APPENDIX G.1
INTRODUCTION AND GENERAL DESCRIPTION OF INSTALLATION
NAC-MAGNASTOR

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G.1. INTRODUCTION AND GENERAL DESCRIPTION OF INSTALLATION

No change or additional information required for the MAGNASTOR Cask System for Chapter 1.

APPENDIX G.2
SITE CHARACTERISTICS
NAC-MAGNASTOR

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G.2. SITE CHARACTERISTICS

No change or additional information required for the MAGNASTOR Cask System for Chapter 2.

APPENDIX G.3
PRINCIPAL DESIGN CRITERIA
NAC-MAGNASTOR

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G.3 PRINCIPAL DESIGN CRITERIA

The MAGNASTOR Cask System principal design criteria for undamaged and damaged PWR fuel is documented in Chapter 2 of the MAGNASTOR Final Safety Analysis Report (FSAR) [Reference G.3-1]. Table G.3-1 provides a comparison of the NAC-MAGNASTOR Cask System principal design criteria and the WCS Consolidated Interim Storage Facility (WCS CISF) design criteria provided in Table 1-2, which demonstrates that the NAC-MAGNASTOR Cask System is bounded by the WCS CISF criteria.

G.3.1 Undamaged and Damaged PWR Fuel

MAGNASTOR is designed to safely store up to 37 undamaged PWR fuel assemblies in the 37 PWR basket assembly. The system is also designed to store up to four damaged fuel cans (DFCs) in the DF basket assembly. The DF Basket Assembly has a capacity of up to 37 undamaged PWR fuel assemblies, including four DFC locations. DFCs may be placed in up to four of the DFC locations. Each DFC may contain an undamaged PWR fuel assembly, a damaged PWR fuel assembly, or PWR fuel debris equivalent to one PWR fuel assembly. Undamaged PWR fuel assemblies may be placed directly in the DFC locations of a DF Basket Assembly.

The fuel assemblies are assigned to two groups of PWR fuel assemblies on the basis of fuel assembly length. The fuel assembly length groupings are included in Chapter 1 of Reference G.3-1.

PWR fuel assemblies that have the parameters shown in Table 2.2-1 of Reference G.3-1 may be stored in MAGNASTOR. PWR fuel assemblies may be stored with nonfuel hardware. Undamaged or damaged PWR fuel assemblies or PWR fuel debris may be stored in a damaged fuel can. PWR fuel assemblies loaded into a DFC shall not contain nonfuel hardware, with the exception of instrument tube tie components and steel inserts.

The minimum initial enrichment limits for PWR fuel are shown in Table 2.2-1 of Reference G.3-1 and exclude the loading of fuel assemblies enriched to less than 1.3 wt% ^{235}U, including unenriched fuel assemblies. Fuel assemblies with low enriched, unenriched, and/or annular axial end-blankets may be loaded into MAGNASTOR.

The design criteria for environmental conditions and natural phenomena for the MAGNASTOR system are described in Section 2.3 of Reference G.3-1. The applicable portions of Section 2.3 have been reviewed against the environmental conditions at the WCS CISF and have been shown to be either bounded by the analysis presented in Reference G.3-1 or require no further analysis than what is presented in Reference G.3-1 because they already meet the regulatory requirements of 10 CFR Part 72.

G.3.1.1 Design Criteria for Environmental Conditions and Natural Phenomena

This section presents the design criteria for site environmental conditions and natural phenomena applied in the design basis analyses of MAGNASTOR. Analyses to demonstrate that the design basis system meets the design criteria defined in this section are presented in the relevant chapters of Reference G.3-1.

G.3.1.1.1 Tornado Missiles and Wind Loadings

The concrete casks are typically placed outdoors on an unsheltered reinforced concrete storage pad at an ISFSI site. This storage condition exposes the casks to tornado and wind loading. The design basis tornado and wind loading is defined based on Regulatory Guide 1.76 Region 1 and NUREG-0800. The design basis tornado missile impacts are defined in Paragraph 4, Subsection III, Section 3.5.1.4 of NUREG 0800. Analyses presented in Reference G.3-1, Section 3.7.3.2 and discussed in Reference G.3-1, Section 12.2.11 demonstrates that the MAGNASTOR design meets these criteria. Therefore, no further site-specific evaluations are required.

G.3.1.1.2 Water Level (Flood) Design

The loaded concrete cask may be exposed to a flood during storage on an unsheltered concrete storage pad at an ISFSI site. The source and magnitude of the probable maximum flood depend on specific site characteristics. The MAGNASTOR concrete cask design basis is a maximum floodwater depth of 50 feet above the base of the cask and a floodwater velocity of 15 ft per second.

As documented in Sections 2.4.2.2 and 3.2.2, the WCS CISF is not in a floodplain and is above the Probable Maximum Flood elevation and, therefore, will remain dry in the event of a flood.

G.3.1.1.3 Seismic Design

The WCC CISF may be subject to seismic events (earthquakes) during its lifetime. The possible significant effect of a beyond-design-basis seismic event on the concrete cask would be a tip-over; however, the loaded concrete cask does not tip over during the design-basis seismic event. Although it is a nonmechanistic event, the loaded concrete cask design basis includes consideration of the consequences of a hypothetical cask tip-over event.

Section 7.6.3 demonstrates that the MAGNASTOR system, experiences minimal sliding (maximum 1.20 inches) and does not tip-over in the design basis earthquake.

Additionally, to evaluate concrete cask stress the evaluation in Section 3.7.3.4 of Reference G.3-1 conservatively applies seismic loads of 0.5g in the horizontal direction and 0.5g in the vertical direction. These accelerations reflect a more rigorous seismic loading and, therefore, bound the design basis earthquake event. These compressive stresses are used in the load combinations for the concrete cask discussed in Section G.3.1.1.5, and the combined stress results meet stress criteria for the accident events.

A detailed analysis of the nonmechanistic tip-over event for a bounding PWR configuration is presented in Section 3.7.3.7 of Reference G.3-1 with results discussed in Section 12.2.12 of Reference G.3-1. The concrete cask is analyzed with conservative fuel heights, canister lengths, concrete pad thicknesses, and soil densities. To bound a range of ISFSI geometries, standard pad and oversized pad configurations are evaluated. Accelerations obtained from this tip-over analysis are applied to the TSC and basket structural evaluations presented in Reference G.3-1, Sections 3.7.1 and 3.7.2, respectively. The cask is shown to not suffer significant adverse consequences due to this event. The concrete cask, TSC, and basket maintain performance requirements for design basis structural integrity, shielding, geometry, criticality control of the contents, and content confinement.

The pad design meets the MAGNASTOR pad requirements and is consistent with analyses performed within Reference G.3-1. The existing analysis bounds the WCS CISF site pad design limits for accelerations at the top pad surface. Therefore, no further evaluations are required.

G.3.1.1.4 Snow and Ice Loadings

The criterion for determining design snow loads is based on ANSI/ASCE 7-93, Section 7.0. MAGNASTOR is assumed to have a Category C exposure factor, which is defined to be "locations in which snow removal by wind cannot be relied on to reduce roof loads because of terrain, higher structures, or several trees nearby." Ground snow loads for the contiguous United States are given in Figures, 5, 6, and 7 of ANSI/ASCE 7-93. A worst case value of 100 pounds per square foot is assumed. Section 2.3.4 of Reference G.3-1 states that the snow load is bounded by the weight of the loaded transfer cask on the top of the concrete cask shell and by the tornado missile loading on the concrete cask lid. No further site-specific evaluations are required.

G.3.1.1.5 Combined Load Criteria

Each normal condition and off-normal and accident event has a combination of load cases that defines the total combined loading for that condition/event. The individual load cases considered include thermal, seismic, external and internal pressure, missile impacts, drops, snow and ice loads, and/or flood water forces. The load conditions to be evaluated for storage casks are identified in 10 CFR 72 and ANSI/ANS-57.9.

The load combinations for concrete structures specified in ANSI/ANS-57.9 and ACI 349 are used to evaluate the MAGNASTOR concrete cask and are shown in Table 2.3-1 of Reference G.3-1. The live loads are considered to vary from 0% to 100% to ensure that the worst-case condition is evaluated. In each case, use of 100% of the live load produces the maximum load condition. The steel liner of the MAGNASTOR concrete cask is a stay-in-place form that also provides radiation shielding. The concrete cask is designed to the requirements of ACI 349. In calculating the design strength of concrete in the concrete cask body, nominal strength values are multiplied by a strength reduction factor in accordance with Section 9.3 of ACI 349.

The TSC is designed in accordance with the ASME Code, Section III, Subsection NB. The basket and damaged fuel can (DFC) are designed in accordance with the ASME Code, Section III, Subsection NG. Structural buckling of the basket is evaluated in accordance with NUREG/CR-6322.

The load combinations for all normal conditions and off-normal or accident events and the corresponding ASME service levels are shown in Table 2.3-2 of Reference G.3-1. Stress intensities produced by pressure, temperature, and mechanical loads are combined before comparison to the ASME Code allowable criteria which are listed in Table 2.3-3 of Reference G.3-1.

The load combinations considered for the fuel basket for normal conditions and off-normal or accident events are the same as those identified for the TSC in Table 2.3-2 of Reference G.3-1, except that there are no internal pressure loads. The analysis criteria of the ASME Code, Section III, Subsection NG are employed.

The transfer cask is a special lifting device. It is designed, fabricated, and load tested to meet the requirements of ANSI N14.6 for the handling of vertical loads defined in NUREG 0612. The transfer cask is designed using the following criteria. The combined shear stress or maximum tensile stress during the lift (with 10% dynamic load factor) shall be $\leq S_y/6$ and $S_u/10$. For off-normal (Level C) conditions, membrane stresses shall be less than $1.2S_m$ and membrane plus bending stresses shall be the lesser of $1.8S_m$ and $1.5S_y$. The ferritic steel material used for the load-bearing members of the transfer cask shall satisfy the material toughness requirements of ANSI N14.6, paragraph 4.2.6.

The structural evaluations presented in Reference G.3-1 demonstrate that the MAGNASTOR concrete cask, TSC, fuel baskets, damaged fuel can, and transfer cask meets or exceeds these design criteria. Therefore, no further site-specific evaluations are required.

G.3.1.1.6 Environmental Temperatures

A temperature of 76°F is defined as the design base normal operations temperature for MAGNASTOR in storage. This temperature conservatively bounds the maximum average annual temperature in the 48 contiguous United States, specifically, Miami, FL, at 75.6°F*, with full insolation,* and meets the normal condition thermal boundary defined in NUREG-1536. Use of this design base establishes a bounding condition for existing and potential ISFSI sites in the United States. The evaluation of this environmental condition along with the thermal analysis models are presented in Chapter 4 of Reference G.3-1. The thermal stress evaluation for the normal operating conditions is included in Chapter 3 of Reference G.3-1. Normal temperature fluctuations are bounded by the severe ambient temperature cases that are evaluated as off-normal and accident events.

Off-normal, severe environmental events are defined as -40°F with no solar loads and 106°F with solar loads. An extreme environmental condition of 133°F with maximum solar loads is evaluated as an accident case to show compliance with the maximum heat load case required by ANSI/ANS-57.9. Thermal performance is also evaluated assuming both the half blockage of the concrete cask air inlets and the complete blockage of the air inlets. Solar insolation is as specified in 10 CFR 71.71 and Regulatory Guide 7.8.

Per the MAGNASTOR Certificate of Compliance (CoC), the environmental conditions that are required to be met are the following:

- *the maximum average yearly temperature allowed is 76°F*
- *the maximum 3-day average temperature extremes shall be greater than -40°F and less than 133°F*
- *the maximum 3-day average ambient temperature allowed is 106°F*

All of these conditions are met at the WCS CISF and are addressed in SAR Section 2.3.3.1 and SAR Tables 2-2 and 2-13. Specifically, SAR Table 2-2 gives a maximum yearly average temperature for the site of 63.5°F, which is less than the 76°F limit. This table also gives the maximum temperature extremes for the site of -1.0°F and 113°F, which is within the 3-day average temperature extreme limits of -40°F and 133°F. SAR Table 2-13 gives a maximum 3-day average temperature of 93.5°F, which is less than the 106°F limit. Therefore, all environmental temperature limits for the MAGNASTOR system at the WCS CSIF are met.

G.3.1.2 Safety Protection Systems

MAGNASTOR relies upon passive systems to ensure the protection of public health and safety, except in the case of fire or explosion. As previously discussed, fire and explosion events are effectively precluded by site administrative controls that prevent the introduction of flammable and explosive materials. The use of passive systems provides protection from mechanical or equipment failure.

G.3.1.2.1 General

MAGNASTOR is designed for safe, long-term storage of spent fuel. The system will withstand all of the evaluated normal conditions and off-normal and postulated accident events without release of radioactive material or excessive radiation exposure to workers or the general public. The major design considerations to assure safe, long-term fuel storage and retrievability for ultimate disposal by the Department of Energy in accordance with the requirements of 10 CFR 72 and ISG-2 are as follows.

- Continued radioactive material confinement in postulated accidents.
- Thick steel and concrete biological shield.
- Passive systems that ensure reliability.
- Pressurized inert helium atmosphere to provide corrosion protection for fuel cladding and enhanced heat transfer for the stored fuel.

Retrievability is defined as: “maintaining spent fuel in substantially the same physical condition as it was when originally loaded into the storage cask, which enables any future transportation, unloading and ultimate disposal activities to be performed using the same general type of equipment and procedures as were used for the initial loading.”

Each major component of the system is classified with respect to its function and corresponding potential effect on public safety. In accordance with Regulatory Guide 7.10, each major system component is assigned a safety classification as shown in Table 2.4-1 or Reference G.3-1. *Table E.3-2 provides the safety classifications for the Auxiliary Equipment referenced in Sections G.4.1.7 of this SAR.* The safety classification is based on review of the component’s function and the assessment of the consequences of its failure following the guidelines of NUREG/CR-6407. The safety classification categories are defined in the following list.

Category A - Components critical to safe operations whose failure or malfunction could directly result in conditions adverse to safe operations, integrity of spent fuel, or public health and safety.

Category B - Components with major impact on safe operations whose failure or malfunction could indirectly result in conditions adverse to safe operations, integrity of spent fuel, or public health and safety.

Category C - Components whose failure would not significantly reduce the packaging effectiveness and would not likely result in conditions adverse to safe operations, integrity of spent fuel, or public health and safety.

As discussed in Section 2.4 of Reference G.3-1, the MAGNASTOR design incorporates features addressing the above design considerations to assure safe operation during fuel loading, handling, and storage of spent nuclear fuel. This section addresses the following:

- Confinement Barriers and Systems
- Concrete Cask Cooling
- Protection by Equipment
- Protection by Instrumentation
- Nuclear Criticality Safety
- Radiological Protection
- Fire Protection
- Explosion Protection
- Auxiliary Structures

The confinement performance requirements for the NAC-MAGNASTOR System are described in Chapter 7, Section 7.2 of Reference G.3-1 for storage conditions. In addition, MAGNATRAN Transport Cask SAR [G.3-2] demonstrates that the confinement boundary is not adversely affected by normal conditions of transport. Specifically, Chapter 2, Section 2.6.12 for the PWR canister. Therefore, transport to the WCS CISF will not adversely impacted confinement integrity of the NAC-MAGNASTOR canister.

