	61	N/A	0.6400	0.4830	0.03000	0.4140	150.0	0.1872
B8_62A	62	N/A	0.6417	0.4830	0.02900	0.4160	150.0	0.1921
B8_63A	63	N/A	0.6420	0.4840	0.02725	0.4195	150.0	0.1985
B8_64A	64	N/A	0.6420	0.4840	0.02725	0.4195	150.0	0.2017
B8_64B	64	N/A	0.6090	0.4576	0.02900	0.3913	150.0	0.1755
B9_72A	72	N/A	0.5720	0.4330	0.02600	0.3740	150.0	0.1803
B9_74A	74[a]	8	0.5720	0.4240	0.02390	0.3760	150.0	0.1873
B9_76A	76	N/A	0.5720	0.4170	0.02090	0.3750	150.0	0.1914
B9_79A	79	N/A	0.5720	0.4240	0.02390	0.3760	150.0	0.2000
B9_80A	80	N/A	0.5720	0.4230	0.02950	0.3565	150.0	0.1821
B10_91A	91[a]	8	0.5100	0.3957	0.02385	0.3420	150.0	0.1906
B10_92A	92[a]	14	0.5100	0.4040	0.02600	0.3455	150.0	0.1966
B10_96A	96[a]	12	0.4880	0.3780	0.02430	0.3224	150.0	0.1787
B10_100A	100	N/A	0.4880	0.3780	0.02430	0.3224	150.0	0.1861

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

[a] Assemblies may 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 6.1.1-10 Damaged Fuel Basket Bounding PWR Fuel Assembly Loading Criteria (Enrichment/Soluble Boron Limits)

	Max. Initial Enrichment (wt % ^{235}U)															
	Absorber[a] 0.036 ^{10}B g/cm^2						Absorber[a] 0.030 ^{10}B g/cm^2					Absorber[a] 0.027 ^{10}B g/cm^2				
Soluble Boron	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	2650 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)
BW15H1	3.7%	4.0%	4.3%	4.6%	4.9%	--	3.6%	3.9%	4.2%	4.5%	4.7%	3.6%	3.8%	4.1%	4.4%	4.7%
BW15H2	3.6%	3.9%	4.2%	4.5%	4.8%	5.0%	3.6%	3.8%	4.1%	4.4%	4.7%	3.5%	3.8%	4.1%	4.3%	4.6%
BW15H3	3.6%	3.9%	4.2%	4.5%	4.8%	--	3.5%	3.8%	4.1%	4.4%	4.6%	3.5%	3.8%	4.0%	4.3%	4.6%
BW15H4	3.8%	4.1%	4.4%	4.7%	5.0%	--	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.8%
BW15H5	--	--	--	--	4.9%	--	--	--	--	--	--	--	--	--	--	--
BW17H1	3.6%	3.9%	4.2%	4.5%	4.8%	--	3.6%	3.9%	4.1%	4.4%	4.7%	3.5%	3.8%	4.1%	4.4%	4.6%
CE14H1	4.4%	4.8%	5.0%	5.0%	5.0%	--	4.3%	4.7%	5.0%	5.0%	5.0%	4.3%	4.6%	4.9%	5.0%	5.0%
CE16H1	4.4%	4.7%	5.0%	5.0%	5.0%	--	4.2%	4.6%	5.0%	5.0%	5.0%	4.2%	4.5%	4.9%	5.0%	5.0%
CE16H2	4.4%	4.7%	5.0%	5.0%	5.0%	--	4.2%	4.6%	5.0%	5.0%	5.0%	4.2%	4.5%	4.9%	5.0%	5.0%
WE14H1	4.6%	5.0%	5.0%	5.0%	5.0%	--	4.5%	5.0%	5.0%	5.0%	5.0%	4.5%	4.9%	5.0%	5.0%	5.0%
WE15H1	3.8%	4.1%	4.4%	4.7%	5.0%	--	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	4.0%	4.3%	4.6%	4.8%
WE15H2	3.9%	4.3%	4.6%	4.9%	5.0%	--	3.8%	4.2%	4.5%	4.8%	5.0%	3.8%	4.1%	4.4%	4.7%	5.0%
WE17H1	3.7%	4.0%	4.3%	4.6%	4.9%	--	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.9%	4.2%	4.5%	4.8%
WE17H2	3.9%	4.3%	4.6%	5.0%	5.0%	--	3.9%	4.2%	4.5%	4.9%	5.0%	3.8%	4.1%	4.5%	4.8%	5.0%

[a] Borated aluminum neutron absorber sheet effective areal ^{10}B density.

Table 6.2.1-1 PWR Fuel Assembly Characteristics

Fuel ID		CE14H1	CE16H1	CE16H2	WE14H1	WE15H1	WE15H2	WE17H1	WE17H2	BW15H1	BW15H2	BW15H3	BW15H4	BW15H5	BW17H1
No. Fuel Rods		**176**	**236**	**236**	**179**	**204**	**204**	**264**	**264**	**208**	**208**	**208**	**208**	**264**	**264**
Base Fuel Type[a]		CE,SPC	CE	W	W,SPC	W,SPC	W,SPC	W,SPC	W,SPC	BW,FCF	BW,FCF	BW,FCF	BW,FCF	BW,FCF	BW,FCF
Pitch (in)	**Max**	0.5800	0.5063	0.5063	0.5560	0.5630	0.5630	0.4960	0.4960	0.5680	0.5680	0.5680	0.5680	0.568	0.5020
	Min	0.5800	0.5063	0.5063	0.5560	0.5630	0.5630	0.4960	0.4960	0.5680	0.5680	0.5680	0.5680	0.568	0.5020
Fuel Pellet OD (in)	**Max**	0.3805	0.3250	0.3225	0.3674	0.3669	0.3570	0.3232	0.3088	0.3686	0.3735	0.3742	0.3622	0.3659	0.3252
	Min	0.3700	0.3250	0.3225	0.3444	0.3565	0.3570	0.3225	0.3030	0.3686	0.3735	0.3707	0.3622	0.3659	0.3232
Fuel Rod OD (in)	**Max**	0.4400	0.3820	0.3740	0.4240	0.4240	0.4170	0.3740	0.3600	0.4300	0.4300	0.4280	0.4140	0.422	0.3790
	Min	0.4400	0.3820	0.3740	0.4000	0.4220	0.4170	0.3720	0.3600	0.4300	0.4300	0.4280	0.4140	0.422	0.3770
Fuel Clad Thick. (in)	**Max**	0.0310	0.0250	0.0225	0.0300	0.0300	0.0265	0.0225	0.0250	0.0265	0.0250	0.0245	0.0220	0.0243	0.0240
	Min	0.0260	0.0250	0.0225	0.0162	0.0242	0.0265	0.0205	0.0225	0.0265	0.0250	0.0230	0.0220	0.0245	0.0220
Guide Tube OD (in)	**Max**	1.115	0.980	0.980	0.481	0.544	0.484	0.482	0.482	0.493	0.493	0.493	0.493	0.493	0.420
	Min	1.115	0.970	0.970	0.481	0.484	0.484	0.482	0.480	0.493	0.493	0.493	0.493	0.493	0.420
Guide Tube Thick.	**Max**	0.040	0.035	0.035	0.034	0.017	0.017	0.015	0.016	0.016	0.015	0.014	0.014	0.014	0.020
(in)	**Min**	0.036	0.035	0.035	0.017	0.015	0.017	0.014	0.015	0.016	0.015	0.014	0.014	0.014	0.018
Active Fuel Length	**Max**	137.0	150.0	150.0	145.2	144.0	144.0	144.0	144.0	144.0	144.0	144.0	144.0	144.0	144.0
(in)	**Min**	134.0	150.0	150.0	142.0	144.0	144.0	144.0	144.0	144.0	144.0	144.0	144.0	144.0	143.0
Fuel Mass (MTU)	**Max**	0.4167	0.4463	0.4395	0.4188	0.4720	0.4469	0.4740	0.4327	0.4858	0.4988	0.5006	0.4690	----	0.4799
	Min	0.3854	0.4463	0.4395	0.3599	0.4457	0.4469	0.4720	0.4166	0.4858	0.4988	0.4913	0.4690	----	0.4707

- Fuel assembly characteristics represent cold, unirradiated, nominal fuel dimension.
- An instrument tube may be located in the center of the assembly. The instrument tube may have slightly different diameter and thickness than the guide tubes. As the instrument tube is limited to one per assembly, dimensional variations have no significant effect on system reactivity and are not listed here.
- Guide tubes may contain "dashpots" near the bottom of the active fuel region narrowing from the listed tube dimension. Stainless steel rod inserts may be installed to displace "dashpot water." Fuel assemblies containing these stainless steel rod inserts are addressed as a fuel assembly containing a nonfuel insert.
- Assemblies may contain unenriched axial blankets.

[a] Indicates assembly and/or nuclear steam supply system (NSSS) vendor/type referenced for fuel input data. Fuel acceptability for loading is not restricted to the indicated vendor provided that the fuel assembly meets the limits listed in Table 6.4.3-1. Abbreviations are as follows: Westinghouse (W), Combustion Engineering (CE), Siemens Power Corporation (SPC), Babcock and Wilcox (BW), and Framatome Cogema Fuels (FCF).

Table 6.2.1-2 BWR Fuel Assembly Characteristics

Fuel ID			B7_48A	B7_49A	B7_49B	B8_59A	B8_60A	B8_60B	B8_61B	B8_62A	B8_63A	B8_64A	B8_64B[a]
No. Fuel Rods			48	49	49	59	60	60	61	62	63	64	64
Base Fuel Type[b]			SPC	GE	GE	GE	GE	GE	GE	SPC	SPC	GE	GE
Pitch	Max	(in)	0.7380	0.7380	0.7380	0.6400	0.6417	0.6400	0.6400	0.6417	0.6420	0.6420	0.6090
	Min	(in)	0.7380	0.7380	0.7380	0.6400	0.6378	0.6378	0.6400	0.6400	0.6400	0.6420	0.6090
Fuel Pellet OD	Max	(in)	0.4900	0.4880	0.4910	0.4160	0.4110	0.4140	0.4140	0.4160	0.4195	0.4195	0.3913
	Min	(in)	0.4900	0.4770	0.4910	0.4160	0.4095	0.4095	0.4140	0.4045	0.4045	0.4195	0.3913
Fuel Rod OD	Max	(in)	0.5700	0.5700	0.5630	0.4930	0.4843	0.4843	0.4830	0.4843	0.4930	0.4840	0.4576
	Min	(in)	0.5700	0.5630	0.5630	0.4930	0.4840	0.4830	0.4830	0.4830	0.4840	0.4840	0.4576
Fuel Clad Thick.	Max	(in)	0.0360	0.0370	0.0320	0.0340	0.0320	0.0320	0.0300	0.0360	0.0360	0.0273	0.0290
	Min	(in)	0.0360	0.0320	0.0320	0.0340	0.0315	0.0300	0.0300	0.0290	0.0273	0.0273	0.0290
No. Water Rods			1	0	0	5	1	4	3	2	1	0	0
Water Rod OD		(in)	0.5700	0.0000	0.0000	0.4930	1.2598	0.4843	0.4830	0.5910	0.4930	0.0000	0.0000
Water Rod Thick.		(in)	Solid[c]	N/A	N/A	0.0340	0.0394	N/A	N/A	N/A	0.0340	N/A	N/A
Active Fuel Length	Max	(in)	144.0	146.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0
	Min	(in)	144.0	144.0	150.0	150.0	145.2	145.2	150.0	145.2	144.0	150.0	150.0
Fuel Mass	Max	(MTU)	0.1981	0.2034	0.2115	0.1828	0.1815	0.1841	0.1872	0.1921	0.1985	0.2017	0.1755
	Min	(MTU)	0.1981	0.1916	0.2115	0.1828	0.1744	0.1744	0.1872	0.1758	0.1772	0.2017	0.1755

- Assemblies may contain unenriched axial blankets.
- Water rods may occupy more than one lattice location. Square water rods are not modeled.
- Assembly lattice structure may be surrounded by a zirconium alloy channel up to 120 mil thickness.