G.3.1.3 Decommissioning Considerations

The principal components of MAGNASTOR are the concrete cask and the TSC. Decommissioning of these principal components is discussed in Chapter 15 of Reference G.3-1.

G.3.2 References

G.3-1 MAGNASTOR Final Safety Analysis Report, Revision 7, July 2015

G.3-2 MAGNATRAN Transport Cask SAR, Revision 12A, October 2012

Table G.3-1
Summary of WCS CISF Principal Design Criteria
(*4* pages)

Design Parameter	WCS CISF Design Criteria	Condition	MAGNASTOR® Design Criteria
Type of fuel	Commercial, light water reactor spent fuel	Normal (Bounded)	MAGNASTOR FSAR Section 2.2
Storage Systems	Transportable canisters and storage overpacks docketed by the NRC	Normal (Bounded)	72-1031 71-9356 (Pending)
Fuel Characteristics	Criteria as specified in previously approved licenses for included systems	Normal (Bounded)	MAGNASTOR FSAR Section 2.2
Tornado (Wind Load)	Max translational speed: 40 mph Max rotational speed: 160 mph Max tornado wind speed: 200 mph Radius of max rotational speed: 150 ft Tornado pressure drop: 0.9 psi Rate of pressure drop: 0.4 psi/sec	Accident (Bounded)	**MAGNASTOR FSAR Section 2.3.1.1** Max translational speed: 70 mph Max rotational speed: 290 mph Max tornado wind speed: 360 mph Radius of max rotational speed: 150 ft Tornado pressure drop: 3.0 psi Rate of pressure drop: 2.0 psi/sec
Tornado (Missile)	Automobile: 4000 lb, 112 ft/s (76.4 mph) Schedule 40 Pipe: 287 lb, 112 ft/s (76.4 mph) Solid Steel Sphere: 0.147 lb, 23 ft/s (15.7 mph)	Accident (Bounded)	**MAGNASTOR FSAR Section 2.3.1.3** Massive Missile: 4000 lb, 126 mph Rigid hardened steel: 280 lb, 126 mph Solid Steel Sphere: 0.15 lb, 126 mph
Floods	The WCS CISF is not in a floodplain and is above the Probable Maximum Flood elevation and will remain dry in the event of a flood.	Accident (Bounded)	**MAGNASTOR FSAR Section 2.3.2.1** Flood height: 50 ft Water velocity: 15 ft/s
Seismic (Ground Motion)	Site-specific ground-surface uniform hazard response spectra (UHRS) with 1E-4 annual frequency of exceedance (AFE) having peak ground acceleration (PGA) of 0.250 g horizontal and 0.175 g vertical. (Table 1-5 and Figure 1-5)	Accident (Bounded)	***See Evaluations in Section 7.6.3***

Table G.3-1
Summary of WCS CISF Principal Design Criteria
(*4* pages)

Design Parameter	WCS CISF Design Criteria	Condition	MAGNASTOR® Design Criteria
Vent Blockage	For MAGNASTOR® Systems: Inlet vents blocked 72 hrs	Accident (Same)	**MAGNASTOR FSAR Section 4.6.3** Inlet vents blocked 72 hrs
Fire/Explosion	For MAGNASTOR® Systems: Equivalent fire 50 gallons of diesel fuel	Accident (Same)	**MAGNASTOR FSAR Section 4.6.2** Equivalent fire 50 gallons of flammable liquid
Cask Drop	For MAGNASTOR® Systems: VCCs Drop height 24 inches	Accident (Same)	**MAGNASTOR FSAR Section 12.2.4** VCCs for MAGNASTOR Systems: Drop height 24 inches
Ambient Temperatures	Yearly average temperature 67.1°F	Normal (Bounded)	**MAGNASTOR FSAR Section 2.3.6** Normal operations temperature 76°F
Off-Normal Temperature	Minimum 3 day avg. temperature 27.9°F Maximum3 day avg. temperature 89.4°F	Off-Normal (Bounded)	**MAGNASTOR FSAR Section 2.3.6** Minimum 3 day avg. temperature -40°F Maximum 3 day avg. temperature 106°F
Extreme Temperature	Maximum temperature 113°F	Accident (Bounded)	**MAGNASTOR FSAR Section 2.3.6** Maximum temperature 133°F
Solar Load (Insolation)	Horizontal flat surface insolation 2949.4 BTU/day-ft^2 Curved surface solar insolation 1474.7 BTU/day-ft^2	Normal (Same)	**MAGNASTOR FSAR Section 4.4.1.1** Curved Surface: 1475 Btu/ft^2 for a 24-hour period. Flat Horizontal Surface: 2950 Btu/ft^2 for a 24-hour period.
Snow and Ice	Snow Load 10 psf	Normal (Bounded)	**MAGNASTOR FSAR Section 2.3.4** Snow Load: 100 psf
Dead Weight	Per design basis for systems listed in Table 1-1	Normal (Same)	TSC Dead Load – MAGNASTOR FSAR Section 3.5.1.2 Cask – MAGNASTOR FSAR Section 3.5.3.2
Internal and External Pressure Loads	Per design basis for systems listed in Table 1-1	Normal (Same)	TSC – MAGNASTOR FSAR Section 3.5.1.3 Maximum Internal Pressure: 110 psig

Table G.3-1
Summary of WCS CISF Principal Design Criteria
(*4* pages)

Design Parameter	WCS CISF Design Criteria	Condition	MAGNASTOR® Design Criteria
Design Basis Thermal Loads	Per design basis for systems listed in Table 1-1	Normal (Same)	TSC – MAGNASTOR FSAR Section 3.5.1.1
Operating Loads	Per design basis for systems listed in Table 1-1	Normal (Same)	Cask – MAGNASTOR FSAR Section 3.5.1.4
Live Loads	Per design basis for systems listed in Table 1-1	Normal (Same)	Cask – MAGNASTOR FSAR Section 3.5.3.2
Radiological Protection	Public wholebody ≤ 5 Rem Public deep dose plus individual organ or tissue ≤ 50 Rem Public shallow dose to skin or extremities ≤ 50 mrem Public lens of eye ≤ 15 mrem	Accident (Same)	**MAGNASTOR FSAR Section 2.4.7.2** Public ≤ 5 Rem from any design base accident
Radiological Protection	Public wholebody ≤ 25 mrem/yr(1) Public thyroid ≤ 75 mrem/yr(1) Public critical organ ≤ 25 mrem/yr(1)	Normal (Same)	**MAGNASTOR FSAR Section 2.4.7.2** Public wholebody ≤ 25 mrem/yr
Confinement	Per design basis for systems listed in Table 1-1	N/A	MAGNASTOR FSAR Chapter 7 Leaktight
Nuclear Criticality	Per design basis for systems listed in Table 1-1	N/A	MAGNASTOR FSAR Chapter 6 K_{eff} <.95
Decommissioning	Minimize potential contamination	Normal (Same)	**MAGNASTOR FSAR Chapter 15** Minimize potential contamination

Table G.3-1
Summary of WCS CISF Principal Design Criteria
(*4* pages)

Design Parameter	WCS CISF Design Criteria	Condition	MAGNASTOR® Design Criteria
Materials Handling and Retrieval Capability	Cask/canister handling system prevent breach of confinement boundary under all conditions Storage system allows ready retrieval of canister for shipment off-site	Normal (Same)	**MAGNASTOR FSAR Section 2.4.2** Cask/canister handling system prevent breach of confinement boundary under all conditions MAGNASTOR FSAR Section 2.5 Storage system allows ready retrieval of canister for shipment off-site

Note

1. In accordance with 10 CFR 72.104(a)(3) limits include any other radiation from uranium fuel cycle operations within the region.

APPENDIX G.4
OPERATING SYSTEMS
NAC-MAGNASTOR

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G.4 OPERATING SYSTEMS

MAGNASTOR is a spent fuel dry storage system consisting of a concrete cask and a welded stainless steel TSC with a welded closure to safely store spent fuel. The TSC is stored in the central cavity of the concrete cask. The concrete cask provides structural protection, radiation shielding, and internal airflow paths that remove the decay heat from the TSC contents by natural air circulation. MAGNASTOR is designed and analyzed for a 50-year service life.

The loaded TSC is moved to and from the concrete cask using the transfer cask. The transfer cask provides radiation shielding during TSC closure and preparation activities. The TSC is transferred into the concrete cask by positioning the transfer cask with the loaded TSC on top of the concrete cask, opening the shield doors, and lowering the TSC into the concrete cask. Figure G.4-1 depicts the major components of MAGNASTOR in such a configuration.

Section G.4.3 provides a reference to all applicable license drawings (i.e., only undamaged and damaged PWR fuel storage systems) from Reference [G.4-1]. In addition to these previously NRC approved license drawings, this WCS CISF SAR appendix includes one site-specific GTCC waste canister storage configuration drawing for previously loaded Zion GTCC waste canisters (GTCC-Canister-ZN).

G.4.1 Undamaged and Damaged PWR Fuel

MAGNASTOR provides for the long-term storage of PWR fuel assemblies as listed in Chapter 2 of Reference G.4-1. During long-term storage, the system provides an inert environment, passive structural shielding, cooling and criticality control, and a welded confinement boundary. The structural integrity of the system precludes the release of contents in any of the design basis normal conditions and off normal or accident events, thereby assuring public health and safety during use of the system. The following provides a general description of the major components of MAGNASTOR. The terminology used throughout these sections is summarized in Section 1.1 of Reference G.4-1.

G.4.1.1 Transportable Storage Canister (TSC)

The stainless steel TSC assembly holds the fuel basket structure and confines the contents (see Figure G.4-2). The TSC is defined as the confinement boundary during storage. The welded TSC weldment, closure lid, closure ring, and redundant port covers prevent the release of contents under normal conditions and off-normal or accident events. The fuel basket assembly provides the structural support and a heat transfer path for the fuel assemblies, while maintaining a subcritical configuration for all of the evaluated normal conditions and off-normal or accident events. Two lengths of TSCs accommodate all evaluated PWR fuel assemblies.

The major components of the TSC assembly are the shell, base plate, closure lid assembly, closure ring, and redundant port covers for the vent and drain ports, which provide the confinement boundary during storage. TSCs are provided in four configurations designated TSC1 through TSC4. The design characteristics, overall dimensions and materials of fabrication for the different TSC configurations are provided in Table 1.3-1 of Reference G.4-1.

The MAGNASTOR TSCs are loaded with spent fuel and welded closed at their respective sites. There are no active components associated with the loaded and welded closed TSCs. Thus, no further loading or closing operations are required to be performed on the TSC and basket at the WCS CISF. Further details about the TSC can be found in Section 1.3.1.1 of Reference G.4-1.

G.4.1.2 Fuel Baskets

Each TSC contains a PWR fuel basket, which positions and supports the stored fuel. The PWR fuel basket design is an arrangement of square fuel tubes held in a right-circular cylinder configuration using support weldments that are bolted to the outer fuel tubes. The design parameters for the two lengths of PWR fuel baskets are provided in Table 1.3-1 of Reference G.4-1.

Fuel tubes support an enclosed neutron absorber sheet on up to four interior sides of the fuel tube. The neutron absorber panels, in conjunction with minimum TSC cavity water boron levels, provide criticality control in the basket. Each neutron absorber panel is covered by a sheet of stainless steel to protect the material during fuel loading and to keep it in position. The neutron absorber and stainless steel cover are secured to the fuel tube using weld posts located across the width and along the length of the fuel tube.

Each PWR fuel basket has a capacity of up to 37 undamaged fuel assemblies. Square tubes are assembled in an array where the tubes function as independent fuel positions and as sidewalls for the adjacent fuel positions in what is called a developed cell array. Consequently, the 37 fuel positions are developed using only 21 tubes. The array is surrounded by weldments that serve both as sidewalls for some perimeter fuel positions and as the structural load path from the array to the TSC shell wall.

The system is also designed to store up to four damaged fuel cans (DFCs) in the DF Basket Assembly. The DF Basket Assembly has a capacity of up to 37 undamaged PWR fuel assemblies, including four DFC locations. DFCs may be placed in up to four of the DFC locations. The arrangement of tubes and fuel positions is the same as in the standard fuel basket, but the design of each of the four corner support weldments is modified with additional structural support to provide an enlarged position for a damaged fuel can at the outermost corners of the fuel basket. A damaged fuel can or an undamaged PWR fuel assembly may be loaded in a damaged fuel can corner location.

Further details about the MAGNASTOR 37 PWR and DF basket assemblies can be found in Section 1.3.1.2 of Reference G.4-1.

G.4.1.3 Concrete Cask

The concrete cask is the storage overpack for the TSC and it is designed to hold both lengths of TSCs. The concrete cask provides structural support, shielding, protection from environmental conditions, and natural convection cooling of the TSC during long-term storage. The principal dimensions and materials of fabrication of the concrete cask are shown in Table 1.3-1 of Reference G.4-1.

The concrete cask is a reinforced structural plain concrete shield wall with a structural steel inner liner and base. The reinforced structural plain concrete shield wall and steel liner provide the neutron and gamma radiation shielding for the stored spent fuel. Reinforcing steel (rebar) is encased within the concrete. The reinforced structural plain concrete shield wall provides the structural strength to protect the TSC and its contents in natural phenomena events such as tornado wind loading and wind-driven missiles and during nonmechanistic tip-over events (refer to Figure G4.1-3). The concrete surfaces remain accessible for inspection and maintenance over the life of the cask, so that any necessary restoration actions may be taken to maintain shielding and structural conditions.

The concrete cask may be supplied in four different configurations designated CC1 through CC4. CC1 is the standard 225.27-in high cylinder. CC2 is also 225.27-in high, but is a segmented design. The CC3 and CC4 configurations are shorter variants at 218.3 inches high. CC1, CC2 and CC4 are equipped with a 1.75-in thick carbon steel liner, while CC3 has a 3-in thick carbon steel liner. CC1, CC2 and CC4 are equipped with standard concrete lids, having a constant thickness, while CC3 lid has a thicker center section for enhanced shielding. Both the CC3 and CC4 cask configurations are equipped with additional shielding at the air inlets.

The concrete cask provides an annular air passage to allow the natural circulation of air around the TSC to remove the decay heat from the contents. The lower air inlets and upper air outlets are steel-lined penetrations in the concrete cask body. 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 concrete cask inner liner, respectively. Heat radiated to the liner can be transferred to the air annulus and by conduction through the concrete cask 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. The concrete cask thermal design also maintains the bulk concrete temperature and surface temperatures below the American Concrete Institute (ACI) limits under normal operating conditions. The inner liner of the concrete cask incorporates standoffs that provide lateral support to the TSC in side impact accident events.

A carbon steel and concrete lid is bolted to the top of the concrete cask. (See Table G.4-2 for the Concrete Cask Lid – Concrete Specification Summary.) The lid reduces skyshine radiation and provides a cover to protect the TSC from the environment and postulated tornado missiles.

To facilitate movement of the storage cask at the WCS CISF, lifting lugs are embedded into the concrete. This provides a place for the vertical cask transporter to engage the storage cask in order to lift and subsequently move empty and loaded storage casks.