[a] Composed of four subchanneled clusters.

[b] Indicates assembly vendor/type referenced for fuel input data. Fuel acceptability for loading is not restricted to the indicated vendor/type provided that the fuel assembly meets the limits listed in Table 6.4.3-2. Abbreviations are as follows: General Electric/Global Nuclear Fuels (GE), Exxon/Advanced Nuclear Fuels/Siemens Power Corporation (SPC).

[c] Assembly contains an inert "solid" zircaloy rod rather than the "tube" type water rod found in other BWR assembly designs.

6.4.3.3 Damaged PWR 37-Assembly Reactivity Result Summary and Enrichment Limits

Maximum enrichments for payloads of up to 37 PWR fuel assemblies, including up to four damaged PWR fuel assemblies in the MAGNASTOR system were determined with effective ^{10}B contents of 0.036, 0.030, and 0.027 g/cm^2 for the absorber sheets. Three variations of damaged PWR fuel are modeled in the DFC. The undamaged assembly case contains an undamaged assembly in the DFC. In the unclad array case, an array without clad or end fittings is modeled in the DFC. Rod pitch is allowed to increase in the unclad array. The maximum size array fills the DFC cross-sectional area. The mixture case models a homogenized mixture of fuel and moderator up to various heights of the DFC cavity.

Maximum reactivities for normal and accident conditions are detailed in Section 6.7.8. Enrichment limits for PWR assemblies placed into the damaged fuel PWR basket are summarized in Table 6.4.3-4.

6.4.3.4 Damaged BWR 81-Assembly Basket Reactivity Result Summary and Enrichment Limits

Maximum enrichments for payloads of up to 81 BWR fuel assemblies, including up to 12 damaged BWR fuel assemblies, in the MAGNASTOR system were determined with effective ^{10}B content of 0.027 g/cm^2 for the absorber sheets. Three variations of damaged BWR fuel are modeled in the DFC. The undamaged assembly case contains an undamaged assembly in the DFC (with or without channel). In the unclad array case, an array without clad or end fittings is modeled in the DFC. Rod pitch is allowed to increase in the unclad array. The maximum size array fills the DFC cross-sectional area. The mixture case models a homogenized mixture of fuel and moderator up to various heights of the DFC cavity.

Maximum reactivities including enrichment limits are detailed in Section 6.7.9.

Table 6.4.3-1 PWR Fuel Basket Allowable Loading (Assembly Description)

Assembly Type	No. of Fuel Rods	No. of Guide Tubes[s]	Max Pitch (inch)	Min Clad OD (inch)	Min Clad Thick. (inch)	Max Pellet OD (inch)	Max Active Length (inch)	Max Load (MTU)
BW15H1	208	17	0.568	0.43	0.0265	0.3686	144.0	0.4858
BW15H2	208	17	0.568	0.43	0.025	0.3735	144.0	0.4988
BW15H3	208	17	0.568	0.428	0.023	0.3742	144.0	0.5006
BW15H4	208	17	0.568	0.414	0.022	0.3622	144.0	0.4690
BW15H5	208	17	0.568	0.422	0.0243	0.3659	144.0	0.4787
BW17H1	264	25	0.502	0.377	0.022	0.3252	144.0	0.4799
CE14H1	176	5	0.58	0.44	0.026	0.3805	137.0	0.4167
CE16H1	236	5	0.5063	0.382	0.025	0.325	150.0	0.4463
CE16H2	236	5	0.5063	0.374	0.0225	0.3225	150.0	0.4395
WE14H1	179	17	0.556	0.40	0.0162	0.3674	145.2	0.4188
WE15H1	204	21	0.563	0.422	0.0242	0.3669	144.0	0.4720
WE15H2	204	21	0.563	0.417	0.0265	0.357	144.0	0.4469
WE17H1	264	25	0.496	0.372	0.0205	0.3232	144.0	0.4740
WE17H2	264	25	0.496	0.36	0.0225	0.3088	144.0	0.4327

Notes:

- Assembly characteristics represent cold, unirradiated, nominal configurations.

[s] Combined number of guide and instrument tubes.

Table 6.4.3-2 Undamaged Fuel Basket PWR Fuel Assembly Allowable Loading (Enrichment/Soluble Boron Limits)

	Max. Initial Enrichment (wt % ^{235}U)															
	Absorber[t] 0.036 ^{10}B g/cm^2						Absorber 0.030 ^{10}B g/cm^2					Absorber 0.027 ^{10}B g/cm^2				
Soluble Boron	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	2600 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)
BW15H1	3.7%	4.1%	4.4%	4.7%	5.0%	--	3.6%	4.0%	4.2%	4.5%	4.8%	3.6%	3.9%	4.2%	4.5%	4.8%
BW15H2	3.7%	4.0%	4.3%	4.6%	4.9%	5.0%	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.8%	4.1%	4.4%	4.7%
BW15H3	3.7%	4.0%	4.3%	4.6%	4.9%	--	3.6%	3.9%	4.2%	4.4%	4.7%	3.5%	3.8%	4.1%	4.4%	4.7%
BW15H4	3.8%	4.2%	4.5%	4.8%	5.0%	--	3.7%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	5.0%
BW15H5	--	--	--	--	5.0%	--	--	--	--	--	--	--	--	--	--	--
BW17H1	3.7%	4.0%	4.3%	4.6%	4.9%	--	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.9%	4.1%	4.5%	4.7%
CE14H1	4.5%	4.8%	5.0%	5.0%	5.0%	--	4.3%	4.7%	5.0%	5.0%	5.0%	4.3%	4.6%	5.0%	5.0%	5.0%
CE16H1	4.4%	4.8%	5.0%	5.0%	5.0%	--	4.3%	4.6%	5.0%	5.0%	5.0%	4.2%	4.6%	4.9%	5.0%	5.0%
CE16H2	4.4%	4.8%	5.0%	5.0%	5.0%	--	4.3%	4.6%	5.0%	5.0%	5.0%	4.2%	4.6%	4.9%	5.0%	5.0%
WE14H1	4.7%	5.0%	5.0%	5.0%	5.0%	--	4.6%	5.0%	5.0%	5.0%	5.0%	4.5%	5.0%	5.0%	5.0%	5.0%
WE15H1	3.8%	4.2%	4.5%	4.8%	5.0%	--	3.7%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	4.9%
WE15H2	4.0%	4.4%	4.7%	5.0%	5.0%	--	3.9%	4.2%	4.6%	4.9%	5.0%	3.8%	4.2%	4.5%	4.8%	5.0%
WE17H1	3.7%	4.1%	4.4%	4.7%	5.0%	--	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.9%
WE17H2	4.0%	4.3%	4.7%	5.0%	5.0%	--	3.9%	4.3%	4.6%	4.9%	5.0%	3.8%	4.2%	4.5%	4.9%	5.0%

Specified soluble boron concentrations are independent of whether a fuel assembly contains a nonfuel insert.

[t] Borated aluminum neutron absorber sheet effective areal ^{10}B density.

Table 6.4.3-3 BWR Fuel Basket Allowable Loading (Assembly Description)

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)
B7_48A	48	N/A	0.7380	0.5700	0.03600	0.4900	144.0	0.1981
B7_49A	49	N/A	0.7380	0.5630	0.03200	0.4880	146.0	0.2034
B7_49B	49	N/A	0.7380	0.5630	0.03200	0.4910	150.0	0.2115
B8_59A	59	N/A	0.6400	0.4930	0.03400	0.4160	150.0	0.1828
B8_60A	60	N/A	0.6417	0.4840	0.03150	0.4110	150.0	0.1815
B8_60B	60	N/A	0.6400	0.4830	0.03000	0.4140	150.0	0.1841
B8_61B	61	N/A	0.6400	0.4830	0.03000	0.4140	150.0	0.1872
B8_62A	62	N/A	0.6417	0.4830	0.02900	0.4160	150.0	0.1921
B8_63A	63	N/A	0.6420	0.4840	0.02725	0.4195	150.0	0.1985
B8_64A	64	N/A	0.6420	0.4840	0.02725	0.4195	150.0	0.2017
B8_64B	64	N/A	0.6090	0.4576	0.02900	0.3913	150.0	0.1755
B9_72A	72	N/A	0.5720	0.4330	0.02600	0.3740	150.0	0.1803
B9_74A	74[a]	8	0.5720	0.4240	0.02390	0.3760	150.0	0.1873
B9_76A	76	N/A	0.5720	0.4170	0.02090	0.3750	150.0	0.1914
B9_79A	79	N/A	0.5720	0.4240	0.02390	0.3760	150.0	0.2000
B9_80A	80	N/A	0.5720	0.4230	0.02950	0.3565	150.0	0.1821
B10_91A	91[a]	8	0.5100	0.3957	0.02385	0.3420	150.0	0.1906
B10_92A	92[a]	14	0.5100	0.4040	0.02600	0.3455	150.0	0.1966
B10_96A	96[a]	12	0.4880	0.3780	0.02430	0.3224	150.0	0.1787
B10_100A	100	N/A	0.4880	0.3780	0.02430	0.3224	150.0	0.1861

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

[a] Assemblies may 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 6.4.3-4 Damaged Fuel Basket PWR Fuel Assembly Loading Criteria (Enrichment/Soluble Boron Limits)

	Max. Initial Enrichment (wt % ^{235}U)															
	Absorber[u] 0.036 ^{10}B g/cm^2						Absorber[a] 0.030 ^{10}B g/cm^2					Absorber[a] 0.027 ^{10}B g/cm^2				
Soluble Boron	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	2650 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)
BW15H1	3.7%	4.0%	4.3%	4.6%	4.9%	--	3.6%	3.9%	4.2%	4.5%	4.7%	3.6%	3.8%	4.1%	4.4%	4.7%
BW15H2	3.6%	3.9%	4.2%	4.5%	4.8%	5.0%	3.6%	3.8%	4.1%	4.4%	4.7%	3.5%	3.8%	4.1%	4.3%	4.6%
BW15H3	3.6%	3.9%	4.2%	4.5%	4.8%	--	3.5%	3.8%	4.1%	4.4%	4.6%	3.5%	3.8%	4.0%	4.3%	4.6%
BW15H4	3.8%	4.1%	4.4%	4.7%	5.0%	--	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.8%
BW15H5	--	--	--	--	4.9%	--	--	--	--	--	--	--	--	--	--	--
BW17H1	3.6%	3.9%	4.2%	4.5%	4.8%	--	3.6%	3.9%	4.1%	4.4%	4.7%	3.5%	3.8%	4.1%	4.4%	4.6%
CE14H1	4.4%	4.8%	5.0%	5.0%	5.0%	--	4.3%	4.7%	5.0%	5.0%	5.0%	4.3%	4.6%	4.9%	5.0%	5.0%
CE16H1	4.4%	4.7%	5.0%	5.0%	5.0%	--	4.2%	4.6%	5.0%	5.0%	5.0%	4.2%	4.5%	4.9%	5.0%	5.0%
CE16H2	4.4%	4.7%	5.0%	5.0%	5.0%	--	4.2%	4.6%	5.0%	5.0%	5.0%	4.2%	4.5%	4.9%	5.0%	5.0%
WE14H1	4.6%	5.0%	5.0%	5.0%	5.0%	--	4.5%	5.0%	5.0%	5.0%	5.0%	4.5%	4.9%	5.0%	5.0%	5.0%
WE15H1	3.8%	4.1%	4.4%	4.7%	5.0%	--	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	4.0%	4.3%	4.6%	4.8%
WE15H2	3.9%	4.3%	4.6%	4.9%	5.0%	--	3.8%	4.2%	4.5%	4.8%	5.0%	3.8%	4.1%	4.4%	4.7%	5.0%
WE17H1	3.7%	4.0%	4.3%	4.6%	4.9%	--	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.9%	4.2%	4.5%	4.8%
WE17H2	3.9%	4.3%	4.6%	5.0%	5.0%	--	3.9%	4.2%	4.5%	4.9%	5.0%	3.8%	4.1%	4.5%	4.8%	5.0%

[u] Borated aluminum neutron absorber sheet effective areal ^{10}B density.

6.6 References

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11. MCNP User's Manual – Code Version 6.2," LA-UR-17-29981 (2017).

6.7.2 PWR 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 guide/instrument tube diameter and thickness.

PWR fuel assemblies are typically undermoderated (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 guide tube 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 are a dry-pellet-to-clad gap condition, a flooded-pellet-to-gap condition (with and without soluble boron in the gap), and nonfuel hardware insertion into the guide tubes. 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 soluble boron level of 2500 ppm and a 5 wt % enrichment. A ^{235}U enrichment of 5 wt % represents the upper boundary for licensing of the system. The 2,500 ppm soluble boron level approximates the level required to maintain reactivity control in the system. The exact soluble boron level required for each assembly type, with and without insert, is determined in Section 6.7.3 at the maximum reactivity basket configuration. As the BW15H5 assembly type represents a minor variation on the other BW15 assembly types, evaluations for the BW15H5 assembly type are limited to the determination of maximum allowed reactivity at specified soluble boron and enrichment levels. Similarly, as the CE16H2 assembly type represents a minor variation on the CE16H1 assembly type, evaluations for the CE16H2 assembly type are limited to the determination of maximum allowed reactivity at specified soluble boron and enrichment levels.

Results of the analysis at various clad-to-gap conditions are shown in Table 6.7.2-1 and demonstrate that system reactivity is closely tied to fuel mass. Reactivity differences associated with improved moderator ratios (higher H/U ratio) are offset by the high soluble boron content in the moderator. This conclusion is validated by the analysis flooding the fuel-pellet-to-clad gap with borated and unborated water. Flooding the gap with borated water did not result in a significant reactivity change for any of the assembly types (judged to be significant if the $\Delta k_{eff}/\sigma > 3$). Flooding the same gap with unborated water significantly increased system reactivity for the majority of fuel types.

As illustrated in Table 6.7.2-2, the effect of the insertion of nonfuel hardware into the active fuel elevation of the guide tube varied by fuel type. The most significant effect associated with the nonfuel hardware insertion is for the CE assembly configuration. The CE core designs contain oversize tubes occupying four lattice locations. Replacing the large amount of soluble absorber in these locations significantly increases system reactivity. The effect of nonfuel hardware may differ at lower soluble boron content; therefore, licensing maximum enrichment and minimum soluble boron content runs are repeated for all assembly types at the maximum reactivity basket configuration with, and without, insert.

The evaluation presented previously assumed that the assemblies are undermoderated and that choosing the corresponding set of parameters maximizes system reactivity. This assumption is 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 leakage), 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. To bound likely loading specifications, the evaluations are performed at three enrichment/boron content levels (i.e., 3 wt % and 1,100 ppm, 4 wt % and 1,800 ppm, 5 wt % and 2,500 ppm) for the nominal parameter range of each of the assembly "hybrids" (e.g., WE17H1 rod outer diameter ranges from 0.372 to 0.374 inch).

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
- Guide/instrument tube unit cell
  - H/U controlled by guide tube diameter and thickness, and
- 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. Refer to Table 6.7.2-3 for the result of the increased variance evaluation for the wet unborated gap, 2,500 ppm, 5.0 wt %

enriched case. Similar results were obtained from the 1,100 ppm / 3 wt % ^{235}U and 1,800 ppm / 4 wt % ^{235}U analyses sets. As shown, the cases containing maximum H/U ratio in the fuel rod lattice location, maximum H/U in the guide/instrument tube location (minimum guide/instrument tube diameter and thickness), and maximum pellet diameter produce a maximum reactivity configuration system. The result set also demonstrates that guide tube dimensions are not crucial to system criticality control (note that the absence of guide/instrument tubes may increase reactivity statistics significantly). Therefore, the number of tubes should be specified in the limiting payload description not tube dimensions. 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)
- Number of guide/instrument tubes

Axial Blankets

Solid pellets of lower than midplane enrichment are bounded by the primary criticality evaluations performed in subsequent sections, as they present less fissile material while not increasing potential moderator volume. Annular pellets have the potential to increase system reactivity due to increased unborated moderator under flooded rod conditions. The improved moderation may compensate for the reduced fissile material quantity. As the blankets are in the axial high neutron leakage basket locations, there is no effect on system reactivity expected. This is confirmed by sample calculations using a 12-inch fully (midplane) enriched annular end-blanket WE17H1 hybrid at low and high soluble boron concentrations. The following data confirms that annular end-blankets represent an allowable MAGNASTOR payload.

Enrichment [wt %]	Boron Content	Annular Void [%]	k_{eff} +2σ	σ	Δk	Δk/σ
3.7	1500 ppm	--	0.93608	0.00074	--	--
3.7	1500 ppm	10	0.93665	0.00075	0.00057	0.54
3.7	1500 ppm	25	0.93411	0.00071	-0.00197	-1.92
3.7	1500 ppm	40	0.93701	0.00071	0.00093	0.91
4.9	2500 ppm	--	0.93389	0.00074	--	--
4.9	2500 ppm	10	0.93511	0.00071	0.00122	1.19
4.9	2500 ppm	25	0.93351	0.00077	-0.00038	-0.36
4.9	2500 ppm	40	0.93533	0.00070	0.00144	1.41

Table 6.7.2-1 System Reactivity Response to PWR Fuel Type and Pellet to Clad Condition

Assembly Type	Dry Gap No Insert k_{eff}	Wet Borated Gap No Insert k_{eff}	Dry Gap To Wet Borated Gap $\Delta k_{eff}/\sigma$	Wet Gap No Insert k_{eff}	Dry Gap to Wet Gap $\Delta k_{eff}/\sigma$	Fuel Mass (MTU)	Water / Fuel Ratio
CE14H1	0.86225	0.86229	0.0	0.86644	3.9	0.4167	1.62
CE16H1	0.86700	0.86937	2.2	0.87280	5.5	0.4463	1.71
BW15H1	0.92089	0.92082	-0.1	0.92563	4.4	0.4858	1.66
BW15H2	0.92674	0.92640	-0.3	0.92983	3.0	0.4988	1.62
BW15H3	0.92727	0.92716	-0.1	0.93045	2.9	0.5006	1.63
BW15H4	0.91301	0.91096	-2.0	0.91601	2.8	0.4690	1.82
BW17H1	0.92595	0.92503	-0.8	0.93079	4.5	0.4799	1.69
WE14H1	0.84955	0.84864	-0.8	0.84949	-0.1	0.4188	1.73
WE15H1	0.91177	0.91132	-0.4	0.91513	3.1	0.4720	1.68
WE15H2	0.90023	0.89780	-2.3	0.90057	0.3	0.4469	1.80
WE17H1	0.91897	0.91796	-1.0	0.92366	4.4	0.4740	1.67
WE17H2	0.89962	0.89730	-2.2	0.90029	0.6	0.4327	1.93

Table 6.7.2-2 System Reactivity Response to PWR Fuel Type and Nonfuel Insert

Assembly Type	Dry Gap No Insert k_{eff}	Dry Gap Insert k_{eff}	No Insert to Insert $\Delta k_{eff}/\sigma$
CE14H1	0.86225	0.87129	8.0
CE16H1	0.86700	0.87282	5.5
BW15H1	0.92089	0.91988	-1.0
BW15H2	0.92674	0.92569	-1.0
BW15H3	0.92727	0.92887	1.5
BW15H4	0.91301	0.91644	3.2
BW17H1	0.92595	0.92508	-0.8
WE14H1	0.84955	0.84863	-0.9
WE15H1	0.91177	0.91192	0.1
WE15H2	0.90023	0.90163	1.3
WE17H1	0.91897	0.91779	-1.1
WE17H2	0.89962	0.89725	-2.2

6.7.3 PWR Undamaged Fuel Criticality Evaluation

6.7.3.1 Optimum System Configuration

Enrichment and soluble boron 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 6.1.1. 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, $k_{eff} < 0.5$.

Initial reactivity analysis is based on a basket and neutron absorber configuration with the following characteristics:

a.) Neutron absorbers on all four sides of each tube.

b.) A single column of weld posts connecting neutron absorber to tube, with 18 weld posts per tube.

c.) A neutron absorber thickness tolerance of ±0.005 inch.

d.) Fuel tube size and tube stack-up controlled by tube outer width and “interface width.”

e.) Neutron absorber sheet effective areal density of 0.036 ^{10}B g/cm^2.

f.) For “insert” cases, only guide tubes are filled with zirconium alloy. The instrument tubes in WE and B&W hybrids contain TSC moderator.

Differences in reactivity due to system configuration and tolerance changes from these characteristics are evaluated in the subsection titled "Neutron Absorber and Tube Modifications" for geometry changes and in the subsection “Instrument Tube Insert” for the fill of both guide and instrument tubes.

Changes in neutron absorber areal density are addressed in Section 6.7.3.2.

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 6.7.3-1, demonstrate that there is no effect of partially flooding the TSC.

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 from the WE17H1 moderator density study are graphically illustrated in Figure 6.7.3-1 for an unborated wet pellet-to-clad gap, moderator containing 2,500 ppm boron, and an enrichment of 5 wt % ^{235}U. Reactivities for dry, unborated wet, and borated wet pellet-to-clad gap conditions under various canister cavity moderator densities are plotted in Figure 6.7.3-2. 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. For the flooded TSC, k_{eff} levels off at moderator density levels above 0.9 g/cm^3 (actual moderator density 0.903 g/cm^3 considering 2,500 ppm soluble boron), with no significant changes to full density 0.9982 g/cm^3 (1.0025 g/cm^3 at 2,500 ppm B). The reactivity curve levels off as increased thermalization from the moderator is offset by soluble boron neutron absorption. At a lower soluble boron level, the curve continues to rise to full moderator density.

Fabrication Tolerances and Component Shift

Fabrication tolerances and shift effect are evaluated using representative fuel types from the major core configurations (WE, CE, and B&W cores). Nominal fuel assembly characteristics are employed in the tolerance and shifting evaluations. Moderator soluble boron content is set to 2,500 ppm boron for the fabrication tolerance and component shift study.