Existing MAGNASTOR storage casks will not be used at the WCS CISF. New storage casks will be constructed on site at the WCS CISF. Fabrication of the concrete cask requires no unique or unusual forming, concrete placement, or reinforcement operations. The concrete portion of the cask is constructed by placing concrete between a reusable, exterior form and the steel liner. Reinforcing bars are used near the inner and outer concrete surfaces to provide structural integrity. Note: inner rebar cage is optional. The structural steel liner and base are shop fabricated. Refer to Table G.4-1 for the fabrication specifications for the concrete cask.

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 of Reference G.4-1. As an alternative to daily visual inspections, the loaded concrete cask 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 some of the concrete casks at the Independent Spent Fuel Storage Installation (ISFSI) facility.

G.4.1.4 Transfer Cask

The transfer cask is designed, fabricated, and tested to meet the requirements of ANSI N14.6 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 concrete cask or a transport cask.

The transfer cask is available in two configurations—MTC1 and MTC2. MTC1 consists of carbon steel shells. MTC2 is a shorter version consisting of stainless steel shells. The principal dimensions and materials of fabrication of the transfer cask are provided in Table 1.3-1 of Reference G.4-1.

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. After placement of the transfer cask on the concrete cask, the doors are retracted using hydraulic cylinders and a hydraulic supply. The TSC is then lowered into a concrete cask for storage. Refer to Figure G.4-1 for the general arrangement of the transfer cask, TSC, and concrete cask during loading.

Sixteen penetrations, eight at the top and eight at the bottom, are available to provide for the introduction of forced air, gas, or water to the transfer cask annulus in order to reduce loaded TSC temperatures during transfer operations. The transfer cask annulus can be isolated using inflatable seals located between the transfer cask inner shell and the outer surface of the TSC near the upper and lower ends of the transfer cask.

G.4.1.5 Damaged Fuel Can

The MAGNASTOR Damaged Fuel Can (DFC), shown in Figure 1.3-4 of Reference G.4-1, is provided to accommodate damaged PWR fuel assemblies or fuel debris equivalent to one PWR fuel assembly. Up to four DFCs may be loaded, one into each outer corner, in the MAGNASTOR DF Basket Assembly.

The primary function of the DFC is to confine the fuel material within the can to minimize the potential for dispersal of the fuel material into the TSC cavity. In normal operation, the DFC is in a vertical orientation. Further details about the MAGNASTOR DFC can be found in Section 1.3.1.5 of Reference G.4-1.

G.4.1.6 Storage Pad

The MAGNSTOR system is designed for long-term storage at an ISFSI. At the ISFSI site, the loaded concrete storage casks are placed in the vertical position on a concrete pad in a linear array. The reinforced concrete foundation of the ISFSI pad is capable of sustaining the transient loads from the vertical cask transporter and the general loads of the stored casks. The pad design meets the MAGNASTOR pad requirements and is consistent with analyses performed within Reference G.4-1.

G.4.1.7 Auxiliary Equipment

This list shows the auxiliary equipment generally needed to use MAGNASTOR.

- automated, remote, and /or manual welding equipment to perform TSC field closure welding operations
- an engine-driven or towed frame or a heavy-haul trailer to move the concrete cask to and from the storage pad and to position the concrete cask on the storage pad
- draining, drying, hydrostatic testing, helium backfill, and water cooling systems for preparing the TSC and contents for storage
- hydrogen monitoring equipment to confirm the absence of explosive or combustible gases during TSC closure welding
- an adapter plate and a hydraulic supply system
- a lifting yoke for lifting and handling the transfer cask and rigging equipment for lifting and handling system components

In addition to these items, the system requires utility services (electric, helium, air, clean borated water, etc.), standard torque wrenches, tools and fittings, and miscellaneous hardware.

G.4.2 References

G.4-1 MAGNASTOR Final Safety Analysis Report, Revision 7, July 2015.

G.4-2 NAC International, "Safety Analysis Report for the MAGNATRAN Transport Cask," Revisions 12A, 14A, 15A, and 16A U.S. NRC Docket Number 71-9356.

G.4.3 Supplemental Data

The licensing drawings for the MAGNASTOR® System are listed in Section 1.8, *License Drawings* of the *MAGNASTOR® System Final Safety Analysis Report*, Revision 7 [G.4-1]. These drawings appear in the FSAR immediately after the drawing list in Section 1.8.1.

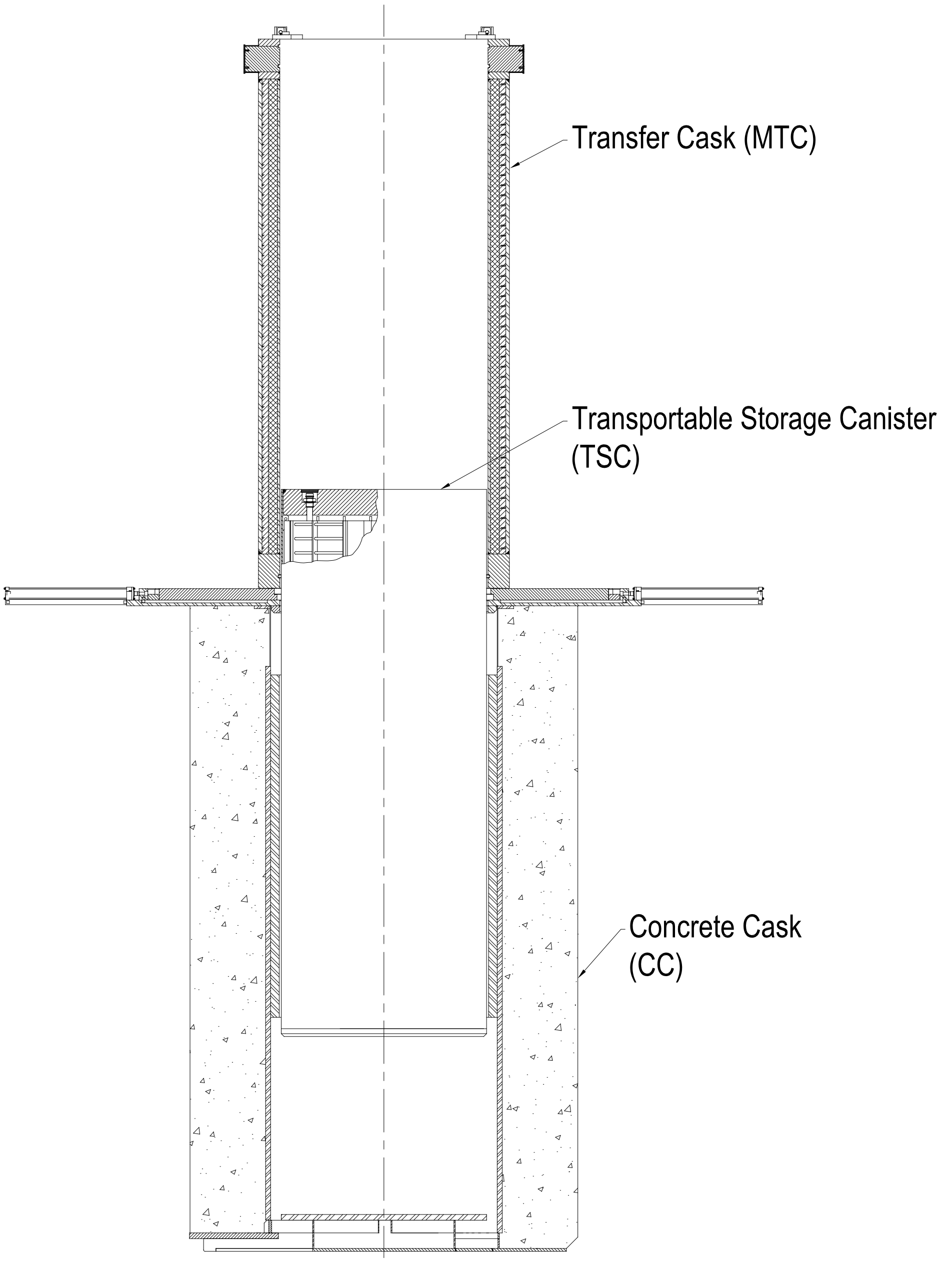

Figure G.4-1
Major Component Configuration for Loading the Concrete Cask

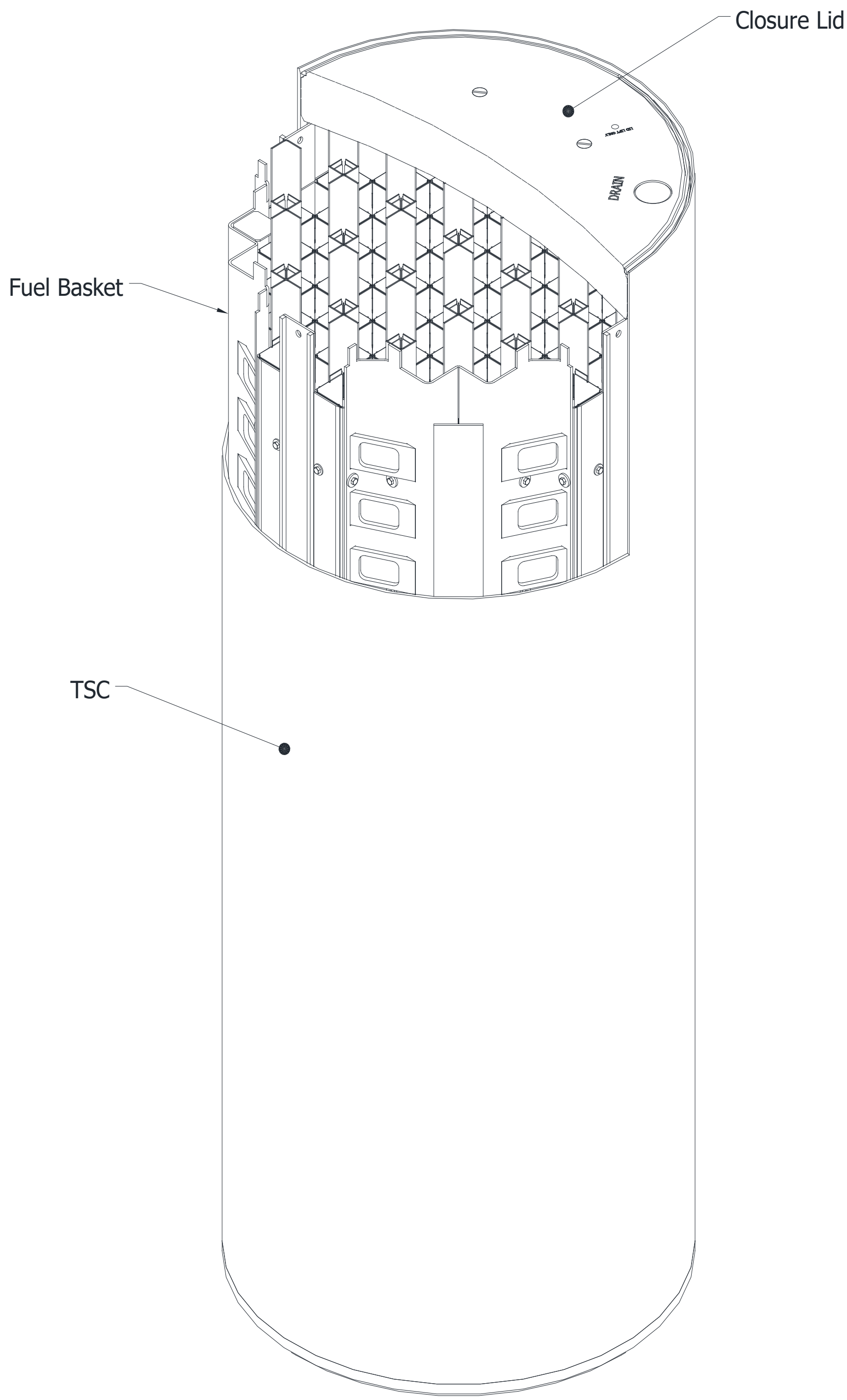

Figure G.4-2
TSC and Basket

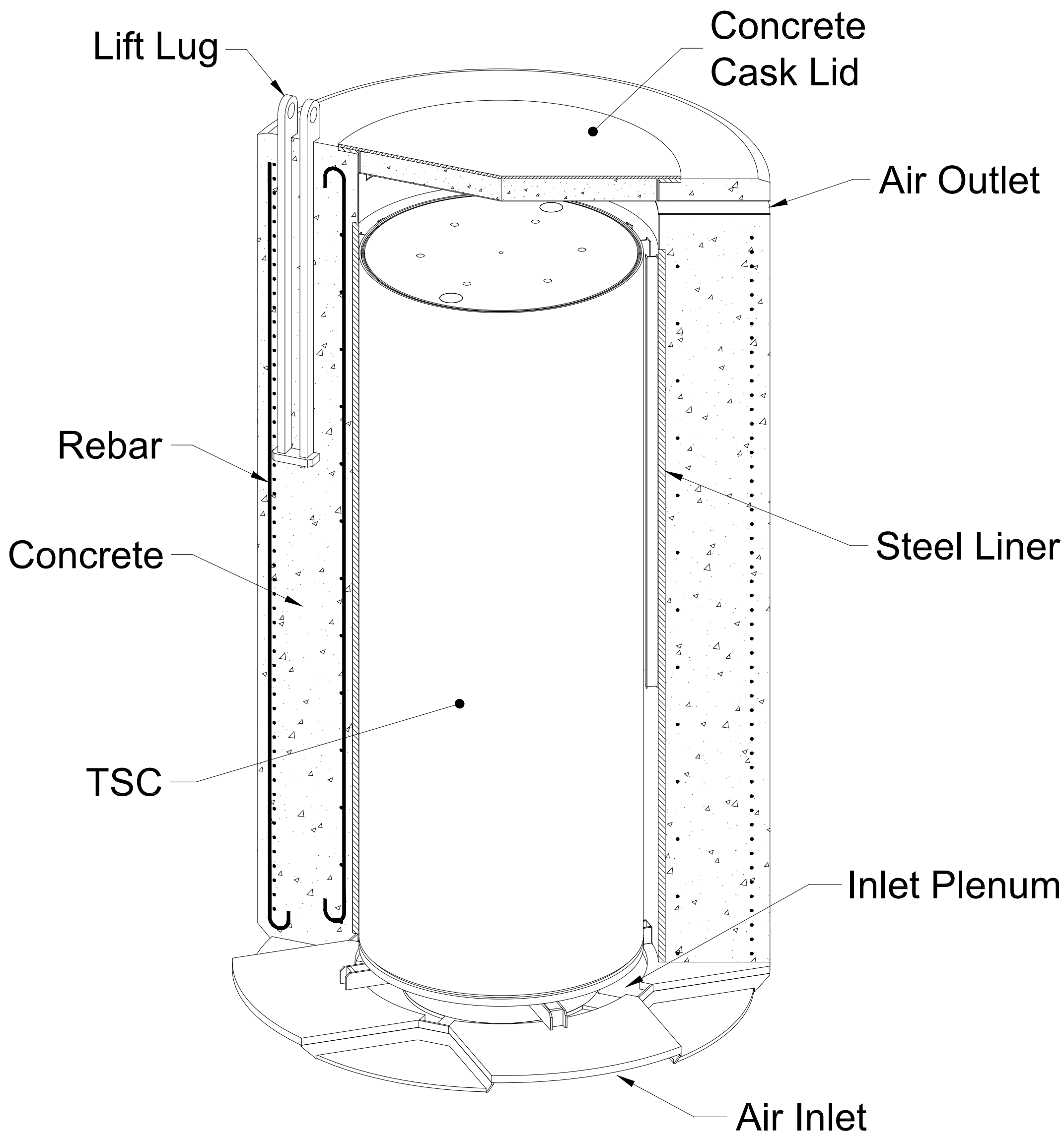

Figure G.4-3
Concrete Cask

Table G.4-1
Concrete Cask Construction Specification Summary

Materials

- Concrete mix shall be in accordance with the requirements of ACI 318 and ASTM C94.
- Type II Portland Cement, ASTM C150.
- Fine aggregate ASTM C33 or C637.
- Coarse aggregate ASTM C33.
- Aggregates that conform to the particle size requirements of a U.S. state's transportation agency, which is in general use in the area, should be considered as having a satisfactory service record with regard to those concrete properties affected by the respective grading requirement.
- Admixtures
  - Water Reducing and Superplasticizing ASTM C494.
  - Pozzolanic Admixture (loss on ignition 6% or less) ASTM C618.
- Compressive strength 4000 psi minimum at 28 days.
- Specified air entrainment per ACI 318.
- All steel components shall be of the material as specified in the referenced drawings.