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. Tube and neutron absorber dimensions have the potential to significantly affect the size of the tube opening and developed cell locations and are,

Table 6.7.3-9 PWR System Load Limits (without Nonfuel Insert in Active Fuel Region and 0.036 ^{10}B g/cm^2 Absorber)

Assembly Type	Minimum 1500 ppm B		Minimum 1750 ppm B		Minimum 2000 ppm B		Minimum 2250 ppm B		Minimum 2500 ppm B		Minimum 2600 ppm B	
	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$
BW15H1	3.70%	0.93032	4.10%	0.93514	4.40%	0.93547	4.70%	0.93489	5.00%	0.93432	--	--
BW15H2	3.70%	0.93554	4.00%	0.93451	4.30%	0.93384	4.60%	0.93295	4.90%	0.93244	5.0%	0.93167
BW15H3	3.70%	0.93538	4.00%	0.93613	4.30%	0.93528	4.60%	0.93569	4.90%	0.93414	--	--
BW15H4	3.80%	0.93189	4.20%	0.93697	4.50%	0.93286	4.80%	0.93228	5.00%	0.92461	--	--
BW15H5	--	--	--	--	--	--	--	--	5.00%	0.92830	--	--
BW17H1	3.70%	0.93311	4.00%	0.93204	4.30%	0.93241	4.60%	0.93215	5.00%	0.93689	--	--
CE14H1	4.50%	0.93324	4.90%	0.93148	5.00%	0.91561	5.00%	0.89718	5.00%	0.87709	--	--
CE16H1	4.40%	0.93350	4.80%	0.93457	5.00%	0.92463	5.00%	0.90197	5.00%	0.88620	--	--
CE16H2	4.40%	0.93283	4.80%	0.93197	5.00%	0.92305	5.00%	0.90295	5.00%	0.88381	--	--
WE14H1	4.70%	0.93673	5.00%	0.92958	5.00%	0.90757	5.00%	0.88721	5.00%	0.86816	--	--
WE15H1	3.80%	0.93088	4.20%	0.93699	4.50%	0.93415	4.80%	0.93224	5.00%	0.92440	--	--
WE15H2	4.00%	0.93406	4.40%	0.93674	4.70%	0.93530	5.00%	0.93129	5.00%	0.91181	--	--
WE17H1	3.70%	0.92991	4.10%	0.93553	4.40%	0.93506	4.70%	0.93425	5.00%	0.93308	--	--
WE17H2	4.00%	0.93428	4.30%	0.92952	4.70%	0.93330	5.00%	0.93079	5.00%	0.91229	--	--

Table 6.7.3-10 PWR System Load Limits (with Nonfuel Insert in Active Fuel Region and 0.036 ^{10}B g/cm^2 Absorber)

Assembly Type	Minimum 1500 ppm B		Minimum 1750 ppm B		Minimum 2000 ppm B		Minimum 2250 ppm B		Minimum 2500 ppm B		Minimum 2650 ppm B	
	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$	Max Initial Enrich. (wt% ^{235}U)	Reactivity $k_{eff} + 2\sigma$
BW15H1	3.80%	0.93273	4.10%	0.93540	4.40%	0.93380	4.70%	0.93644	5.00%	0.93468	--	--
BW15H2	3.70%	0.92923	4.00%	0.93281	4.30%	0.93250	4.60%	0.93389	4.90%	0.93451	5.0%	0.93400
BW15H3	3.70%	0.93169	4.00%	0.93345	4.30%	0.93311	4.60%	0.93475	4.90%	0.93564	--	--
BW15H4	3.80%	0.92945	4.20%	0.93582	4.50%	0.93322	4.80%	0.93247	5.00%	0.92658	--	--
BW15H5	--	--	--	--	--	--	--	--	5.00%	0.93113	--	--
BW17H1	3.80%	0.93545	4.10%	0.93648	4.40%	0.93695	4.60%	0.93200	4.90%	0.93284	--	--
CE14H1	4.50%	0.93588	4.80%	0.93066	5.00%	0.92489	5.00%	0.90699	5.00%	0.89106	--	--
CE16H1	4.40%	0.93241	4.80%	0.93602	5.00%	0.92723	5.00%	0.90831	5.00%	0.89213	--	--
CE16H2	4.40%	0.93287	4.80%	0.93522	5.00%	0.92681	5.00%	0.90771	5.00%	0.89313	--	--
WE14H1	4.80%	0.93574	5.00%	0.92232	5.00%	0.90377	5.00%	0.88564	5.00%	0.86589	--	--
WE15H1	3.90%	0.93411	4.20%	0.93343	4.50%	0.93351	4.80%	0.93262	5.00%	0.92694	--	--
WE15H2	4.00%	0.93138	4.40%	0.93683	4.70%	0.93626	5.00%	0.93357	5.00%	0.91454	--	--
WE17H1	3.90%	0.93532	4.20%	0.93495	4.50%	0.93712	4.80%	0.93706	5.00%	0.93241	--	--
WE17H2	4.10%	0.93359	4.40%	0.93279	4.80%	0.93707	5.00%	0.92966	5.00%	0.91118	--	--

Table 6.7.3-11 PWR System Generic Load Limits (0.036 ^{10}B g/cm^2 Absorber)

Assembly Type	# of Fuel Rods	# of Guide Tubes[a]	Max Pitch (inch)	Min Clad OD (inch)	Min Clad Thick. (inch)	Max Pellet OD (inch)	Max Active Length (inch)	Max Load (MTU)	Max. Initial Enrichment (wt % ^{235}U) Soluble Boron 1500 ppm	Soluble Boron 1750 ppm	Soluble Boron 2000 ppm	Soluble Boron 2250 pm	Soluble Boron 2500 ppm	Soluble Boron 2600 ppm
BW15H1	208	17	0.568	0.43	0.0265	0.3686	144.0	0.4858	3.70%	4.10%	4.40%	4.70%	5.00%	--
BW15H2	208	17	0.568	0.43	0.025	0.3735	144.0	0.4988	3.70%	4.00%	4.30%	4.60%	4.90%	5.00%
BW15H3	208	17	0.568	0.428	0.023	0.3742	144.0	0.5006	3.70%	4.00%	4.30%	4.60%	4.90%	--
BW15H4	208	17	0.568	0.414	0.022	0.3622	144.0	0.4690	3.80%	4.20%	4.50%	4.80%	5.00%	--
BW15H5	208	17	0.568	0.422	0.0243	0.3659	144.0	0.4787	--	--	--	--	5.00%	--
BW17H1	264	25	0.502	0.377	0.022	0.3252	144.0	0.4799	3.70%	4.00%	4.30%	4.60%	4.90%	--
CE14H1	176	5	0.58	0.44	0.026	0.3805	137.0	0.4167	4.50%	4.80%	5.00%	5.00%	5.00%	--
CE16H1	236	5	0.5063	0.382	0.025	0.325	150.0	0.4463	4.40%	4.80%	5.00%	5.00%	5.00%	--
CE16H2	236	5	0.5063	0.374	0.0225	0.3225	150.0	0.4395	4.40%	4.80%	5.00%	5.00%	5.00%	--
WE14H1	179	17	0.556	0.40	0.0162	0.3674	145.2	0.4188	4.70%	5.00%	5.00%	5.00%	5.00%	--
WE15H1	204	21	0.563	0.422	0.0242	0.3669	144.0	0.4720	3.80%	4.20%	4.50%	4.80%	5.00%	--
WE15H2	204	21	0.563	0.417	0.0265	0.357	144.0	0.4469	4.00%	4.40%	4.70%	5.00%	5.00%	--
WE17H1	264	25	0.496	0.372	0.0205	0.3232	144.0	0.4740	3.70%	4.10%	4.40%	4.70%	5.00%	--
WE17H2	264	25	0.496	0.36	0.0225	0.3088	144.0	0.4327	4.00%	4.30%	4.70%	5.00%	5.00%	--

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

[a] Combined number of guide and instrument tubes.

Table 6.7.3-12 PWR System Tube Location Study Summary

Configuration			Δk/σ from Baseline Square Tube @ 45º		
Tube	**Tube Location**	**Grind**	**Average**	**Minimum**	**Maximum**
Square	45º	Even		--	
Square	45º	Biased	0.6	-2.3	2.6
Square	Shift	Even	-1.3	-2.9	2.2
Square	Shift	Biased	0.3	-2.8	2.9
Rectangular	Shift	Even		N/A	
Rectangular	Shift	Biased	-5.7	-9.9	2.5

Table 6.7.3-13 PWR System Tube Location Study Detail – Baseline to Square Tube/Biased Grind/45º Alignment

Assembly Type	Minimum 1500 ppm B Change in Reactivity	Minimum 1750 ppm B Change in Reactivity	Minimum 2000 ppm B Change in Reactivity	Minimum 2250 ppm B Change in Reactivity	Minimum 2500 ppm B Change in Reactivity
	Δk/σ	**Δk/σ**	**Δk/σ**	**Δk/σ**	**Δk/σ**
BW15H1	0.4	-1.8	1.7	0.6	0.5
BW15H2	-0.6	-1.3	-2.3	-0.8	0.8
BW15H3	-0.1	1.1	0.5	-0.6	0.8
BW15H4	0.5	-0.1	1.7	2.1	-0.4
BW17H1	-0.2	0.7	-0.2	-1.4	1.9
CE14H1	-0.1	0.7	2.6	2.4	1.2
CE16H1	2.6	1.0	1.1	2.1	0.2
WE14H1	0.8	2.6	1.0	1.6	2.6
WE15H1	0.3	1.0	1.1	0.3	-0.1
WE15H2	-0.2	0.0	1.5	1.1	0.1
WE17H1	-0.7	-0.3	1.5	0.6	0.5
WE17H2	-0.1	1.3	0.1	-1.9	1.6

Table 6.7.3-14 PWR System Load Limits for Reduced Absorber

Max. Initial Enrichment (wt % ^{235}U)										
	Absorber 0.030 ^{10}B g/cm^2					Absorber 0.027 ^{10}B g/cm^2				
Soluble Boron	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)
BW15H1	3.6%	4.0%	4.2%	4.5%	4.8%	3.6%	3.9%	4.2%	4.5%	4.8%
BW15H2	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.8%	4.1%	4.4%	4.7%
BW15H3	3.6%	3.9%	4.2%	4.4%	4.7%	3.5%	3.8%	4.1%	4.4%	4.7%
BW15H4	3.7%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	5.0%
BW17H1	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.9%	4.1%	4.5%	4.7%
CE14H1	4.3%	4.7%	5.0%	5.0%	5.0%	4.3%	4.6%	5.0%	5.0%	5.0%
CE16H1	4.3%	4.6%	5.0%	5.0%	5.0%	4.2%	4.6%	4.9%	5.0%	5.0%
CE16H2	4.3%	4.6%	5.0%	5.0%	5.0%	4.2%	4.6%	4.9%	5.0%	5.0%
WE14H1	4.6%	5.0%	5.0%	5.0%	5.0%	4.5%	5.0%	5.0%	5.0%	5.0%
WE15H1	3.7%	4.1%	4.4%	4.7%	5.0%	3.7%	4.0%	4.3%	4.6%	4.9%
WE15H2	3.9%	4.2%	4.6%	4.9%	5.0%	3.8%	4.2%	4.5%	4.8%	5.0%
WE17H1	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.9%
WE17H2	3.9%	4.3%	4.6%	4.9%	5.0%	3.8%	4.2%	4.5%	4.9%	5.0%

- Specified soluble boron concentrations are independent of whether a fuel assembly contains a nonfuel insert.

Table 6.7.8-2 DFC Unclad Rod Array Pitch Study Results

Assembly	Enrichment	Reactivity with Maximum Pitch		Reactivity with Average Pitch			Reactivity with Nominal Pitch		
	(wt% ^{235}U)	σ	$k_{eff} + 2σ$	σ	$k_{eff} + 2σ$	Δk/σ	σ	$k_{eff} + 2σ$	Δk/σ
BW15H1	4.7%	0.00071	0.93472	0.00072	0.93607	1.34	0.00075	0.93646	1.68
BW15H2	4.6%	0.00073	0.93589	0.00075	0.93641	0.50	0.00076	0.93473	-1.10
BW15H3	4.6%	0.00066	0.93711	0.00073	0.93765	0.55	0.00078	0.93778	0.66
BW15H4	4.8%	0.00071	0.93398	0.00077	0.93390	-0.08	0.00075	0.93433	0.34
BW15H5(1)	4.9%	--	0.92346	--	--	--	--	--	--
BW17H1	4.6%	0.00073	0.93383	0.00072	0.93446	0.61	0.00073	0.93466	0.80
CE14H1	5.0%	0.00079	0.89735	0.00077	0.89484	-2.28	0.00074	0.89522	-1.97
CE16H1	5.0%	0.00075	0.90438	0.00074	0.90395	-0.41	0.00077	0.90557	1.11
CE16H2(1)	5.0%	--	0.88318	--	--	--	--	--	--
WE14H1	5.0%	0.00077	0.88574	0.00078	0.88600	0.24	0.00079	0.88591	0.15
WE15H1	4.8%	0.00074	0.93410	0.00075	0.93307	-0.98	0.00075	0.93368	-0.40
WE15H2	5.0%	0.00079	0.93251	0.00075	0.93201	-0.46	0.00073	0.93239	-0.11
WE17H1	4.7%	0.00073	0.93349	0.00075	0.93626	2.65	0.00074	0.93546	1.90
WE17H2	5.0%	0.00073	0.93227	0.00071	0.93048	-1.76	0.00077	0.93145	-0.77

Notes:

(1) BW15H5 and CE16H2 only evaluated at 2500ppm and maximum enrichment to demonstrate that the unclad array of pellets is significantly below USL. As demonstrated in this table there is no significant impact of pitch on system reactivity for any of the fuel types.

Table 6.7.8-3 Sample Results for Unclad Rod/Loose Pellet Fuel in DFC (Damaged Fuel Basket)

Assembly Type	Minimum 1500 ppm B Max. Initial Enrichment	Reactivity			Minimum 2000 ppm B Max. Initial Enrichment	Reactivity			Minimum 2500 ppm B Max. Initial Enrichment	Reactivity		
	(wt% ^{235}U)	σ	k_{eff} + 2σ	Δk/σ	(wt% ^{235}U)	σ	k_{eff} + 2σ	Δk/σ	(wt% ^{235}U)	σ	k_{eff} + 2σ	Δk/σ
BW15H1	3.7%	0.00073	0.92965		4.4%	0.00073	0.93538		5.0%	0.00070	0.93416	
	3.7%	0.00072	0.93127	1.58	4.4%	0.00073	0.93700	1.57	5.0%	0.00075	0.93608	1.87
BW15H2	3.7%	0.00068	0.93581		4.3%	0.00071	0.93498		4.9%	0.00072	0.93317	
	3.7%	0.00070	0.93704	1.26	4.3%	0.00075	0.93589	0.88	4.9%	0.00073	0.93554	2.31
BW15H3	3.7%	0.00071	0.93700		4.3%	0.00074	0.93514		4.9%	0.00072	0.93415	
	3.7%	0.00069	0.93818	1.19	4.3%	0.00069	0.93668	1.52	4.9%	0.00071	0.93579	1.62
	3.6%	0.00072	0.93134									
BW15H4	3.8%	0.00071	0.93146		4.5%	0.00073	0.93364		5.0%	0.00073	0.92368	
	3.8%	0.00072	0.93393	2.44	4.5%	0.00073	0.93438	0.72	5.0%	0.00074	0.92418	0.48
BW17H1	3.7%	0.00073	0.93296		4.3%	0.00070	0.93382		5.0%	0.00072	0.93716	
	3.7%	0.00072	0.93545	2.43	4.3%	0.00071	0.93443	0.61	5.0%	0.00069	0.93818	1.02
									4.9%	0.00072	0.93174	
CE14H1	4.5%	0.00073	0.93518		5.0%	0.00078	0.91583		5.0%	0.00078	0.87766	
	4.5%	0.00077	0.93387	-1.23	5.0%	0.00079	0.91801	1.96	5.0%	0.00081	0.87926	1.42
CE16H1	4.4%	0.00075	0.93329		5.0%	0.00077	0.92515		5.0%	0.00080	0.88644	
	4.4%	0.00076	0.93404	0.70	5.0%	0.00076	0.92362	-1.41	5.0%	0.00073	0.88414	-2.12
WE14H1	4.7%	0.00073	0.93682		5.0%	0.00073	0.90625		5.0%	0.00077	0.86657	
	4.7%	0.00074	0.93777	0.91	5.0%	0.00077	0.90693	0.64	5.0%	0.00074	0.86736	0.74
	4.6%	0.00074	0.93090									
WE15H1	3.8%	0.00072	0.93295		4.5%	0.00078	0.93614		5.0%	0.00074	0.92470	
	3.8%	0.00070	0.93213	-0.82	4.5%	0.00075	0.93689	0.69	5.0%	0.00072	0.92569	0.96
WE15H2	4.0%	0.00077	0.93454		4.7%	0.00072	0.93520		5.0%	0.00071	0.91355	
	4.0%	0.00074	0.93465	0.10	4.7%	0.00070	0.93439	-0.81	5.0%	0.00076	0.91163	-1.85
WE17H1	3.7%	0.00074	0.92921		4.4%	0.00076	0.93628		5.0%	0.00070	0.93402	
	3.7%	0.00075	0.92991	0.66	4.4%	0.00070	0.93500	-1.24	5.0%	0.00072	0.93484	0.82
WE17H2	4.0%	0.00073	0.93415		4.7%	0.00071	0.93342		5.0%	0.00071	0.91309	
	4.0%	0.00072	0.93379	-0.35	4.7%	0.00074	0.93522	1.76	5.0%	0.00072	0.91258	-0.50

Table 6.7.8-6 DFC Fuel Mixture Maximum Reactivity Height for 0.036 g/cm² ^{10}B – No Inserts

Assembly	Parameter	Minimum 1500 ppm	Minimum 1750 ppm	Minimum 2000 ppm	Minimum 2250 ppm	Minimum 2500 ppm	Minimum 2650 ppm
BW15H1	Enrichment	3.7%	4.0%	4.3%	4.6%	4.9%	--
	k_{eff}+2σ	0.93323	0.93439	0.93553	0.93571	0.93410	--
	Configuration	MIX90	MIX70	MIX70	MIX70	MIX60	--
BW15H2	Enrichment	3.6%	3.9%	4.2%	4.5%	4.8%	5.0%
	k_{eff}+2σ	0.93147	0.93234	0.93312	0.93368	0.93355	0.93507
	Configuration	MIX80	MIX80	MIX90	MIX80	MIX70	MIX70
BW15H3	Enrichment	3.6%	3.9%	4.2%	4.5%	4.8%	--
	k_{eff}+2σ	0.93380	0.93398	0.93450	0.93518	0.93674	--
	Configuration	MIX80	MIX100	MIX90	MIX80	MIX80	--
BW15H4	Enrichment	3.8%	4.1%	4.4%	4.7%	5.0%	--
	k_{eff}+2σ	0.93650	0.93692	0.93368	0.93302	0.93165	--
	Configuration	MIX80	MIX90	MIX70	MIX70	MIX70	--
BW15H5	Enrichment	--	--	--	--	4.9%	--
	k_{eff}+2σ	--	--	--	--	0.93011	--
	Configuration	--	--	--	--	MIX80	--
BW17H1	Enrichment	3.6%	3.9%	4.2%	4.5%	4.9%	--
	k_{eff}+2σ	0.92912	0.92805	0.93055	0.93166	0.93694	--
	Configuration	MIX70	MIX60	MIX80	MIX90	MIX90	--
CE14H1	Enrichment	4.5%	4.9%	5.0%	5.0%	5.0%	--
	k_{eff}+2σ	0.93728	0.93616	0.91968	0.90123	0.88176	--
	Configuration	MIX70	MIX70	MIX90	MIX60	MIX90	--
CE16H1	Enrichment	4.4%	4.7%	5.0%	5.0%	5.0%	--
	k_{eff}+2σ	0.93575	0.93022	0.92902	0.90938	0.89002	--
	Configuration	MIX80	MIX70	MIX60	MIX80	MIX100	--
CE16H1	Enrichment	4.4%	4.7%	5.0%	5.0%	5.0%	--
	k_{eff}+2σ	0.93623	0.93071	0.92716	0.90691	0.88818	--
	Configuration	MIX70	MIX90	MIX80	MIX60	MIX70	--
WE14H1	Enrichment	4.7%	5.0%	5.0%	5.0%	5.0%	--
	k_{eff}+2σ	0.93751	0.92989	0.90915	0.88872	0.87013	--
	Configuration	MIX50	MIX60	MIX80	MIX80	MIX60	--
WE15H1	Enrichment	3.8%	4.1%	4.4%	4.7%	5.0%	--
	k_{eff}+2σ	0.93538	0.93541	0.93150	0.93075	0.93028	--
	Configuration	MIX100	MIX70	MIX90	MIX80	MIX60	--
WE15H2	Enrichment	3.9%	4.3%	4.6%	5.0%	5.0%	--
	k_{eff}+2σ	0.93365	0.93581	0.93464	0.93720	0.91729	--
	Configuration	MIX70	MIX70	MIX70	MIX60	MIX70	--
WE17H1	Enrichment	3.7%	4.0%	4.3%	4.6%	4.9%	--
	k_{eff}+2σ	0.93327	0.93385	0.93517	0.93304	0.93417	--
	Configuration	MIX80	MIX90	MIX70	MIX90	MIX90	--
WE17H2	Enrichment	3.9%	4.3%	4.6%	5.0%	5.0%	--
	k_{eff}+2σ	0.92934	0.93490	0.93343	0.93722	0.91805	--
	Configuration	MIX70	MIX70	MIX80	MIX70	MIX80	--

Table 6.7.8-7 DFC Fuel Mixture Maximum Reactivity Height for 0.036 g/cm2 10B – Inserts