Construction

- A minimum of two samples for each concrete cask shall be taken in accordance with ASTM C172 and ASTM C31 for the purpose of obtaining concrete slump, density, air entrainment, and 28-day compressive strength values. The two samples shall not be taken from the same batch or truck load.
- Test specimens shall be tested in accordance with ASTM C39.
- Formwork shall be in accordance with ACI 318.
- All sidewall formwork shall remain in place in accordance with the requirements of ACI 318.
- Grade, type, and details of all reinforcing steel shall be in accordance with the referenced drawings.
- Embedded items shall conform to ACI 318 and the referenced drawings.
- The placement of concrete shall be in accordance with ACI 318.
- Surface finish shall be in accordance with ACI 318.
- Welding and inspection requirements and acceptance criteria are specified in Chapter 10.

Quality Assurance

- The concrete cask shall be constructed under a quality assurance program that meets 10 CFR 72, Subpart G.

Table G.4-2
Concrete Cask Lid – Construction Specification Summary

Concrete mix shall be in accordance with the following ACI 318 requirements:

- Standard weight concrete density shall be 140 pcf (minimum)
- No strength requirements – commercial grade concrete from a commercial grade supplier

APPENDIX G.5
OPERATING PROCEDURES
NAC-MAGNASTOR

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G.5 OPERATING PROCEDURES

The following are operating procedures for using the MAGNASTOR spent fuel storage system. These procedures are based on the general guidance found in Chapter 9 of the MAGNASTOR Final Safety Analysis Report (FSAR) [Reference G.5-1]. The procedures covered are:

1. Transferring the loaded TSC to the Concrete Cask.

2. Transporting and placing the loaded Concrete Cask.

3. Removing the loaded TSC from a Concrete Cask.

4. Receiving the MAGNATRAN Transport Cask and Unloading the loaded TSC.

The operating procedure for transferring a loaded TSC from a MAGNASTOR concrete cask to the MAGNATRAN Transport Cask is described in the MAGNATRAN Safety Analysis Report, Docket 71-9356. Also, the detailed operating procedures for receiving a loaded MAGNATRAN Transport Cask and unloading the transportable storage canister are described in Section 7.2 of the MAGNATRAN Safety Analysis Report.

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

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

Tables in Chapter 3 of Reference G.5-1 provide the handling weights for the major components of MAGNASTOR and the loads to be lifted during various phases of the loading and unloading operations. Licensees/users must perform appropriate reviews and evaluations to ensure that the lifted loads do not exceed rated load limits of user-supplied lifting equipment and comply with the facility’s heavy-load program.

Pictograms of the NAC-MAGNASTOR System operations are presented in Figure G.5-1.

G.5.1 Undamaged and Damaged PWR Fuel

Operation of the MAGNASTOR system requires the use of auxiliary equipment. Refer to Table 9.1-1 of Reference G.5-1 for a listing of the major auxiliary equipment generally required by the user to operate the system. MAGNASTOR provides effective shielding for operations personnel; however, the licensee/user may utilize supplemental shielding to further reduce operator radiation exposure. The planned location, type, and possible interactions of the temporary supplemental shielding with MAGNASTOR shall be appropriately evaluated by the licensee/user.

G.5.1.1 Transferring the TSC to the Concrete Cask

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

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

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

   Note: The minimum ambient air temperature (either in the facility or external air temperature, as applicable for the handling sequence) must be $\geq 0°F$ for the use of the concrete cask, per Section 4.3.1.g. of the MAGNASTOR Technical Specifications.

2. Inspect all concrete cask openings for foreign objects and remove if present; install supplemental shielding in four outlets.
3. Install a four-legged sling set to the lifting points on the transfer adapter.
4. Using the crane, lift the transfer adapter and place it on top of the concrete cask ensuring that the guide ring sits inside the concrete cask lid flange. Remove the sling set from the crane and move the slings out of the operational area.
5. Connect a hydraulic supply system to the hydraulic cylinders of the transfer adapter.
6. Verify the movement of the connectors and move the connector tees to the fully extended position.
7. Connect the lift yoke to the crane and engage the lift yoke to the transfer cask trunnions. Ensure all lines, temporary shielding and work platforms are removed to allow for the vertical lift of the transfer cask.

Note: The minimum ambient air temperature (either in the facility or external air temperature, as applicable for the handling sequence) must be ≥ 0ºF for the use of the transfer cask, per Section 4.3.1.f. of the MAGNASTOR Technical Specifications.

8. Raise the transfer cask and move it into position over the empty concrete cask.
9. Slowly lower the transfer cask into the engagement position on top of the transfer adapter to align with the door rails and engage the connector tees.
10. Following set down, remove the lock pins from the shield door lock tabs.
11. Install a stabilization system for the transfer cask, if required by the facility heavy load handling or seismic analysis programs.
12. Disengage the lift yoke from the transfer cask trunnions and move the lift yoke from the area.
13. As appropriate to the TSC lifting system being used, move the lifting system to a position above the transfer cask. If redundant sling sets are being used, connect the sling sets to the crane hook.
14. Using the TSC lifting system, lift the TSC slightly (approximately ½-1 inch) to remove the TSC weight from the shield doors.

    Note: The lifting system operator must take care to ensure that the TSC is not lifted such that the retaining blocks (MTC1/MTC2) or the retaining ring (MTC2) is engaged by the top of the TSC.

15. Open the transfer cask shield doors with the hydraulic system to provide access to the concrete cask cavity.
16. Using the cask handling crane in slow speed (or other approved site-specific handling system), slowly lower the TSC into the concrete cask cavity until the TSC is seated on the pedestal.

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

    Note: The completion of the transfer of the TSC to the concrete cask (i.e., the top of the TSC is in the concrete cask cavity) completes the TSC transfer evolution time from Step 69 in Section 9.1.1.

17. When the TSC is seated, disconnect the slings (or other handling system) from the lifting system, and lower the sling sets through the transfer cask until they rest on top of the TSC.
18. Retrieve the lift yoke and engage the lift yoke to the transfer cask trunnions.
19. Remove the seismic/heavy load restraints from the transfer cask, if installed.

20. Close the shield doors using the hydraulic system and reinstall the lock pins into the shield door lock tabs.
21. Lift the transfer cask from the top of the concrete cask and return it to the cask preparation area for next fuel loading sequence or to its designated storage location.
22. Disconnect hydraulic supply system from the transfer adapter hydraulic cylinders.
23. Remove redundant sling sets, swivel hoist rings, or other lifting system components from the top of the TSC, if installed.
24. Verify all equipment and tools have been removed from the top of the TSC and transfer adapter.
25. Connect the transfer adapter four-legged sling set to the crane hook and lift the transfer adapter off the concrete cask. Place the transfer adapter in its designated storage location and remove the slings from the crane hook. Remove supplemental shielding from outlets.

    Note: If the optional low profile concrete cask is used, proceed to Step 26. If the standard concrete cask is provided, proceed to Step 38.
26. Install three swivel hoist rings and the three-legged sling set on the concrete cask shield ring.
27. Using the crane, lift the shield ring and place it into position inside of the concrete cask top flange.
28. Remove the three-legged sling and swivel hoist rings.
29. Using the designated transport equipment, move the loaded concrete cask out of the low clearance work area or truck/rail bay.
30. Install the three swivel hoist rings into the three threaded holes and attach the three-legged sling set to the shield ring.
31. Using an external or mobile crane, lift and remove the shield ring. Place the shield ring in position for the next loading sequence or return it to its designated storage location.
32. Install four swivel hoist rings in the threaded holes of the concrete cask extension using the manufacturer-specified torque.
33. Install the four-legged sling set and attach to the crane hook.

    Note: A mobile crane of sufficient capacity may be required for concrete cask extension and lid installations performed outside the building.

34. Perform visual inspection of the top of the concrete cask and verify all equipment and tools have been removed.

    Note: Take care to minimize personnel access to the top of the unshielded loaded concrete cask due to shine from the TSC.

35. Lift the concrete cask extension and move it into position over the concrete cask, ensuring alignment of the two anchor cavities with their mating lift anchor embedment.

36. Lower the concrete cask extension into position and remove the sling set from the crane hook.

37. Remove the four swivel hoist rings and cables from the concrete cask extension.

    Note: If concrete cask transport is to be performed by a vertical cask transporter, proceed to Step 38.

38. Install the lift lugs into the anchor cavities of the concrete cask extension, or directly on top of the lifting embedment for the standard concrete cask, if applicable to the concrete cask design utilized.

39. Install the lift lug bolts through each lift lug and into the threaded holes in the embedment base. Torque each of the lug bolts to the value specified in Table 9.1-2 of Reference G.5-1.

40. Install three swivel hoist rings into the concrete cask lid and attach the three-legged sling set. Attach the lifting sling set to the crane hook.

41. At the option of the user, install the weather seal on the concrete cask lid flange. Lift the concrete cask lid and place it in position on the top of the flange.

42. Remove the sling set and swivel hoist rings and install the concrete cask lid bolts. Torque to the value specified in Table 9.1-2 of Reference G.5-1.

43. Move the loaded concrete cask into position for access to the site-specific transport equipment.

G.5.1.2 Transporting and Placing the Loaded Concrete Cask

This section describes the general procedures for moving a loaded concrete cask to the ISFSI pad using a vertical cask transporter.

1. Using the vertical cask transporter lift fixture or device, engage the two concrete cask lifting lugs.

2. Lift the loaded concrete cask and move it to the ISFSI pad following the approved onsite transport route.

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

Note: Do not exceed the maximum lift height for a loaded concrete cask of 24 inches, per Section 4.3.1.h. of the MAGNASTOR Technical Specifications.

3. Move the concrete cask into position over its intended ISFSI pad storage location. Ensure the surface under the concrete cask is free of foreign objects and debris.

   Note: The spacing between adjacent loaded concrete casks must be at least 15 feet.

4. Using the vertical transporter, slowly lower the concrete cask into position.
5. Disengage the vertical transporter lift connections from the two concrete cask lifting lugs. Move the cask transporter from the area.
6. Detorque and remove the lift lug bolts from each lifting lug, if the lugs are to be reused.

   Note: At the option of the user, the lift lugs may be left installed during storage operations.

7. Lift out and remove the concrete cask lift lugs. Store the lift lugs for the next concrete cask movement.
8. Install the lug bolts through the extension base (or through the cover plate for the standard concrete cask) and into the threaded holes. Torque each bolt to the value specified in Table 9.1-2 of Reference G.5-1.
9. For the casks with extensions containing anchor cavities, install the weather seal and cover plates. Install the bolts and washers and torque to the value specified in Table 9.1-2 of Reference G.5-1.
10. If optional temperature monitoring is implemented, install the temperature monitoring devices in each of the four outlets of the concrete cask and connect to the site’s temperature monitoring system.
11. Install inlet and outlet screens to prevent access by debris and small animals.

    Note: Screens may be installed on the concrete cask prior to TSC loading to minimize operations personnel exposure.

12. Scribe and/or stamp the concrete cask nameplate to indicate the loading date. If not already done, scribe or stamp any other required information.
13. Perform a radiological survey of the concrete cask within the ISFSI array to confirm dose rates comply with ISFSI administrative boundary and site boundary dose limits.

14. Initiate a daily temperature monitoring program or daily inspection program of the inlet and outlet screens to verify continuing effectiveness of the heat removal system.

G.5.1.3 Removing the Loaded TSC from a Concrete Cask

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

As the steps to move a loaded concrete cask are essentially the reverse of the procedures in Section G.5.1.1 and Section G.5.1.2, the procedural steps are only summarized here.

1. Remove inlet and outlet screens and temperature measuring equipment (if installed).

   Note: The minimum ambient air temperature (either in the facility or external air temperature, as applicable for the handling sequence) must be ≥ 0ºF for the use of the concrete cask, per Section 4.3.1.g. of the MAGNASTOR Technical Specifications.

2. For concrete casks to be transported by a vertical cask transporter, remove anchor cavity cover plates, remove the lid assembly bolts, and install the lift lugs. Torque the lift lug bolts for each lift lug to the value specified in Table 9.1-2 of Reference G.5-1. Attach the concrete cask to the vertical cask transporter.
3. For concrete casks to be transported on a flat-bed vehicle, install an air pad rig set in the inlets. Inflate the air pads and move concrete cask onto the vehicle deck.

   Note: Ensure that air pads are not installed longer than eight hours to complete concrete cask transfer.

4. Move the loaded concrete cask to the facility.
5. Remove the concrete cask lid. Install concrete cask shield ring, if required.
6. Install the six hoist rings into the canister closure lid threaded holes. Remove shield ring, if installed.

   Note: Utilize high temperature-resistant slings (≤ 350°F)

7. Install transfer adapter on top of the concrete cask.
8. Place transfer cask onto the transfer adapter and engage the shield door connectors.

Note: The minimum ambient air temperature (either in the facility or external air temperature, as applicable for the handling sequence) must be ≥ 0ºF for the use of the transfer cask, per Section 4.3.1.f. of the MAGNASTOR Technical Specifications.

9. Open the shield doors, retrieve the lifting slings, and install the slings on the lifting system.
10. Slowly withdraw the TSC from the concrete cask. The chamfer on the underside of the transfer adapter assists in the alignment into the transfer cask.
11. Bring the TSC up to just below the retaining blocks (MTC1/MTC2) or the retaining ring (MTC2). Close the transfer cask shield doors and install the shield door lock pins.
12. Lift transfer cask off the concrete cask and move to the designated workstation.

After the transfer cask with the loaded TSC is in, or adjacent to, the facility, the operational sequence to load another concrete cask is performed in accordance with the procedures in Section G.5.1.1. Note that the amount of time that a loaded TSC can remain in the transfer cask without cooling is limited to 11 hours from the time the TSC is removed from the concrete cask. Internal or external cooling of the TSC is required to be initiated within 11 hours as described in Section 9.3 of Reference G.5-1.

G.5.1.4 Receiving the MAGNATRAN Transport Cask and Unloading the Loaded TSC

The following procedure(s) cover inspecting the cask upon receipt, preparing the cask for removal from its conveyance, and unloading the transportable storage canister into the transfer cask. Following unloading of the transportable storage canister into the transfer cask, the previously described procedures should be followed to place the transportable storage canister into dry storage in a vertical concrete cask, or an equivalent, approved storage configuration. Note, the requirements of the transport cask CoC must be followed at all times. In the event there is conflict between the following procedures and the transport CoC requirements, the transport CoC requirements take precedence.