Assembly	Parameter	Minimum 1500 ppm	Minimum 1750 ppm	Minimum 2000 ppm	Minimum 2250 ppm	Minimum 2500 ppm	Minimum 2650 ppm
BW15H1	Enrichment	3.7%	4.0%	4.3%	4.6%	4.9%	--
	$k_{eff}+2\sigma$	0.93185	0.93353	0.93536	0.93570	0.93666	--
	Configuration	MIX70	MIX90	MIX80	MIX70	MIX100	--
BW15H2	Enrichment	3.7%	3.9%	4.2%	4.5%	4.8%	5.0%
	$k_{eff}+2\sigma$	0.93732	0.92857	0.93295	0.93446	0.93579	0.93645
	Configuration	MIX80	MIX100	MIX80	MIX80	MIX70	MIX70
BW15H3	Enrichment	3.6%	3.9%	4.2%	4.5%	4.8%	--
	$k_{eff}+2\sigma$	0.92862	0.93150	0.93343	0.93497	0.93723	--
	Configuration	MIX80	MIX70	MIX80	MIX100	MIX80	--
BW15H4	Enrichment	3.8%	4.1%	4.4%	4.7%	5.0%	--
	$k_{eff}+2\sigma$	0.93574	0.93435	0.93620	0.93567	0.93522	--
	Configuration	MIX70	MIX70	MIX80	MIX70	MIX70	--
BW15H5	Enrichment	--	--	--	--	4.9%	--
	$k_{eff}+2\sigma$	--	--	--	--	0.93265	--
	Configuration	--	--	--	--	MIX80	--
BW17H1	Enrichment	3.7%	4.0%	4.3%	4.5%	4.8%	--
	$k_{eff}+2\sigma$	0.93562	0.93574	0.93608	0.93184	0.93432	--
	Configuration	MIX70	MIX70	MIX80	MIX80	MIX70	--
CE14H1	Enrichment	4.4%	4.8%	5.0%	5.0%	5.0%	--
	$k_{eff}+2\sigma$	0.93160	0.93612	0.92831	0.91230	0.89638	--
	Configuration	MIX80	MIX70	MIX70	MIX60	MIX80	--
CE16H1	Enrichment	4.4%	4.7%	5.0%	5.0%	5.0%	--
	$k_{eff}+2\sigma$	0.93572	0.93177	0.93160	0.91441	0.89748	--
	Configuration	MIX80	MIX80	MIX70	MIX70	MIX90	--
CE16H2	Enrichment	4.4%	4.7%	5.0%	5.0%	5.0%	--
	$k_{eff}+2\sigma$	0.93621	0.93386	0.93001	0.91375	0.89643	--
	Configuration	MIX70	MIX90	MIX60	MIX60	MIX70	--
WE14H1	Enrichment	4.8%	5.0%	5.0%	5.0%	5.0%	--
	$k_{eff}+2\sigma$	0.93667	0.92601	0.90543	0.88775	0.86940	--
	Configuration	MIX90	MIX60	MIX80	MIX70	MIX70	--
WE15H1	Enrichment	3.8%	4.1%	4.4%	4.7%	5.0%	--
	$k_{eff}+2\sigma$	0.93169	0.93364	0.93274	0.93291	0.93317	--
	Configuration	MIX70	MIX80	MIX70	MIX70	MIX100	--
WE15H2	Enrichment	4.0%	4.3%	4.6%	4.9%	5.0%	--
	$k_{eff}+2\sigma$	0.93503	0.93522	0.93350	0.93434	0.92239	--
	Configuration	MIX90	MIX80	MIX90	MIX80	MIX90	--
WE17H1	Enrichment	3.8%	4.1%	4.4%	4.7%	4.9%	--
	$k_{eff}+2\sigma$	0.93430	0.93452	0.93541	0.93710	0.93099	--
	Configuration	MIX90	MIX70	MIX70	MIX80	MIX90	--
WE17H2	Enrichment	4.0%	4.3%	4.7%	5.0%	5.0%	--
	$k_{eff}+2\sigma$	0.93202	0.93278	0.93680	0.93721	0.91961	--
	Configuration	MIX60	MIX80	MIX80	MIX90	MIX70	--

Table 6.7.8-10 PWR Damaged Fuel Assembly Allowable Loading (Enrichment/Soluble Boron Limits)

	Max. Initial Enrichment (wt % ^{235}U)															
	Absorber[ii] 0.036 ^{10}B g/cm^2						Absorber[a] 0.030 ^{10}B g/cm^2					Absorber[a] 0.027 ^{10}B g/cm^2				
Soluble Boron	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	2650 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)	1500 (ppm)	1750 (ppm)	2000 (ppm)	2250 (ppm)	2500 (ppm)
BW15H1	3.7%	4.0%	4.3%	4.6%	4.9%	--	3.6%	3.9%	4.2%	4.5%	4.7%	3.6%	3.8%	4.1%	4.4%	4.7%
BW15H2	3.6%	3.9%	4.2%	4.5%	4.8%	5.0	3.6%	3.8%	4.1%	4.4%	4.7%	3.5%	3.8%	4.1%	4.3%	4.6%
BW15H3	3.6%	3.9%	4.2%	4.5%	4.8%	--	3.5%	3.8%	4.1%	4.4%	4.6%	3.5%	3.8%	4.0%	4.3%	4.6%
BW15H4	3.8%	4.1%	4.4%	4.7%	5.0%	--	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	3.9%	4.2%	4.5%	4.8%
BW15H5	--	--	--	--	4.9%	--	--	--	--	--	--	--	--	--	--	--
BW17H1	3.6%	3.9%	4.2%	4.5%	4.8%	--	3.6%	3.9%	4.1%	4.4%	4.7%	3.5%	3.8%	4.1%	4.4%	4.6%
CE14H1	4.4%	4.8%	5.0%	5.0%	5.0%	--	4.3%	4.7%	5.0%	5.0%	5.0%	4.3%	4.6%	4.9%	5.0%	5.0%
CE16H1	4.4%	4.7%	5.0%	5.0%	5.0%	--	4.2%	4.6%	5.0%	5.0%	5.0%	4.2%	4.5%	4.9%	5.0%	5.0%
CE16H2	4.4%	4.7%	5.0%	5.0%	5.0%	--	4.2%	4.6%	5.0%	5.0%	5.0%	4.2%	4.5%	4.9%	5.0%	5.0%
WE14H1	4.6%	5.0%	5.0%	5.0%	5.0%	--	4.5%	5.0%	5.0%	5.0%	5.0%	4.5%	4.9%	5.0%	5.0%	5.0%
WE15H1	3.8%	4.1%	4.4%	4.7%	5.0%	--	3.7%	4.0%	4.3%	4.6%	4.9%	3.6%	4.0%	4.3%	4.6%	4.8%
WE15H2	3.9%	4.3%	4.6%	4.9%	5.0%	--	3.8%	4.2%	4.5%	4.8%	5.0%	3.8%	4.1%	4.4%	4.7%	5.0%
WE17H1	3.7%	4.0%	4.3%	4.6%	4.9%	--	3.6%	3.9%	4.2%	4.5%	4.8%	3.6%	3.9%	4.2%	4.5%	4.8%
WE17H2	3.9%	4.3%	4.6%	5.0%	5.0%	--	3.9%	4.2%	4.5%	4.9%	5.0%	3.8%	4.1%	4.5%	4.8%	5.0%

[ii] Borated aluminum neutron absorber sheet effective areal ^{10}B density.

Table 6.7.8-11 MCNP5 V1.3 vs. MCNP6.2 Results for 2650 ppm BW15H2 at 5 wt% ^{235}U

	8.75 Width (MCNP5)		8.75 Width (MCNP62)		Delta between Code Versions		
Description	k_{eff}+2σ	σ	keff+2σ	σ	Δk	σ (Δk)	Δk / σ(Δk)
URA_Insert	0.93099	0.00038	0.93369	0.00019	0.00270	0.00042	6.43
URA	0.9286	0.00036	0.93125	0.00019	0.00265	0.00041	6.46
MIX50p_Insert	0.93142	0.00036	0.93552	0.00019	0.00410	0.00041	10
MIX50p	0.92884	0.00036	0.93273	0.00019	0.00389	0.00041	9.49
MIX60p_Insert	0.93473	0.00038	0.93772	0.00019	0.00299	0.00042	7.12
MIX60p	0.93251	0.00036	0.93531	0.00018	0.00280	0.00040	7
MIX70p_Insert	0.93571	0.00038	0.93912	0.00018	0.00341	0.00042	8.12
MIX70p	0.93433	0.00038	0.93663	0.00019	0.00230	0.00042	5.48
MIX80p_Insert	0.93551	0.00037	0.93931	0.00019	0.00380	0.00042	9.05
MIX80p	0.93419	0.00037	0.93683	0.00019	0.00264	0.00042	6.29
MIX90p_Insert	0.93555	0.00038	0.93908	0.00019	0.00353	0.00042	8.4
MIX90p	0.9332	0.00036	0.9368	0.00019	0.00360	0.00041	8.78
MIX100p_Insert	0.93497	0.00037	0.93824	0.00019	0.00327	0.00042	7.79
MIX100p	0.93188	0.00038	0.93592	0.00018	0.00404	0.00042	9.62

Table 6.7.8-12 MCNP5 V1.3 vs. MCNP6.2 Results for 2500 ppm BW15H5 at 4.9 wt% ^{235}U

	8.70 Width (MCNP5)		8.70 Width (MCNP62)		Delta between Code Versions		
Description	k_{eff}+2σ	σ	keff+2σ	σ	Δk	σ (Δk)	Δk / σ(Δk)
URA_Insert	0.92687	0.00037	0.92902	0.00019	0.00215	0.00042	5.12
URA	0.92346	0.00037	0.92616	0.00019	0.00270	0.00042	6.43
MIX50p_Insert	0.92940	0.00037	0.93105	0.00019	0.00165	0.00042	3.93
MIX50p	0.92595	0.00037	0.92873	0.00018	0.00278	0.00041	6.78
MIX60p_Insert	0.93152	0.00039	0.93341	0.00019	0.00189	0.00043	4.4
MIX60p	0.92910	0.00038	0.93073	0.00019	0.00163	0.00042	3.88
MIX70p_Insert	0.93233	0.00038	0.93499	0.00019	0.00266	0.00042	6.33
MIX70p	0.92929	0.00037	0.9319	0.00018	0.00261	0.00041	6.37
MIX80p_Insert	0.93265	0.00037	0.93477	0.00019	0.00212	0.00042	5.05
MIX80p	0.93011	0.00036	0.93229	0.00019	0.00218	0.00041	5.32
MIX90p_Insert	0.93191	0.00039	0.93429	0.00019	0.00238	0.00043	5.53
MIX90p	0.92886	0.00037	0.93158	0.00019	0.00272	0.00042	6.48
MIX100p_Insert	0.93095	0.00035	0.93331	0.00019	0.00236	0.00040	5.9
MIX100p	0.92803	0.00041	0.93056	0.00019	0.00253	0.00045	5.62

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9.3 Loading MAGNASTOR Using Light Weight MAGNASTOR Transfer Cask (LMTC)

MAGNASTOR is used to load, transfer, and store spent fuel. The three principal components of the system are: the transportable storage canister (TSC), the stainless steel Light Weight MAGNASTOR Transfer Cask (LMTC), and the concrete cask. The LMTC contains and supports the TSC during fuel loading, lid welding and closure operations. The LMTC, 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 the following initial conditions.

- the LMTC is located in a facility's designated workstation for cask preparation
- the LMTC liquid neutron shield and expansion tank water levels are established for maximum ALARA performance based on Site specific conditions.
- an empty TSC (properly receipt inspected and accepted) is located in the LMTC 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 and thermal shunts are installed (as applicable for the approved loading configuration) with the Approved Content provisions of the CoC. Up to four damaged fuel cans (DFCs) containing damaged or undamaged PWR fuel assemblies or PWR fuel debris may be loaded in a TSC with a DF Basket Assembly, as authorized in the Approved Contents provisions of the CoC. Up to twelve damaged fuel cans (DFCs) containing damaged or undamaged BWR fuel assemblies or BWR fuel debris may be loaded in a TSC with a DF Basket Assembly, as authorized in the Approved Contents provisions of the CoC. Undamaged fuel assemblies may be loaded directly (i.e., without a DFC) into DFC locations in the DF Basket Assembly.

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. At the option of the user, the closure ring welding sequence can be completed later in the cask loading operational sequence following completion of vacuum drying and helium backfill.

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 TSC closure lid, shell, closure ring and port covers complete the assembly of the confinement boundary and redundant closure.

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.

9.3.1 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 LMTC located at the designated workstation.

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

   Note: Removable TSC centering shims may be used to assist in centering the TSC in the LMTC cavity. After TSC positioning in the LMTC, the TSC centering shims are removed prior to installation of the shield/seal insert.
2. Visually inspect the top of the TSC shell and closure lid weld preps.
3. Establish the LMTC Shield Tank and Expansion Tank water level as needed to meet Site specific conditions.