G.5.1.4.1 Performing Receiving Inspection of the Loaded MAGNATRAN Transport Cask

1. Upon receipt of the loaded MAGNATRAN transport cask, perform and record radiation and removable contamination surveys on the transport vehicle, personnel barrier and package surfaces to verify that radiation dose rates and contamination levels comply with the requirements of 10 CFR 20.1906, the limits of 10 CFR 71.87(i), and the limits of 10 CFR 71.47.
2. Remove the personnel barrier and complete radiation and contamination surveys of the now-accessible package surfaces to verify that radiation dose rates and contamination levels comply with the requirements of 10 CFR 20.1906, the limits of 10 CFR 71.87(i), and the limits of 10 CFR 71.47.
3. Perform a visual receipt inspection of the vehicle and package to identify any transport damage. Clean the vehicle and cask of road dirt and debris. Cleaning of the package exterior shall ensure that surfaces are cleaned of chloride-containing salts and other corrosive agents. Confirm the acceptable removal of chloride-containing salts and other corrosive agents.
4. Verify the tamper indicating device (TID) installed on the upper impact limiter is intact and the identification number matches the number documented on the shipping papers. Make appropriate notifications if tampering is suspected. Remove the TID.
5. Move the transport vehicle to the cask unloading area. Secure the vehicle by applying the brakes or chocking the wheels. Attach impact limiter slings to the upper impact limiter and a suitable crane hook and take up the slack in the slings.
6. Remove the impact limiter lock wires and the jam and attachment nuts. Remove the impact limiter retaining rods. Remove the upper impact limiter and store it in the upright position in a clean area.
7. Repeat Steps 5-6 for the lower impact limiter.
8. Complete radiation and contamination surveys for exposed transport cask surfaces.
9. Release the front tie-down assembly from the top forging of the cask and remove the rotation trunnion tie-downs. Remove the two trunnion plugs and store the plugs and bolts to prevent damage. Visually inspect the trunnion recesses for any damage.
10. Using a crane and slings, lift and position a lifting trunnion, install the attachment bolts, and torque the bolts as specified. Repeat for the second lifting trunnion.
11. Attach the cask lifting yoke to the cask handling crane hook. Verify the proper operation of the lift arm pneumatic actuation system. Position the cask lifting yoke arms adjacent to the cask lifting trunnions and close the arms using the actuation system. Visually verify proper yoke arm engagement.

12. Lift and rotate the cask to the vertical orientation on the rotation trunnions. Lift the cask from the transport frame/vehicle rear support structure and position the cask vertically in the designated unloading area.
13. Disengage the yoke from the cask lifting trunnions and remove it from the immediate area. Wash any dust and dirt off the cask and decontaminate cask exterior, as required
14. Install appropriate work platforms, scaffolding or lifts to facilitate access to the top of the cask.

G.5.1.4.2 Preparing to unload the transportable storage canister (TSC) from the MAGNATRAN Transport Cask

The assumptions underlying this procedure are:

- The MAGNATRAN Transport Cask is in a vertical position in the designated unloading area.
- The top of the MAGNATRAN Transport Cask is accessible.

The procedures for preparing to unload the TSC from the MAGNATRAN Transport Cask are:

1. Detorque and remove the lid port coverplate bolts. Visually inspect the bolt threads for damage and store them. Remove the coverplate and store it.
2. Attach a pressure fixture, including a pressure gauge, evacuated gas sample bottle and a valve to the lid port quick-disconnect valve. Measure the cask internal pressure. Withdraw a sample of the cavity gas using the evacuated sample bottle and determine the cask cavity's gaseous activity. If activity and pressure levels are acceptable per facility criteria, vent the cavity gas to an appropriate filter/system. Disconnect the pressure fixture from the lid port.
3. Detorque and remove the cask lid bolts using the reverse of the torquing sequence shown on the lid. Clean and inspect the bolt threads for damage and store them.
4. Install and torque swivel hoist rings, as specified, in the four threaded lifting holes in the cask lid. Install and hand-tighten the lid alignment pins in their designated hole locations.
5. Attach an appropriate lid sling set to the swivel hoist rings (or equivalent site-specific approved lid lifting system) and a suitable crane. Lift and remove the cask lid. Decontaminate and store the lid to prevent damage to the seal surfaces and cask cavity spacer, if installed. Record the time the lid is removed.

Caution: In order to ensure that the fuel clad temperatures do not exceed 400ºC, as established by ISG-11, Revision 3, a fuel TSC containing maximum heat load contents (i.e., PWR - 23 kW; BWR - 22 kW) shall be removed from the MAGNATRAN following cask lid removal and placed in a safe condition (i.e., in a MTC or equivalent transfer device). The maximum time to complete the operational sequence shall be < 6 hours. This maximum transfer and preparation time is not applicable to the loading of GTCC waste TSCs as the ISG-11 temperature limits are not applicable.

G.5.1.4.3 Unloading the transportable storage canister (TSC) from the MAGNATRAN Transport Cask

A transfer cask (MTC) is used to unload the transportable storage canister (TSC) from the transport cask and to transfer it to a storage or disposal overpack. The transfer cask retaining ring or retaining blocks must be installed.

The procedures for unloading the transportable storage canister from the MAGNATRAN Transport Cask are:

1. Remove the lid alignment pins, and using a suitable crane and sling set, install the transfer shield ring in the lid recess.

   Note: The transfer shield ring aligns the transfer adapter to the cask cavity, provides additional side shielding and protects the cask lid seating surface from damage.
2. Position the transfer adapter on the top of the transport cask and connect the shield door ancillary hydraulic actuation system.
3. Install the TSC lifting system swivel hoist rings and lifting slings (or other appropriate TSC lifting system meeting the facility's heavy load program) to the threaded holes in the TSC closure lid and torque as specified.
4. Using the MTC lift yoke, lift the empty MTC and place it on the transfer adapter on top of the transport cask. Ensure that the connector assemblies are in the engaged position. Remove the door stops.
5. Disengage the MTC lift yoke and remove it from the area.
6. Open the MTC bottom shield doors using the ancillary hydraulic actuation system. Connect the handling crane to the TSC lifting sling set(s) or the site-specific approved lifting system meeting the facility's heavy load program. Verify that the MTC retaining device is in the engaged position and raise the loaded TSC from the transport cask cavity into the MTC.

7. Using the ancillary hydraulic actuation system, close the MTC bottom shield doors and set the TSC down on the doors. Install the shield door stops.
8. Disengage the TSC lifting sling set(s) from the cask handling crane or disengage the site-specific approved lifting system meeting the facility's heavy load program.
9. Using the MTC lift yoke, engage the lift yoke to the MTC lifting trunnions. Lift the MTC containing the loaded TSC and move it to the designated location for further processing, on-site storage or unloading.

Continue operations to place the canister in an approved storage configuration as described in Paragraph G.5.1.1.

G.5.2 References

G.5-1 MAGNASTOR Final Safety Analysis Report, Revision 7, July 2015

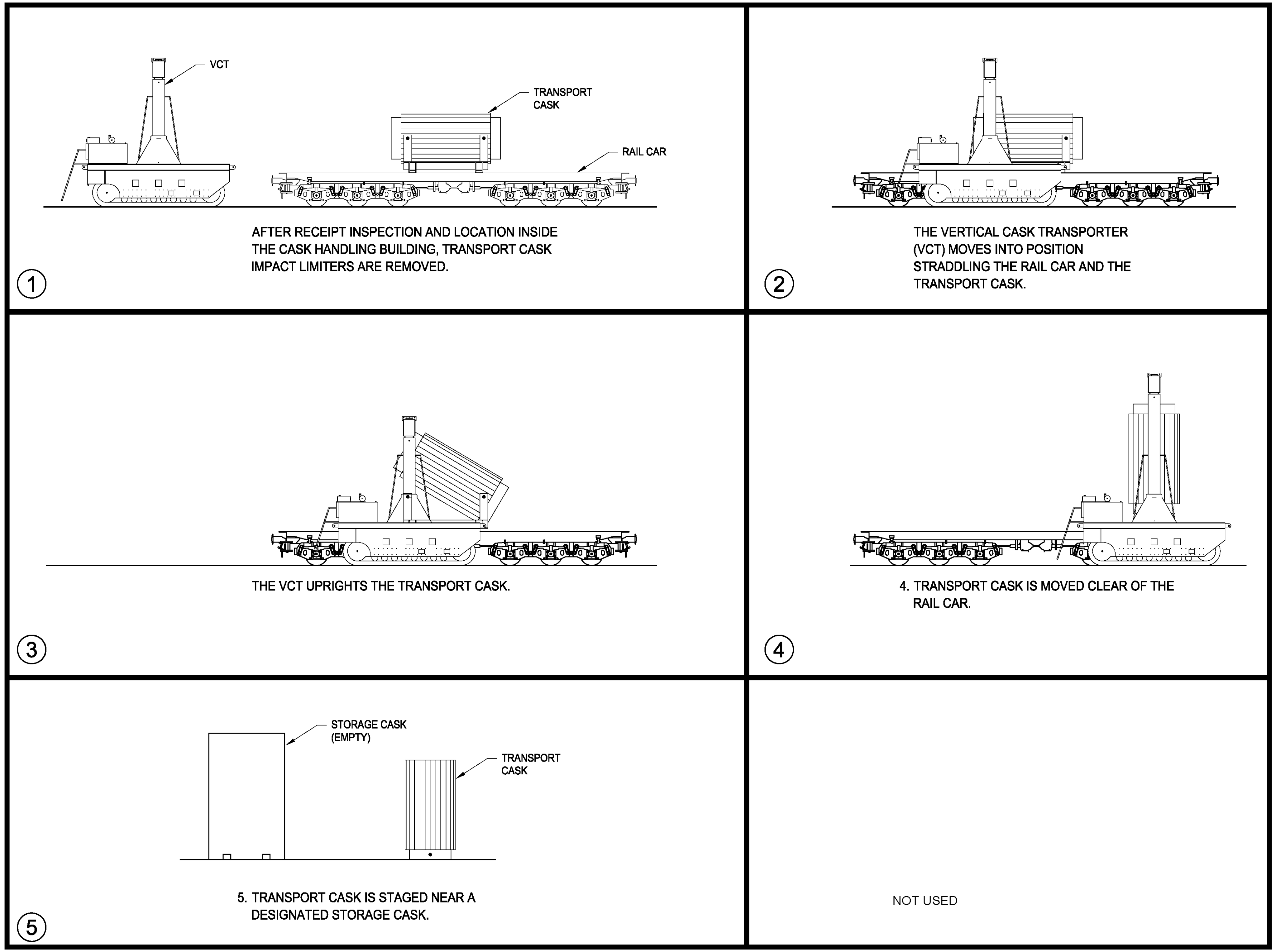

Figure G.5-1
Canister Transfer Operations
2 Pages

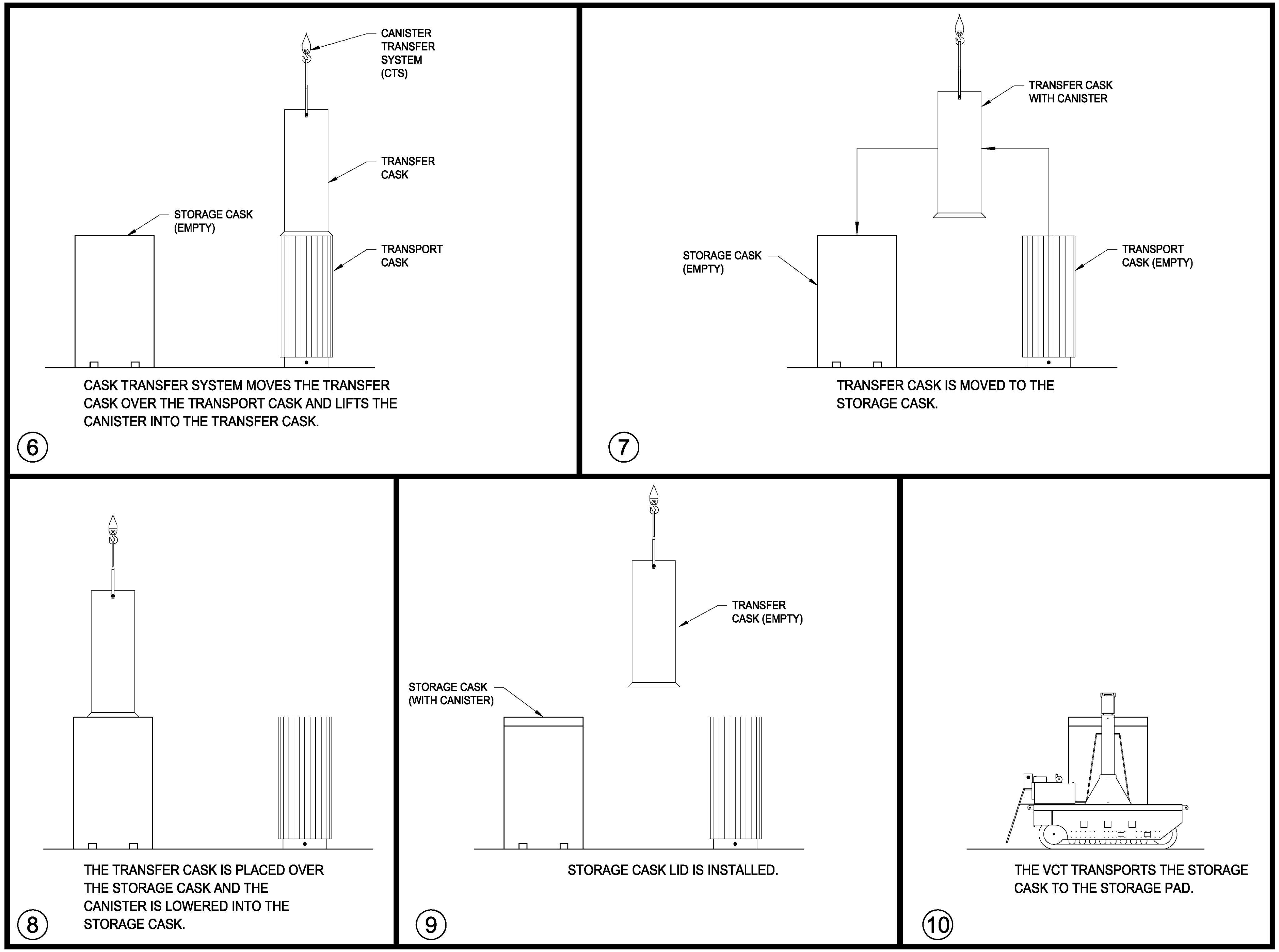

Figure G.5-1
Canister Transfer Operations
2 Pages

APPENDIX G.6
WASTE CONFINEMENT AND MANAGEMENT
NAC-MAGNASTOR

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G.6. WASTE CONFINEMENT AND MANAGEMENT

No change or additional information required for the MAGNASTOR Cask System for Chapter 6.

APPENDIX G.7
STRUCTURAL EVALUATION
NAC-MAGNASTOR

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G.7 STRUCTURAL EVALUATION

This appendix summarizes the location of the detailed structural analyses for the MAGNASTOR system under normal operating conditions in Reference G.7-1. Off-normal and accident events are covered in WCS CISF SAR Appendix G.12.

G.7.1 Undamaged and Damaged PWR Fuel

Sections G.7.1.1 through G.7.1.8 outline the structural analyses of normal operating conditions for MAGNASTOR with undamaged and damaged PWR fuel presented in Reference G.7-1. Finally, bounding evaluations in Section G.7.1.9 are referenced to demonstrate that the confinement boundaries for the MAGNASTOR canisters do not exceed ASME B&PV Subsection NB Article NB-3200 (Level A allowables) during normal conditions of transport to provide reasonable assurance that the confinement boundary is not adversely impacted by transport to the WCS CISF.

G.7.1.1 Structural Design

Details of the structural design of the MAGNASTOR system are provided in Section 3.1 of Reference G.7-1.

G.7.1.2 Weights and Centers of Gravity

The weights and centers of gravity of the MAGNASTOR system are provided in Section 3.2 of Reference G.7-1.

G.7.1.3 Materials

The significant physical, chemical, mechanical, and thermal properties of materials used in components of MAGNASTOR are defined, and the material specifications, tests and acceptance conditions important to material use are identified in Chapter 8 of Reference G.7-1.

G.7.1.4 Chemical and Galvanic Reactions

The materials used in the fabrication and operation of MAGNASTOR are evaluated in Section 8.10 of Reference G.7-1 to determine whether chemical, galvanic or other reactions among the materials, contents, and environments can occur.

G.7.1.5 Positive Closure

The positive closure evaluation for MAGNASTOR is provided in Section 3.4.2 of Reference G.7-1.

G.7.1.6 Lifting Devices

The evaluations of the MAGNASTOR system’s lifting devices are provided in Section 3.4.3 of Reference G.7-1.

G.7.1.7 Normal Operating Conditions

The analyses of the major structural components of MAGNASTOR for normal conditions of storage are provided in Section 3.5 of Reference G.7-1.

G.7.1.8 Fuel Rods

The structural evaluations of PWR fuel rods for the storage conditions of the MAGNASTOR system are provided in Section 3.8 of Reference G.7-1.

G.7.1.9 Structural Evaluation of NAC-MAGNASTOR Canister Confinement Boundaries under Normal Conditions of Transport

The NAC-MAGNASTOR canister primary confinement boundaries consist of a canister shell, bottom closure plate, closure lid, the two port covers, and the welds that join these components. Redundant closure is provided by two outer port covers and a closure ring. Additional details, geometry, and shell and plate thicknesses are provided on the figures in Section G.4. The confinement boundary is addressed in Section G.11.1.1. The evaluation findings for the NAC-MAGNASTOR canister shell for normal conditions of transport are provided in Section 2.6.12 of [G.7-2] *(to provide reasonable assurance that the confinement boundary is not adversely impacted by transport to the WCS CISF)*.

The result of the structural analysis is acceptable for the loads and combinations described in Section 2.6.12 of [G.7-2], and is therefore structurally adequate for normal conditions of transport loading conditions.

G.7.2 References

G.7-1 MAGNASTOR Final Safety Analysis Report, Revision 7, July 2015.

G.7-2 MAGNATRAN Transport Cask Safety Analysis Report, Revision 12A, October 2012.

APPENDIX G.8
THERMAL EVALUATION
NAC-MAGNASTOR

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G.8 THERMAL EVALUATION

Chapter 4 of Reference G.8-1 presents the thermal design and analyses of MAGNASTOR. Results of the analyses contained therein demonstrate that with the design basis contents, MAGNASTOR meets the thermal performance requirements of 10 CFR 72, NUREG-1567, and NUREG-1536.

The MAGNASTOR design basis heat load is 35.5 kW for PWR fuel. The fuel loading may be in the 37 PWR Basket Assembly, i.e., up to 37 undamaged PWR fuel assemblies, or up to 37 PWR minimum reduced cool time fuel, or in the DF Basket Assembly, which has a capacity of up to 37 undamaged fuel assemblies including four DFC locations. Damaged fuel cans may be located in the DFC locations at the four outer corners of the DF basket assembly. Both the PWR fuel basket and the DF basket assembly can accommodate a uniform heat load of 959 W per assembly, or a preferential loading pattern as discussed in Section 4.1 of Reference G.8-1.

MAGNASTOR system thermal evaluations are performed using conservative environmental thermal parameters. The following sections details those thermal parameters and shows that they bound the site-specific thermal environmental parameters at the WCS CISF.

G.8.1 Undamaged and Damaged PWR Fuel

Chapter 4 of Reference G.8-1 provides the thermal analyses used evaluate the thermal performance of the MAGNASTOR system. The limiting environmental conditions (thermal) used in these evaluations are presented and compared to WCS CISF site specific conditions in the following sections. Additionally, surveillance requirements used to ensure the concrete cask heat removal system is operable are presented.

G.8.1.1 Maximum Average Yearly Ambient Temperature

For the MAGNASTOR system, the maximum average yearly temperature allowed is 76°F. The the average yearly temperature for the site is conservatively bounded by using the maximum average annual temperature in the 48 contiguous United States, of 75.6°F. This temperature meets the normal condition thermal boundary defined in NUREG-1536. Therefore, no further WCS CISF site-specific evaluations are required.

G.8.1.2 Maximum Average 3-Day Ambient Temperature

The maximum average 3-day ambient temperature allowed is 106°F for the MAGNASTOR system. This temperature bounds the WCS CISF maximum average 3-day ambient temperature of 89.4°F. Therefore, no further site-specific evaluations are needed.

G.8.1.3 Maximum Extreme 3-Day Ambient Temperature Range

For the MAGNASTOR system, the maximum allowed temperature extremes, averaged over a 3-day period, shall be greater than -40°F and less than 133°F. This bounds the WCS CISF maximum temperature extreme of -1°F and 113°F. No further site-specific evaluations are needed.

G.8.1.4 Thermal Performance Surveillance Requirements

For the MAGNASTOR system, in order to confirm that the concrete cask heat removal system is operable, one of the following two surveillance options with a frequency of 24 hours is required:

1. Visually verify all concrete cask air inlet and outlet screens are free of blockage.

2. Verify the difference between the concrete cask air outlet average temperature and the ambient temperature is less than 119ºF for the PWR concrete cask configurations CC1, CC2, and CC4 or less than 134ºF for PWR concrete cask configuration CC3.

G.8.2 References

G.8-1 MAGNASTOR Final Safety Analysis Report, Revision 7, July 2015

APPENDIX G.9
RADIATION PROTECTION
NAC-MAGNASTOR

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G.9 RADIATION PROTECTION

This appendix summarizes the shielding analysis for the MAGNASTOR system. Specific dose rate limits for individual casks in a storage array are not established by 10 CFR 72. Annual dose limit criteria for the ISFSI-controlled area boundary are established by 10 CFR 72.104 and 10 CFR 72.106 for normal operating conditions and for design basis accident conditions, respectively. These regulations require that, for an array of casks in an ISFSI, the annual dose to an individual outside the controlled area boundary must not exceed 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other organ during normal operations. For a design basis accident, the dose to an individual outside the controlled area boundary must not exceed 5 rem to the whole body. In addition, the occupational dose limits and radiation dose limits established in 10 CFR Part 20 (Subparts C and D) for individual members of the public must be met.

The MAGNASTOR system is designed with two transfer cask and four concrete cask configurations. Transfer casks are designed with either carbon steel shells (MTC1) or stainless steel shells (MTC2). Concrete casks are designed in:

- A standard shielding configuration (one piece – CC1 and segmented – CC2) with a 1.75-inch liner thickness (PWR and BWR systems);
- An augmented shielding configuration (CC3) with a 3-inch liner thickness, an increased lid thickness and additional shielding at the air inlets (PWR system);
- And a short, standard shielding configuration cask (CC4) with a 1.75-inch liner thickness and additional shielding at the air inlets (PWR system).

Canisters may be sealed with either an all stainless steel closure lid or a composite carbon steel and stainless steel lid assembly. The composite lid assembly bounds the all stainless steel lid in shielding evaluations due to the lower density of carbon steel.

Chapter 5 of Reference G.9-1 describes the shielding design and the analysis used to establish bounding radiological dose rates for the safe storage of up to 37 undamaged PWR fuel assemblies in the MAGNASTOR 37 PWR basket assembly. The MAGNASTOR system is also designed to store up to four damaged fuel cans (DFCs) in the DF Basket Assembly. The DF Basket Assembly has a capacity of up to 37 undamaged PWR fuel assemblies, including four DFC locations. DFCs may be placed in up to four of the DFC locations. Each DFC may contain an undamaged PWR fuel assembly or damaged fuel, which may be a damaged PWR fuel assembly or PWR fuel debris equivalent to one PWR fuel assembly. Undamaged PWR fuel assemblies may be placed directly in the DFC locations of a DF Basket Assembly.

PWR fuel assemblies may contain nonfuel hardware – i.e., reactor control components (RCCs), burnable poison rod assemblies (BPRAs), 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 the lower section of guide tubes), and components of these devices, such as individual rods. The analysis shows that for the design basis fuel, the system meets the requirements of 10 CFR 72.104 and 10 CFR 72.106 and complies with the requirements of 10 CFR 20 with regard to annual and occupational doses at the owner-controlled area boundary.

Minimum cool times prior to fuel transfer and storage are specified as a function of minimum assembly average fuel enrichment and maximum assembly average burnup (MWd/MTU). To minimize the number of loading tables, PWR and BWR fuel assemblies are grouped by bounding fuel and hardware mass. Key characteristics of each assembly grouping are shown in Section 5.2 of Reference G.9-1. Refer to Section 5.8.9 of Reference G.9-1 for detailed loading tables meeting the system heat load limits.

Source terms for the various vendor-supplied fuel types are generated using the SCALE 4.4 sequence as discussed in Section 5.2 of Reference G.9-1. Three-dimensional MCNP shielding evaluations provide dose rates for transfer and concrete casks at distances up to four meters. NAC-CASC, a modified version of the SKYSHINE-III code, calculates site boundary dose rates for either a single cask or cask array. See Section 5.6 of Reference G.9-1 for more detail on the shielding codes.

Table G.9-1 provides estimated occupational exposures for receipt and handling of the NAC-MAGNASTOR system loaded with PWR fuel at the WCS CISF facility. For each procedural step the number of workers, occupancy time, worker distance, dose rates, and total dose are estimated. Dose rates used were obtained and estimated via the listed references in the table. The total occupational exposure for receiving, transferring and placing these canisters on the storage pad in their storage overpack (VCC) is *1,035* person-mrem each.

The total collective dose for unloading a NAC-MAGNASTOR PWR canister from its VCC and preparing it for transport off-site is bounded by the loading operations (*1,035* person-mrem). Operations for retrieving these canisters from the VCC and off-site shipment are identical to loading operations, except in reverse order. The collective dose for unloading is bounded because during storage at the WCS CISF the source terms will have decayed reducing surface dose rates. The total collective dose is the sum of the receipt, transfer, retrieval, and shipment is 2,046 person-mrem.

G.9.1 Undamaged and Damaged PWR Fuel

Section 5.1 of Reference G.9-1 provides a summary of the results of the shielding evaluation of the MAGNASTOR system. With the exception of the offsite dose discussion, the dose results are presented based on bounding heat loads and corresponding source terms based on a 35.5 kW PWR cask heat load. Offsite dose results are produced by similar bounding values of a 40 kW PWR cask heat load. Cool time tables for the thermally restricting payloads are listed in Section 5.8.9 of Reference G.9-1. Based on the code validation discussion in Section 5.2 of Reference G.9-1, a 5% uncertainty is applied to the heat loads for fuel burnups above 45 GWd/MTU. This results in an extension in minimum allowed cool time for high burnup fuel assemblies. All dose rates calculated at higher cask heat loads are bounding for the reduced heat load. For any fuel type, burnup, initial enrichment, and cool time combination allowed, additional cool time and, therefore, reduced sources are associated with the lower cask heat load. This conclusion applies also to the PWR preferential loading patterns.

A reduced minimum cool time of 2.5 years and four-zone preferential loading pattern (max 1.8 kW/assy heat load) are evaluated in Section 5.9 of Reference G.9-1 for undamaged or damaged PWR assembles in the CC4 or MTC2.

Dose rates (detector tallies) presented in Chapter 5 of Reference G.9-1 are calculated using Monte Carlo methods and, therefore, contain a result and statistical uncertainty of the result. The statistical uncertainty is expressed as a percentage and referred to as fractional standard deviation (FSD) or relative uncertainty.

G.9.1.1 Transfer Cask Shielding Discussion and Dose Results

The transfer cask radial shield is comprised of steel inner and outer shells connected by solid steel top and bottom forgings. License drawings for these components are provided in Section G.4.3. The shell encloses a lead gamma shield and a solid borated polymer (NS-4-FR) neutron shield. The TSC shell and the basket internal structure provide additional radial shielding. The transfer operation bottom shielding is provided by the TSC bottom plate and solid steel transfer cask doors. The TSC closure lid provides radiation shielding at the top of the TSC.

The three-dimensional transfer cask shielding analysis provides a complete, nonhomogenized representation of the transfer cask and TSC structure. The model assumes the following TSC/transfer cask configuration for all dose rate evaluations.

- Dry canister cavity: The majority of the TSC operations, in particular closure lid welding, are performed with the TSC cavity filled with water. Evaluating a dry canister cavity is conservative. Note that the water filling the TSC/transfer cask annulus between the inflatable seals is modeled. Transfer cask dose rates from a wet canister, while containing an increased neutron source due to a higher subcritical multiplication resulting from a higher k_{eff}, are lower than those of the dry system due to the additional radiation shielding provided by the water within and surrounding the source region. Confirmatory calculations comparing dry, wet and partially flooded canister configurations are included in Section 5.8.11 of Reference G.9-1.
- 6-in auxiliary weld shield: Closure lid weld operations are typically performed with an automated weld system that is mounted on a weld platform. The presence of this platform provides significant auxiliary shielding during the TSC closure operation.
- Homogenization of the fuel assembly into five source regions: While TSC and concrete cask features are discretely modeled, the fuel assembly is homogenized into upper and lower end-fitting (nozzle) regions, upper and lower plenum regions (lower plenum regions are modeled only for B&W fuel assemblies), and an active fuel region. For shielded applications, such as in the heavily shielded spent fuel transfer and concrete casks, homogenizing the fuel region does not introduce a significant bias in the dose results presented.

Undamaged Fuel Dose Rates

The carbon steel and stainless steel transfer cask maximum calculated dose rates are shown in Table 5.1.3-1 and Table 5.1.3-4 of Reference G.9-1. Payload types producing maximum surface dose rates are listed in Table 5.1.3-3 and Table 5.1.3-6 of Reference G.9-1. TSC surface contamination release dose rates are shown in Section 5.6.5. Dose rates are based on a three-dimensional Monte Carlo analysis using surface detectors. Uncertainty in Monte Carlo results is indicated in parentheses. Further detail on the detector geometry is included in Section 5.5 of Reference G.9-1. There is no design basis off-normal or accident event that will affect the shielding performance of the transfer cask.