   Note: User's may elect to adjust the Shield Tank and Expansion Tank levels as needed to obtain the optimal ALARA conditions based on the limitations of the Facility lifting equipment.
4. Inflate the upper LMTC 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.

Note: Gas supply lines may be left connected to ensure against unintended deflation.

Note: The sequence and use of upper and lower annulus seals are at the discretion of the Licensee/User based on selected in-plant operational procedures and approved site-specific TSC cooling methods to maintain TSC and fuel clad temperatures within FSAR limits.

Note: Optional TSC annulus shims may be utilized at the discretion of the user to assist in centering the TSC in the LMTC annulus.

5. Verify the retaining ring is removed.
6. Verify that at least one lock pin is installed on each LMTC shield door.
7. 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.
8. Attach the lift yoke to a crane suitable for handling the loaded TSC, LMTC and yoke. Position the lift yoke over the LMTC and engage it with the two LMTC trunnions.
9. Lift the LMTC containing the empty TSC and move it to the spent fuel pool following the prescribed load path.

   Note: An optional bottom protective cover may be used to prevent imbedding contaminated particles in the shield doors and door rails.
10. Connect the clean water lines to the lower annulus fill ports of the LMTC. Ensure that the unused ports are closed or capped to prevent pool water in-leakage.
11. Lower the LMTC to the pool surface and turn on the clean water supply lines to the LMTC fill port to fill the LMTC/TSC annulus.

    Note: Sequence on connection and filling/draining LMTC/TSC annulus is at the discretion of the user based on approved site-specific procedures.
12. Spray the LMTC 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.
13. Lower the LMTC 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.

    Note: Due to the numerous fuel types and specifications associated with the fuel stored at the various Sites, detailed Site-Specific procedures are required to ensure loaded meets the fuel specifications as listed in the approved contents section of the MAGNASTOR CoC.
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 including limitations on fuel assembly positions within the basket, and the boron concentration limits of LCO 3.2.1. Specific fuel assembly positions for preferential and zoned loading patterns shall be in full compliance with the requirements of Appendix B of the Technical Specifications. Assembly selection, placement and compliance with preferential zone loading patterns within the basket shall be independently verified.

Note: Ensure that the Thermal Shunts are installed in accordance with the approved heat load pattern.

Note: Up to four DFCs containing authorized PWR contents may be loaded in a TSC with a DF Basket Assembly. A DFC spacer is required to be positioned in the designated DF Basket Assembly corner locations for the shorter length DFCs. Independently, visually verify proper placement and correct orientation of each required DFC spacer.

Note: Up to twelve DFCs containing authorized BWR contents may be loaded in a TSC with a DF Basket Assembly. A DFC spacer may be required to position in the designated DF Basket Assembly corner locations for the shorter length DFCs. Independently, visually verify proper placement and correct orientation of each required DFC spacer.

Note: At the option of the user, install fuel assembly spacers for the axial positioning of the fuel assembly types to be loaded. Verify spacer identification and install fuel spacers in each intended fuel loading location based on the fuel spacer plan prepared, which is based on the fuel assembly inventory and nonfuel hardware to be loaded. Independently, visually verify proper placement and correct orientation of each required fuel spacer.

16. Visually verify the fuel assembly (DFC and Thermal Shunts, as applicable) identifications to confirm the serial numbers match the approved fuel loading pattern.
17. Install three swivel hoist rings hand tight in the three closure lid lifting holes or in three of the six TSC lift holes, and torque to the value specified in Table 9.1-2. 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 LMTC 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 (± ½ inch).

    Caution: Following closure lid installation of the TSC, the time limit to begin the Annulus Circulating Water System (ACWS) or site approved alternative annulus flow system operation and to begin temperature measurement of the LMTC annulus outlet flow is:

- For PWR [BWR] heat loads ≤ 35.5 kW [≤ 33.0 kW] - < 19 hours
- For PWR [BWR] heat loads > 35.5 kW ≤ 42.5 kW [>33.0 kW≤ 42.5 kW] - < 15 hours
- For PWR [BWR] heat loads > 42.5 kW [> 42 kW] - < 11 hours

and verify LMTC outlet temperature is maintained:

- For PWR [BWR] heat loads ≤ 35.5 kW [≤ 33.0 kW] - < 113°F.
- For PWR [BWR] heat loads > 35.5 kW [>33.0 kW] - < 87°F

21. Allow sling cables to go slack and move the lift yoke into position to engage the LMTC trunnions. Engage the lift yoke to the trunnions, apply a slight tension, and visually verify engagement.
22. Raise the LMTC until the 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 LMTC with clean water as the equipment is raised above the pool surface.
23. Rinse and flush the top of the LMTC 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 LMTC to check for radioactive particles.
24. As the LMTC 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 LMTC to the designated workstation for TSC closure operations.

    Note: At the option of the user, the TSC closure operations may be performed with the LMTC 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 LMTC trunnions. Place lift yoke and sling set in storage/lay-down area.
27. Inflate the LMTC lower annulus seal with air or nitrogen. Disconnect the gas supply from the transfer cask.

    Note: The installation, use, and operational sequence of the lower annulus seal is at the discretion of the user based on approved site-specific procedures. At the option of the user, the gas supply can be maintained continuously to the annulus seals.
28. Install the ACWS or site approved annulus cooling system, to the lower and upper annulus fill lines. Unused fill lines are to be closed or capped.

    Note: For TSCs prepared with the LMTC partially submerged on an in-pool shelf, partially drained cask loading pit or equivalent partial submerged condition, or in an ACWS catch basin, alternative ACWS operations may be utilized to maintain TSC and fuel clad temperatures within normal operational limits.

Note: ACWS operation allows the vacuum drying and TSC transfer times in LCO 3.1.1 to be utilized.

29. Initiate clean water flow into the LMTC lower fill lines with annulus water discharging through the upper fill lines. Ensure water flow is maintained to keep the outlet water temperature:
    - For PWR [BWR] heat loads ≤ 35.5 kW [≤ 33.0 kW] - ≤ 113ºF
    - For PWR [BWR] heat loads > 35.5 kW [. 33.0 kW] - ≤ 87°F

Note: Analysis of ACWS operations for PWR [BWR] fuel are detailed in Chapter 4, demonstrating that the fuel clad and TSC temperatures are maintained below the limiting values when the following ACWS parameters are maintained:

For PWR [BWR] heat loads ≤ 35.5 kW [≤ 33.0kW]:

- A maximum inlet water temperature of ≤ 100°F,
- A minimum inlet flow rate of ≥ 50 GPM

For PWR [BWR] heat loads > 35.5 kW [>33.0kW]:

- A maximum inlet water temperature of ≤ 70°F,
- A minimum inlet flow rate of ≥ 40 GPM

30. Remove the lifting hoist rings from the closure lid.
31. If the LMTC Shield Tank and Expansion Tank water level was lowered to optimize ALARA conditions for the Site specific crane lifting limits, then re-fill the LMTC shield tank with water as follows:
    a. Remove the threaded plugs from the two “Fill To” ports in the two expansion tanks.
    b. Remove the threaded plugs from the two shield tank manifolds.
    c. Fill the shield tank and expansion tanks with demineralized water until water flows out of the two “Fill To” ports in the expansion tanks.
    d. Stop filling operation and install threaded plugs in the two “Fill To” ports.
    e. Remove demineralized water supply from the two fill manifolds and install threaded plugs in the manifold fill lines.
32. Using a portable suction pump, remove any standing water from the closure lid weld groove, and the vent and drain ports.

Chapter 10
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The Metal Storage Overpack (MSO) is designed to be lifted and transported using trunnions. The trunnions are welded to the inner liner shell of the MSO. The trunnions 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 MSO trunnion pair will be load tested by applying a vertical load to the trunnions at a value that is equal to 150% of the maximum MSO weight. The test load shall be applied for a minimum of 10 minutes. After release of the test loads, the accessible portions of the trunnions and the adjacent areas shall be visually examined to verify no deformation, distortion, or cracking occurred. Critical load-bearing welds of the trunnions shall be magnetic particle (MT) examined in accordance with ASME Code, Section V, Articles 1, 7 and 25, or liquid penetrant (PT) examined in accordance with ASME Code, Section V, Articles 1, 6 and 24, with acceptance criteria per Section III, Subsection NF, Article NF-5340 or NF-5350.

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 MSO trunnions 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 at not less than 125% of the design pressure of 110 psig in accordance with ASME Code, Section III, Subsection NB, NB-6200 requirements as described and defined in Section 9.1.1. A bounding minimum test pressure of 150 psig shall be applied to the drain port connection for a minimum 10-minute hold period. There shall be no visible water leakage from the closure lid-to-TSC shell weld based on visual examination of the weld after a minimum 10-minute hold period, while maintaining the test pressure. Test pressure shall be maintained until the completion of the visual weld examination. The design pressure and minimum test pressure are identical for both PWR and BWR TSCs. The minimum test pressure conservatively exceeds the hydrostatic test pressure commitment stated in Table 2.1-2 (125% of MNOP).

10.1.2.4 Load Testing of Damaged Fuel Can (DFC)

To qualify the design of the MAGNASTOR DFC, the first DFC to be provided to a user shall be load tested to 150% of the total weight of the DFC plus the heaviest contents to be loaded in the DFC. The test load on the DFC shall be applied and held for a minimum of 10 minutes. Following completion of the load test, all load bearing welds and surfaces shall be visually inspected for permanent deformation, galling or cracking. Load bearing welds shall be inspected using liquid penetrant examination in accordance with ASME Code, Section V, Article 6. Acceptance criteria shall be in accordance with ASME Code, Section III, NG-5350. Any evidence of permanent deformation, cracking or galling of load bearing surfaces, or unacceptable liquid penetrant examination results shall be cause for rejection, repair, reperformance of the load test and reexamination of the DFC.

10.1.2.5 Pressure Testing of the Passive MAGNASTOR Transfer Cask (PMTC)

Following completion of the load testing of the PMTC, the neutron shield tank and the expansion tanks shall be hydrostatically tested simultaneously, since they are joined by siphon tubes. The hydrostatic test shall be performed at a pressure of 45 (+5, -0) psig (125% of the design pressure of 36 psig) for a minimum hold period of 10 minutes in accordance with the ASME Boiler and Pressure Vessel Code, Section III, NB-6200. All tank weld seams and joints shall be visually inspected for evidence of leakage while the test pressure is maintained following the minimum hold period. Any evidence of leakage, seam failure or deformation is cause for rejection. Following neutron shield tank and expansion tank depressurization, all accessible welds on the neutron shield structure shall be visually examined in accordance with ASME Code, Section V, Articles 1 and 9 with acceptance per Section III, Subsection NF, Article NF-5360, and dye penetrant examined in accordance with ASME Code, Section V, Articles 1, 6 and 24, with acceptance criteria per Section III, Subsection NF, Article NF-5350.

If leakage, seam failure or deformation is detected, the area of leakage, failure or deformation shall be identified, repaired and re-examined in accordance with ASME Code, Section III, Subsection NF, NF-4130. Following repair and completion of required NDE, the hydrostatic test shall be re-performed to the original test acceptance criteria.

Hydrostatic testing of the PMTC neutron shield and expansion tanks shall be performed in accordance with written and approved procedures, and the test results documented.