Transfer cask top-, side-, and bottom-surface average dose rates are 254 (1.1 %) mrem/hr, 895 (<1%) mrem/hr, and 3,000 (<1%) mrem/hr, respectively. Access to the bottom of the cask is limited to pool-to-workstation transfer operations and the workstation-to-vertical concrete cask transfer operations. Site ALARA plans should specify limited access to areas below and around the loaded transfer cask during lifting and transfer operations.

Damaged Fuel Dose Rates

Damaged PWR fuel assemblies may be loaded in damaged fuel cans in the four corner assembly locations of the PWR damaged fuel basket. DFC slots are locations 4, 8, 30 and 34 in Figure 5.8.12-10 of Reference G.9-1. To ensure that the worst case configuration is considered, two damaged fuel scenarios are evaluated.

The first scenario assumes the damaged fuel collects over the active fuel length of the fuel assembly. This scenario is modeled by filling the fuel assembly interstitial volume with UO_2 and increasing the fuel neutron, gamma and n-gamma source consistent with this increase in mass. Dose rate profiles for the 37-assembly undamaged assemblies are compared with profiles for 33 undamaged and 4 damaged assemblies in Section 5.8.12 of Reference G.9-1. Based on the self-shielding of the added mass compensating for the increase in source, damaged fuel dose rates for the first scenario are bounded by either the corresponding undamaged fuel dose rates or the second damaged fuel scenario.

In the second scenario, damaged fuel is assumed to migrate from the active fuel into the lower end fitting region of the fuel assembly, filling all the modeled void space. However, no credit is taken for the reduction in the lower end fitting hardware dose rate due to the added UO_2 mass and self-shielding nor for the reduction in fuel mass migrated from the active fuel region. In this case, transfer cask bottom surface dose rates increase due to the addition of damaged fuel. The transfer cask bottom axial dose rate increases 53 mrem/hr, increasing the bottom axial dose rate by approximately 0.9 percent.

Damaged fuel dose rates are computed using the carbon steel transfer cask, as it produces higher dose rates than the stainless steel transfer cask due to the higher density of stainless steel versus carbon steel.

Damaged fuel maximum dose rates in the carbon steel transfer cask are summarized in Table 5.1.3-9 of Reference G.9-1.

G.9.1.2 Concrete Cask Shielding Discussion and Dose Results

The concrete cask is composed of body and lid components. License drawings for these components are provided in Section G.4.3. The body contains the air inlets, air outlets, and the cavity for TSC placement. The lid provides environmental closure for the TSC. The radial shield design is comprised of a carbon steel inner liner surrounded by concrete. The concrete contains radial and axial rebar for structural support. As in the transfer cask, the TSC shell provides additional radial shielding. The concrete cask top shielding design is comprised of the TSC lid and concrete cask lid. The concrete cask lid incorporates both concrete and steel plate to provide additional gamma shielding. The bottom shielding is comprised of the stainless steel TSC bottom plate, the pedestal/air inlet structure, and a carbon steel base plate. Radiation streaming paths consist of air inlets located at the bottom and air outlets located above the top of the TSC, and above the annulus between the concrete cask body and the

TSC. Air inlets and outlets are radial openings to the concrete cask. The inlets and outlets are axially offset from the source regions to minimize dose and meet ALARA principles.

No auxiliary shielding is considered in the concrete cask shielding evaluation. All components relevant to safety performance are explicitly included in the concrete cask model. Homogenization of materials used in the models is limited to the fuel assembly as described in Section 5.1.1 of Reference G.9-1.

Undamaged Fuel Dose Rates

Refer to Table 5.1.3-2, Table 5.1.3-5, and Table 5.1.3-7 of Reference G.9-1 for a summary of the concrete cask normal condition and accident event maximum calculated dose rates for the standard (CC1/ CC2), augmented shield (CC3), and short, standard (CC4) cask configurations. Listed maximum dose rates include fuel and nonfuel hardware contributions. Payload types producing maximum surface dose rates are listed in Table 5.1.3-3, Table 5.1.3-6, and Table 5.1.3-8 of Reference G.9-1. Refer to Section 5.6.5 of Reference G.9-1 for TSC surface contamination release dose rates. Dose rates are based on three-dimensional Monte Carlo analysis using surface detectors. Further detail on the detector geometry is included in Section 5.5.

The maximum concrete cask side (cylindrical) average surface dose rate is 58 (<1%) mrem/hour. On the concrete cask top (disk), the average surface dose rate is 104 (2%) mrem/hour. Average dose rates for the standard shielding concrete cask are more than twice as high on the radial surface and approximately 20% higher on the axial surface than the augmented shielding cask configuration for the PWR system (augmented cask shield analysis limited to PWR payloads). The maximum inlet and outlet dose rates are 434 and 59 mrem/hr, respectively. No design basis normal condition or accident event exposes the bottom of the concrete cask.

Damaged Fuel Dose Rates

The two damaged fuel scenarios described in Section G.9.1.1 are also evaluated for the concrete cask.

The first scenario assumes the damaged fuel collects over the active fuel length of the fuel assembly. Dose rate profiles for the 37- undamaged assemblies are compared with profiles for 33 undamaged and 4 damaged assemblies in Section 5.8.12 of Reference G.9-1. Based on the self-shielding of the added mass compensating for the increase in source, damaged fuel dose rates for the first scenario are bounded by either the corresponding undamaged fuel dose rates or the second damaged fuel scenario.

In the second scenario, damaged fuel is assumed to migrate from the active fuel into the lower end fitting region of the fuel assembly, filling all the modeled void space. In this case, concrete cask inlet and radial dose rates increase due to the addition of damaged fuel. The concrete cask inlet dose rate increase is 38 mrem/hr, increasing the inlet dose rate by approximately 9 percent. The maximum concrete cask radial dose rate increases to 82.3 mrem/hr, an increase of approximately 4 percent.

Damaged fuel dose rates are computed using the standard concrete cask (CC1/CC2) or the short, standard concrete cask (CC4), as they produce higher dose rates than the augmented shield concrete cask.

Damaged fuel maximum dose rates in the standard concrete cask are summarized in Table 5.1.3-10 of Reference G.9-1.

G.9.1.3 Offsite Dose Discussion and Results

Contributions from concrete casks to site radiation dose exposure are limited to either radiation emitted from the concrete cask surface or a hypothetical release of surface contamination from the TSC. As documented in Section 5.6.5 of Reference G.9-1, there is no significant site dose effect from the expected surface contamination of the system. The TSCs are comprised of a welded shell, bottom plate and lid structure. The vent and drain ports in the lid are covered by redundant welded plates. There is, therefore, no credible leakage from the system, and no significant effluent source can be released from the TSC contents. Details on the TSC confinement boundary are provided in Appendix G.11, with leakage test information provided in Section 10.1.3 of Reference G.9-1.

Controlled area boundary exposure from the concrete cask surface radiation is evaluated using the NAC-CASC code. (As previously stated, NAC-CASC is a modified version of SKYSHINE- III.) NAC-CASC calculates the direct dose rate as well as the air scattered contribution of the total dose rate. As the detectors are below the top surface of the cask, only the cylindrical shell (radial) cask surface current contributes a direct component to the total dose rate. NAC-CASC primary enhancements to SKYSHINE-III allow the input of an angular surface current, the input of cylindrical shell (side) and disk (top) geometries, and the accounting of concrete cask self-shielding (i.e., radiation emitted from one cask intersecting another cask in the array—in particular, front/back row interaction in the array). The cylindrical shell and top surfaces are Monte Carlo sampled to generate the surface current input into the code. Each of the sampled locations represents a point source to which the SKYSHINE-III line beam response functions are applicable.

The NAC-CASC (SKYSHINE-III) method assumes that radiation emitted from the source does not interact with the cask/source structure after emission (beyond the additional routines added by NAC to account for self-shielding). This assumption does not represent a significant effect on site dose rates as the calculated surface current is near normal to the surface and any backscatter to the cask from the air surrounding the array would then require a second backscatter from the cask surface to reach a detector location. As detector locations for site exposure are at significant distances from the array (typically 100+ meters), there would not be a significant contribution from radiation having undergone such repeated large angle scatter.

Both a single cask and a 2×10 array of casks are evaluated for site exposure evaluations. Each cask in the array is assigned the maximum dose (surface current) source allowed by the cask loading tables. A combination of the maximum cask side and top dose cases provides for a conservative estimate on the controlled area boundary exposure, since the different fuel types produce the highest cask surface dose components.

G.9.2 References

G.9-1 MAGNASTOR Final Safety Analysis Report, Revision 7, July 2015.

Table G.9-1
Estimated Occupational Collective Dose for Receipt of NAC MAGNATRAN Cask Loaded with PWR SNF in MAGNASTOR TSC and Transfer to MAGNASTOR VCC
7 Sheets

Process Step	Number of Workers	Occupancy Time (hours)	Worker Location Around Cask	Worker Distance (m)	Total Dose Rate (mrem/hr)	Total Dose (person-mrem)[1]	Reference SAR/FSAR Table/Figure
Perform radiation and contamination survey of MAGNATRAN Cask.	*1*	0.5	All Around MAGNATRAN Cask	>2	10	*5*	SAR Figure 5.1-1, Table. 5.1-3, Figure 5.8-7, Figure 5.8-11, Figure 5.8-14, Figure 5.8-15
Inspect top impact limiter security seal and verify it is intact and correct ID.	1	*0.1*	Top Impact Limiter *Periphery*	>1	<*1*	1	SAR Figure 5.1-1, Table. 5.1-3, Figure 5.8-7, Figure 5.8-11, Figure 5.8-14, Figure 5.8-15
Remove Security Seal	*1*	*0.1*	*Top Impact Limiter Periphery*	*>1*	*<1*	*1*	*SAR Figure 5.1-1, Table 5.1-3, Figure 5.8-7, Figure 5.8-11, Figure 5.8-14,and Figure 5.8-15*
Remove Personnel Barrier.	2	0.5	Center of MAGNATRAN Cask	1	<20	*20*	SAR Figure 5.1-1, Table. 5.1-3, Figure 5.8-7, Figure 5.8-11, Figure 5.8-14, Figure 5.8-15
Attach slings to top Impact Limiter and remove 32 retention nuts/rods. Remove and store Impact Limiter.	2	1	Top of MAGNATRAN Cask	>1	< 5	10	SAR Figure 5.1-1, Table. 5.1-3, Figure 5.8-7, Figure 5.8-11, Figure 5.8-14, Figure 5.8-15
Attach slings to bottom Impact Limiter and remove 32 retention nuts/rods. Remove and store Impact Limiter.	2	1	Bottom of MAGNATRAN Cask	>1	< 5	10	SAR Figure 5.1-1, Table. 5.1-3, Figure 5.8-7, Figure 5.8-11, Figure 5.8-14, Figure 5.8-15

Table G.9-1
Estimated Occupational Collective Dose for Receipt of NAC MAGNATRAN Cask Loaded with PWR SNF in MAGNASTOR TSC and Transfer to MAGNASTOR VCC
7 Sheets

Process Step	Number of Workers	Occupancy Time (hours)	Worker Location Around Cask	Worker Distance (m)	Total Dose Rate (mrem/hr)	Total Dose (person-mrem)[1]	Reference SAR/FSAR Table/Figure
Perform contamination survey of cask surfaces. If necessary, decontaminate the cask until acceptable smearable contamination levels are achieved.	*2*	*0.5*	*Top, side, and bottom of MAGNATRAN*	*>1*	*<20*	*20*	*SAR Figure 5.1-1, Table 5.1-3, Figure 5.8-7, Figure 5.8-11, Figure 5.8-14,and Figure 5.8-15*
Visually inspect MAGNATRAN Cask surface for transport/road damage and record.	*1*	*0.25*	*All Around Cask*	*>4*	*2.5*	*1*	*SAR Figure 5.1-1, Table. 5.1-3, Figure 5.8-7, Figure 5.8-11, Figure 5.8-14, Figure 5.8-15*
Release Front Tie-Down Assembly.	2	1	Top Side MAGNATRAN Cask Surface	1	50	100	SAR Figure 5.1-1, Table. 5.1-3, Figure 5.8-7, Figure 5.8-11, Figure 5.8-14, Figure 5.8-15
Remove front trunnion plugs and bolts, and ring segments, and store.	2	0.5	Top Side MAGNATRAN Cask Surface	1	50	50	SAR Figure 5.1-1, Table. 5.1-3, Figure 5.8-7, Figure 5.8-11, Figure 5.8-14, Figure 5.8-15
Install front trunnions and bolts and torque to specified value.	2	1	Top Side MAGNATRAN Cask Surface	1	50	100	SAR Figure 5.1-1, Table. 5.1-3, Figure 5.8-7, Figure 5.8-11, Figure 5.8-14, Figure 5.8-15
Engage Vertical Cask Transporter (VCT) Lift Arms to Front Trunnions and rotate cask to vertical orientation on rear rotation trunnions.	2	1	Top Side MAGNATRAN Cask Surface	>2	10	20	SAR Figure 5.1-1, Table. 5.1-3, Figure 5.8-7, Figure 5.8-11, Figure 5.8-14, Figure 5.8-15

Table G.9-1
Estimated Occupational Collective Dose for Receipt of NAC MAGNATRAN Cask Loaded with PWR SNF in MAGNASTOR TSC and Transfer to MAGNASTOR VCC
7 Sheets

Process Step	Number of Workers	Occupancy Time (hours)	Worker Location Around Cask	Worker Distance (m)	Total Dose Rate (mrem/hr)	Total Dose (person-mrem)[1]	Reference SAR/FSAR Table/Figure
Lift and Remove MAGNATRAN from the Transport Skid Rear supports and move cask to gantry Canister Transfer Facility (CTF), set cask down and release VCT Lift Arms. Establish Radiation Control boundaries.	2	2	Top Side MAGNATRAN Cask Surface	>2	10	40	SAR Figure 5.1-1, Table. 5.1-3, Figure 5.8-7, Figure 5.8-11, Figure 5.8-14, Figure 5.8-15
Using VCT, move empty MAGNASTOR VCC to transfer position in CTF and set down adjacent to MAGNATRAN cask. Set up appropriate work platforms/man lifts for access to top of VCC and MAGNATRAN.	2	1	Top Of Empty MAGNASTOR VCC	*>4*	*2.5*	*5*	Empty VCC */ Loaded MAGNATRAN*
Remove VCC Lid and bolts, and VCC Shield Plug.	2	1	Top Of Empty MAGNASTOR VCC	1	0	0	Empty VCC
Install Transfer Adapter on VCC and connect hydraulic system.	2	1	Top Of Empty MAGNASTOR VCC	1	0	0	Empty VCC

Table G.9-1
Estimated Occupational Collective Dose for Receipt of NAC MAGNATRAN Cask Loaded with PWR SNF in MAGNASTOR TSC and Transfer to MAGNASTOR VCC
7 Sheets