10.1.2.6 Pressure Testing of the Light Weight MAGNASTOR Transfer Cask (LMTC)

Following completion of the load testing of the LMTC, the neutron shield tank and the expansion tanks shall be hydrostatically tested simultaneously, since they are joined by siphon tubes. The hydrostatic test shall be performed at a pressure of 20 (+5, -0) psig (125% of the design pressure of 15.0 psig) for a minimum hold period of 10 minutes in accordance with the ASME Boiler and Pressure Vessel Code, Section III, NB-6200. All tank weld seams and joints shall be visually inspected for evidence of leakage while the test pressure is maintained following the minimum hold period. Any evidence of leakage, seam failure or deformation is cause for rejection. Following neutron shield tank and expansion tank depressurization, all accessible welds on the neutron shield structure shall be visually examined in accordance with ASME Code, Section V, Articles 1 and 9 with acceptance per Section III, Subsection NF, Article NF-5360, and dye penetrant examined in accordance with ASME Code, Section V, Articles 1, 6 and 24, with acceptance criteria per Section III, Subsection NF, Article NF-5350.

If leakage, seam failure or deformation is detected, the area of leakage, failure or deformation shall be identified, repaired and re-examined in accordance with ASME Code, Section III, Subsection NF, NF-4130. Following repair and completion of required NDE, the hydrostatic test shall be re-performed to the original test acceptance criteria.

Hydrostatic testing of the LMTC neutron shield and expansion tanks shall be performed in accordance with written and approved procedures, and the test results documented.

10.1.2.7 Pressure Testing of the Reduced Width LMTC

Following completion of the load testing of the Reduced Width LMTC, the neutron shield tank and the expansion tanks shall be hydrostatically tested simultaneously, since they are joined by siphon tubes. The hydrostatic test shall be performed at a minimum pressure of 13 (+5, -0) psig (125% of the design pressure of 10 psig) for a minimum hold period of 10 minutes in accordance with the ASME Boiler and Pressure Vessel Code, Section III, NB-6200. All tank weld seams and joints shall be visually inspected for evidence of leakage while the test pressure is maintained following the minimum hold period. Any evidence of leakage, seam failure or deformation is cause for rejection. Following neutron shield tank and expansion tank depressurization, all accessible welds on the neutron shield structure shall be visually examined in accordance with ASME Code, Section V, Articles 1 and 9 with acceptance per Section III, Subsection NF, Article NF-5360, and dye penetrant examined in accordance with ASME Code, Section V, Articles 1, 6 and 24, with acceptance criteria per Section III, Subsection NF, Article NF-5350.

If leakage, seam failure or deformation is detected, the area of leakage, failure or deformation shall be identified, repaired and re-examined in accordance with ASME Code, Section III, Subsection NF, NF-4130. Following repair and completion of required NDE, the hydrostatic test shall be re-performed to the original test acceptance criteria.

Hydrostatic testing of the Reduced Width LMTC neutron shield and expansion tanks shall be performed in accordance with written and approved procedures, and the test results documented.

10.1.3 Leakage Tests

The confinement boundary is defined as the TSC shell weldment, closure lid assembly, 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.

At the completion of the TSC shell weldment confinement boundary welds (e.g., TSC shell seam and shell to bottom plate), the TSC shell weldment shall be leakage tested. The leakage test shall be performed in accordance with the requirements and approved methods of ASME Code, Section V, Article 10, and ANSI N14.5-1997 [20] to confirm the total leakage rate (i.e., leaktight) is less than, or equal to, 1×10^{-7} ref. cm^3/s (air) or approximately 2×10^{-7} cm^3/sec (helium). The sensitivity of the test shall be one-half of the acceptance test criteria as specified in ANSI N14.5-1997.

The TSC shell weldment will be closed using a test lid installed over the top of the shell and the cavity evacuated. A test envelope will be installed around the TSC enclosing all of the TSC shell confinement welds and base metal plates, and filled with 99.995% (minimum) pure helium to an acceptable test concentration. The percentage of helium gas in the test envelope shall be accounted for in the determination of the test sensitivity. A mass spectrometer leak detector (MSLD) will be used to sample the evacuated volume for helium.

If helium leakage is detected, the area of leakage shall be identified, repaired and re-examined in accordance with the ASME Code, Section III, Subsection NB, NB-4450 or NB-4130, as appropriate. Following repair, the complete helium leakage test shall be re-performed 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, shop helium leakage testing of the 9-inch thick closure lid is not required. However, due to the reduced thickness of the stainless steel closure lid (4-inch thick base material) of the composite closure lid assembly, and the presence of extended bolt holes for attachment of the shield plate assembly, a shop helium leakage test of the composite closure lid stainless steel plate shall be performed following fabrication. The leakage test shall be performed in accordance with the requirements and approved methods of ASME Code, Section V, Article 10, and ANSI N14.5-1997 to confirm the total leakage rate is less than, or equal to, 2×10^{-7} cm^3/s (helium). The sensitivity of the test shall be one-half of the acceptance test criteria as specified in ANSI N14.5-1997.

If leakage is detected, the area of leakage shall be identified, repaired and re-examined in accordance with ASME Code, Section III, Subsection NB, NB-4130. Following repair and completion of required NDE, the helium leak test shall be re-performed to the original test acceptance criteria.

Leakage testing of the composite closure lid shall be performed in accordance with written and approved procedures, and the test results documented.

In order to ensure the integrity of the vent and drain inner port cover welds, a helium leakage test of each weld is performed following welding of the inner port covers to the closure lid assembly 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 $\leq 2\times10^{-7}$ cm^3/s helium. 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 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, repaired and re-examined in accordance with ASME Code, Section III, Subsection NB, NB-4450. Following repair, the helium leak test shall be re-performed 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 optional 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. The Metal Storage Overpack (MSO) has no mechanical seals or gaskets.

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 or the MSO.

10.1.6 Neutron Absorber Tests

NOTE

Sections 10.1.6.4.5, 10.1.6.4.6, 10.1.6.4.7 and 10.1.6.4.8 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 four 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. Testing will be used to verify the areal density and the uniform distribution of ^{10}B in the neutron absorber materials. Section 8.8 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 yield strength listed in Section 8.3. 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.

All neutron absorber materials are procured and qualified under a Quality Assurance/Quality Control program in conformance with the requirements of 10 CFR 72, Subpart G.

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 testing of the material as described in Section 10.1.6.4.8.

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 Metal Matrix and Borated Aluminum 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 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 for the PWR fuel basket and a 0.10-in nominal thickness sheet for the BWR fuel basket. The required minimum thermal conductivities for the MAGNASTOR absorbers are as follows.

[redacted]

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].

Neutron absorber material yield strength must be equal to or greater than 1.6 ksi at 700ºF. Per Section 8.3, a yield strength of 1.6 ksi is the material strength of the neutron absorber at 700ºF 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 Borated Aluminum Alloy and Borated MMC 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, which may be composed of homogeneous or heterogeneous materials. The heterogeneous standard will be calibrated to a recognized standard (e.g., homogeneous material**

such as ZrB_2 plate material or a NIST-produced standard) or by attenuation of a thermal neutron beam correlated to the known cross-section of ^{10}B at the beam energies. 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.

- **The ^{10}B areal density is measured using a collimated thermal neutron beam of up to 2.54 cm in diameter, with a tolerance of 10 percent.**
- **Based on the MAGNASTOR required ^{10}B minimum effective areal densities for the PWR basket of 0.036, 0.030 or 0.027 g/cm^2, the ^{10}B minimum effective areal densities for the BWR basket of 0.027, 0.0225 or 0.020 g/cm^2 and the 90% credit applied 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 Metal Matrix and Borated Aluminum 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 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, i.e., roller machine hardware or final sheet cutting methods, water jet, shear cut, etc., 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.

Open porosity for borated aluminum and borated MMC neutron absorber material must be no greater than 0.5% unless qualification tests are performed to ensure that blisters are not produced under submerging and subsequent vacuum drying conditions.

Chemical composition of the boron carbide powder must meet the requirements of Table 1 of ASTM C 750-03, Type 3. Additional chemical requirements, applicable to a particular absorber material, may be placed on the boron carbide powder as a result of the "key manufacturing process controls" invoked by Section 10.1.6.4.6. Additional requirements may include, but are not limited to, upper limits on fluorine and chlorine content.

10.1.6.4.8 Boral Neutron Absorber Tests

NOTE

Section 10.1.6.4.8 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.

The Boral neutron absorbing material is an aluminum matrix material formed from aluminum and boron-carbide. The mixing of the aluminum and boron-carbide powder forming the neutron absorber material is controlled to assure the required ^{10}B areal density. The constituents of the neutron absorber material shall be verified by chemical testing and by dimensional measurement to ensure the quality of the finished plate or sheet. The results of all neutron absorber material tests and inspections, including the results of wet chemistry coupon testing, are documented and become part of the quality records documentation package for the fuel tube and basket assembly.

The manufacturing process of Boral consists of several steps. The initial step is the mixing of the aluminum and boron carbide powders that form the core of the finished material. The amount of each powder is a function of the desired ^{10}B areal density. The methods used to control the weight and blend the powders are proprietary processes of the manufacturer.

After manufacturing, test samples from each Boral batch of neutron absorber sheets shall be tested using wet chemistry techniques to verify the presence and minimum weight percent of ^{10}B. The tests shall be performed in accordance with approved written procedures.

The neutron absorber sampling plan is selected to demonstrate a 95/95 statistical confidence level in the neutron absorber sheet material in compliance with the specification. In addition to the specified sampling plan, each sheet of material is visually and dimensionally inspected using at least six measurements on each sheet. The sampling plan is supported by written and approved procedures.

The sampling plan requires that a coupon sample be taken from each of the first 100 sheets of absorber material. Thereafter, coupon samples are taken from 20 randomly selected sheets from each set of 100 sheets. This 1 in 5 sampling plan continues until there is a change in lot or batch of constituent materials of the sheet (i.e., boron carbide powder, aluminum powder, or aluminum extrusion) or a process change. If either of these circumstances occurs, the sampling plan reverts back to a coupon sample being taken from each of the first 100 sheets of absorber material, followed by the 20 randomly selected sheets from each set of 100 sheets. The sheet samples are indelibly marked and recorded for identification. This identification is used to document neutron absorber test results, which become part of the quality record documentation package.

Neutron Absorber Wet Chemistry Testing

Wet chemistry testing of the test coupons obtained from the sampling plan is used to verify the ^{10}B content of the neutron absorber material. Wet chemistry testing is applied because it provides an accurate and practical direct measurement of the boron and B_4C content of metal materials.

An approved facility with chemical analysis capability, which could include the neutron absorber vendor's facility, shall be selected to perform the wet chemistry tests. Personnel performing the testing shall be trained and qualified in the process and in the test procedure.

Wet chemistry testing is performed by dissolving the aluminum in the matrix, including the powder and cladding, in a strong acid, leaving the B_4C material. A comparison of the amount of B_4C material remaining to the amount required to meet the ^{10}B content specification is made using a mass-balance calculation based on sample size.

A statistical conclusion about the neutron absorber sheet from which the sample was taken and that batch of neutron absorber sheets may then be drawn based on the test results and the controlled manufacturing processes.

The adequacy of the wet chemistry method is based on its use to qualify the standards employed in neutron blackness testing. The neutron absorption performance of a test material is validated based on its performance compared to a standard. The material properties of the standard are demonstrated by wet chemistry testing. Consequently, the specified test regimen provides adequate assurance that the neutron absorber sheet thus qualified is acceptable.

Acceptance Criteria

The wet chemistry test results shall be considered acceptable if the ^{10}B areal density is determined to be equal to, or greater than, that specified on the fuel tube License Drawings. Failure of any coupon wet chemistry test shall result in 100% sampling, as described in the sampling plan, until compliance with the acceptance criteria is demonstrated.

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 Boral, a laminated absorber, yield strength credited in the structural analysis was limited to the outer aluminum cover sheets. Therefore, only the cover sheet must be shown to meet the required strength.

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