Process Step	Number of Workers	Occupancy Time (hours)	Worker Location Around Cask	Worker Distance (m)	Total Dose Rate (mrem/hr)	Total Dose (person-mrem)[1]	Reference SAR/FSAR Table/Figure
Remove vent port cover and connect pressure test system to vent port to check for excessive pressure. If pressure is high, take sample and check. If clean vent to HEPA filter.	1	0.5	Top of Cask	0.5	50	25	FSAR Table *5.1.3-1*, FSAR Section 5.8.3.3.2 + MAGNATRAN Closure Lid Thickness 7.75 in.
Remove 48 MAGNATRAN lid bolts, install alignment pins and lid lifting hoist rings/slings and remove inner lid and store. Remove alignment pins.	2	1	Top of Cask	0.5	30	60	FSAR Table *5.1.3-1*, FSAR Section 5.8.3.3.2 + MAGNATRAN Closure Lid Thickness 7.75 in.
Install adapter ring to inner lid recess and torque captured bolts.	2	0.5	Top of Cask	0.5	30	30	FSAR Table *5.1.3-1*, FSAR Section 5.8.3.3.2 Remote operation from side of MAGNATRAN
Install transfer adapter plate on adapter ring and install and torque the four transfer adapter plate bolts.	2	1	Top of Cask	1	15	30	FSAR Table *5.1.3-1*, FSAR Section 5.8.3.3.2 Remote operation from side of MAGNATRAN
Install TSC Lid Lifting Adapter Plate and bolts on the MAGNASTOR Closure Lid, and torque to specified value.	2	1	Top of Cask	0.5	75	150	FSAR Table *5.1.3-1*, FSAR Section 5.8.3.3.2 Remote operation from side of MAGNATRAN

Table G.9-1
Estimated Occupational Collective Dose for Receipt of NAC MAGNATRAN Cask Loaded with PWR SNF in MAGNASTOR TSC and Transfer to MAGNASTOR VCC
7 Sheets

Process Step	Number of Workers	Occupancy Time (hours)	Worker Location Around Cask	Worker Distance (m)	Total Dose Rate (mrem/hr)	Total Dose (person-mrem)[1]	Reference SAR/FSAR Table/Figure
Using the CTF crane, lower the appropriate MAGNASTOR Transfer Cask (MTC) and set it down on the transfer adapter on the MAGNATRAN Cask.	2	1.5	Top of Cask	>4	<1	3	Remote handling operation
Remove lock pins and open shield doors with hydraulic system.	1	0.5	Top of Cask	1	15	8	FSAR Table *5.1.3-1*, FSAR Section 5.8.3.3.2 + 2 inch TSC Lid Lift Adapter Plate Remote operation from side of MTC/MAGNATRAN
Using the CTF, lower the Air-Powered Chain Hoist hook through the MTC and engage to the TSC Lift Adapter Plate.	2	1.5	Remote Operating Location	>4	<5	15	Remote operation using CTF mounted cameras
Using the Chain Hoist System slowly lift the TSC into the MTC.	2	1	Remote Operating Location	>4	<5	10	Remote operation using CTF mounted cameras
Close the MTC shield doors and install lock pins.	1	0.5	Bottom of MTC	0.5	30	15	Operation from side of MTC FSAR Section 5.8.3.3.2 and Figure 5.8.3-17
Lower the TSC onto the shield doors and using the CTF, lift the MTC off of the MAGNATRAN transfer adapter plate.	2	1	Remote Operating Location	>4	<5	10	Remote operation using CTF mounted cameras

Table G.9-1
Estimated Occupational Collective Dose for Receipt of NAC MAGNATRAN Cask Loaded with PWR SNF in MAGNASTOR TSC and Transfer to MAGNASTOR VCC
7 Sheets

Process Step	Number of Workers	Occupancy Time (hours)	Worker Location Around Cask	Worker Distance (m)	Total Dose Rate (mrem/hr)	Total Dose (person-mrem)[1]	Reference SAR/FSAR Table/Figure
Move the MTC over the VCC and lower onto the VCC transfer adapter plate.	1	1	Remote Operating Location	>4	<5	5	Remote operation using CTF mounted cameras
Remove the MTC door lock pins.	1	0.5	Bottom of MTC	0.5	30	15	Operation from side of MTC on top of VCC transfer adapter FSAR Section 5.8.3.3.2 and Figure 5.8.3-17 and Figure 5.8.3-10
Using the Chain Hoist System, lift the TSC off of the shield doors and open the shield doors.	2	0.5	Remote Operating Location	>4	<5	5	Remote operation using CTF mounted cameras
Using the chain hoist lower the TSC into the VCC.	2	1	Remote Operating Location	>4	<5	10	Remote operation using CTF mounted cameras
Release chain hoist system hook from the TSC Lift Adapter Plate and retract chain hoist hook through the MTC.	1	0.5	Remote Operating Location	>4	<5	3	Remote operation using CTF mounted cameras
Close MTC shield doors and install lock pins.	1	0.5	Bottom of MTC	0.5	30	15	Operation from side of MTC on top of VCC transfer adapter FSAR Figure 5.8.3-10
Using the CTF, lift and remove the MTC from the top of the VCC.	1	0.5	Remote Operating Location	>4	<5	3	Remote operation using CTF mounted cameras

Table G.9-1
Estimated Occupational Collective Dose for Receipt of NAC MAGNATRAN Cask Loaded with PWR SNF in MAGNASTOR TSC and Transfer to MAGNASTOR VCC
7 Sheets

Process Step	Number of Workers	Occupancy Time (hours)	Worker Location Around Cask	Worker Distance (m)	Total Dose Rate (mrem/hr)	Total Dose (person-mrem)[1]	Reference SAR/FSAR Table/Figure
Unbolt and remove TSC Lift Adapter Plate from the top of the TSC and store.	2	1	Top of MAGNASTOR TSC	1	75	150	FSAR Figure 5.8.3-20 and operation performed on top of transfer adapter mounted on VCC
Using mobile crane, remove transfer adapter plate from VCC and store.	2	1	Top of MAGNASTOR VCC	1	10	20	Remote operation using CTF mounted cameras after connection of lifting slings
Install and bolt in place the VCC lid.	2	1	Top of MAGNASTOR VCC	1	25	50	Operation performed from top of VCC Figure 5.8.3-10
Using the VCT, lift and move loaded UMS VCC and position it in the designated storage location.	2	1	VCT Platform	>4	10	20	Operation performed from VCT and FSAR Figure 5.8.3-8
Prepare empty MAGNATRAN cask for empty return transport. Transfer and rotate to horizontal MAGNATRAN cask on the transport/shipping frame. Install transport tie-downs, impact limiters and personnel barrier.	3	9	CTF/VCT/Rail Car	1 to 4	0	0	Empty cask preparation activities
					Total (person-mrem)	*1,035*	

Note:

1. Rounded up to the nearest whole number

APPENDIX G.10
CRITICALITY EVALUATION
NAC-MAGNASTOR

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G.10 CRITICALITY EVALUATION

Chapter 6 of Reference G.10-1 documents the method, input, and result of the criticality analysis of the MAGNASTOR system. The results demonstrate that the effective neutron multiplication factor, k_{eff}, of the system under normal conditions, or off-normal and accident events, is less than 0.95 including biases and uncertainties. The system design meets the criticality requirements of 10 CFR 72 and Chapter 6 of NUREG-1536.

G.10.1 Undamaged and Damaged PWR Fuel

MAGNASTOR consists of a TSC (Transportable Storage Canister), a transfer cask, and a concrete cask. The system is designed to safely store up to 37 undamaged PWR fuel assemblies in the 37 PWR basket assembly. The system is also designed to store up to four damaged fuel cans (DFCs) in the DF Basket Assembly. The DF Basket Assembly has a capacity of up to 37 undamaged PWR fuel assemblies, including 4 DFC locations. DFCs may be placed in up to four of the DFC locations. Each DFC may contain an undamaged PWR fuel assembly, a damaged PWR fuel assembly, or PWR fuel debris equivalent to one PWR fuel assembly. Undamaged PWR fuel assemblies may be placed directly in the DFC locations of a DF Basket Assembly.

The TSC is comprised of a stainless steel canister and a basket within which fuel is loaded. The PWR system each includes two TSC lengths to store fuel assemblies without the requirement of spacers. Spacers may be employed to simplify loading or unloading operations. The TSC is loaded into the concrete cask for storage. A transfer cask is used for handling the TSC during loading of spent fuel. Fuel is loaded into the TSC contained within the transfer cask underwater in the spent fuel pool. Once loaded with fuel, the TSC closure lid is welded and the TSC is drained, dried and backfilled with helium. The transfer cask is then used to move the TSC into or out of the concrete cask. The transfer cask provides shielding during the TSC loading and transfer operations. Multiple-size concrete and transfer casks accommodate all variations of TSCs.

Under normal conditions, such as loading in a spent fuel pool, moderator (water) is present in the TSC during the initial stages of fuel transfer. During draining and drying operations, moderator with varying density is present. Thus, the criticality evaluation of the transfer cask includes a variation in moderator density and a determination of optimum moderator density. Cask accident conditions are bounded by inclusion in the analysis of the most reactive mechanical basket configuration as well as moderator intrusion into the fuel cladding. The PWR TSC is evaluated at minimum soluble boron levels during flooded conditions.

Structural analyses demonstrate that the TSC confinement boundary remains intact through all storage operating conditions. Therefore, moderator is not present in the TSC while it is in the concrete cask. However, access to the concrete cask interior environment is possible via the air inlets and outlets and the heat transfer annulus between the TSC and the cask steel liner. This access provides paths for moderator intrusion during a flood. Under off-normal and accident conditions, moderator intrusion into the convective heat transfer annulus is evaluated.

PWR system criticality control is achieved through a combination of neutron absorber sheets on the interior faces of the fuel tubes/developed cells and soluble boron. Individual fuel assemblies are held in place by the fuel tubes, by developed cells formed from fuel tubes, or by a combination of fuel tubes and side or corner weldments. The neutron absorber modeled is a borated aluminum sheet. Any material meeting the physical dimension requirements specified on the License Drawings and the effective 10B areal density specified in Table 6.1.1-5 of Reference G.10-1 will produce similar reactivity results. A combination of steel cover sheets and weld posts holds the neutron absorber sheets in place. The PWR undamaged fuel basket design includes 21 fuel tubes forming 37 fuel-assembly-sized openings while the PWR damaged fuel basket design includes 17 fuel tubes and four corner weldments forming 37 openings. A sketch of a cross-section of the damaged fuel basket is shown in figure 6.1.1-2 of Reference G.10-1.

Initial criticality evaluations rely on neutron absorber sheet effective ^{10}B loadings of 0.036 g/cm^2 for the PWR system. The system is also evaluated for effective ^{10}B loading of 0.030 and 0.027 g/cm^2 for PWR baskets. Depending on the PWR payload, variable soluble boron concentrations in the pool water are necessary to achieve sufficient neutron absorber content in the system. The soluble boron absorbs thermal neutrons inside the assembly, in addition to the neutrons removed by the absorber sheets on the tubes.

The minimum as-manufactured loading of the neutron absorber sheets depends on the effectiveness of the absorber and the minimum effective absorber areal density. Effectiveness of the absorber is influenced by the uniformity and quantity of the ^{10}B nuclide within the absorber base material. Table 6.1.1-5 of Reference G.10-1 translates the effective absorber content to absorber materials at 75% and 90% credit.

MCNP, a three-dimensional Monte Carlo code, is used in the system criticality analysis. Evaluations are primarily based on the ENDF/B-VI continuous energy neutron cross-section library 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.

Key assembly physical characteristics, maximum initial enrichment, and soluble boron requirements for each PWR fuel assembly type are shown in Reference G.10-1 Table 6.1.1-1, Table 6.1.1-2 and Table 6.1.1-6. 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. 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. Analysis demonstrated that variations in the guide/instrument tube thickness and diameter have no significant effect on system reactivity.

The continued efficacy of the neutron absorbers is assured when the canister arrives at the WCS CISF because the basket, including poison material, is designed and analyzed to maintain its configuration for all normal, off-normal and accident conditions of storage and for normal and hypothetical accidents during transport in the MAGNATRAN cask as documented in of the MAGNATRAN Safety Analysis Report.

G.10.1.1 Undamaged Fuel Criticality Results

The maximum multiplication factors (k_{eff} +2σ) 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 of Reference G.10-1. The results of the analyses are presented in detail in Sections 6.4.3 and 6.7 of Reference G.10-1, and are summarized as follows.

Cask Body	Gap Condition	Operating Condition	Water Density (g/cc)		PWR
			Interior	Exterior	k_{eff} + 2σ
Transfer	Dry	Normal	0.9982	0.0001	0.93183
Transfer	Wet	Normal	0.9982	0.0001	0.93712
Transfer	Dry	Normal	0.9982	0.9982	0.92975
Transfer	Wet	Normal	0.9982	0.9982	0.93615
Storage	Dry	Normal	0.0001	0.0001	0.48145
Storage	Dry	Accident	0.0001	0.9982	0.47104

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. 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.

G.10.1.2 Damaged 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 of Reference G.10-1 and are summarized as follows. All results are below the USL of 0.9376.

Cask Body	Gap Condition	Operating Condition	Water Density (g/cc)		PWR
			Interior	Exterior	$k_{eff} + 2\sigma$
Transfer	Wet	Normal	0.9982	N/A[a]	0.93757
Storage	Dry	Normal	0.0001	0.0001	0.49142
Storage	Dry	Accident	0.0001	0.9982	0.48211

[a] Exterior moderator has been demonstrated in Section 6.7.3 of Reference G.10-1 to not affect system reactivity for a fully flooded TSC.

Three damaged fuel configurations are evaluated. Damaged fuel includes fuel debris. In the first configuration, undamaged fuel is loaded into a DFC to demonstrate the effect of the additional stainless steel from the DFC and the DFC corner weldments. In the second configuration, damaged fuel is postulated to lose its cladding and the array is modeled at an increased pitch. In the third configuration, mixtures of fuel and water simulate small fuel rubble inside the DFC.

Three moderator configurations are evaluated. Moderator density studies are performed on the preferentially flooded DFC, partially flooded cask, and mixture moderator density. In the preferentially flooded DFC scenario, the DFC is assumed to vary in moderator density with a wet and dry canister. A partial draindown of the TSC to the top of the active fuel is referred to as partial flooding. A study on the mixture moderator density is performed to ensure that the homogenized mixture remains undermoderated.

For each of the fuel types, with and without nonfuel inserts in the active fuel region of the undamaged assemblies, several combinations of minimum soluble boron and maximum initial enrichments are determined. The allowable loadings are documented in Table 6.1.1-6 of Reference G.10-1.

G.10.2 References

G.10-1 MAGNASTOR Final Safety Analysis Report, Revision 7, July 2015

APPENDIX G.11
CONFINEMENT EVALUATION
NAC-MAGNASTOR

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G.11 CONFINEMENT EVALUATION

The MAGNASTOR TSC provides confinement for its radioactive contents in long-term storage. The confinement boundary provided by the TSC is closed by welding, creating a solid barrier to the release of contents in the design basis normal conditions and off-normal or accident events. The welds are visually inspected and nondestructively examined to verify integrity. The figure illustrating the confinement boundary for the NAC-MAGNASTOR is found in Figure 7.1-1 of Reference G.11-1.

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

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

The codes and standards for the design, fabrication, and inspection of the canister and confinement boundary are detailed in Reference G.11-2. Specifically, Appendix A, Section 4.2, “Codes and Standards,” which states the 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 canister and Section 4.2.1, “Alternatives to Codes, Standard, and Criteria,” which lists the approved alternatives to the ASME Code in Table 2.1-2 in the NAC MAGNASTOR Final Safety Analysis Report (FSAR). In addition, Section 4.1.4, “TSC Confinement Integrity,” which states the leaktight criterion for the canister in ANSI N14.5.

Appendix A, Section 3.1, “MAGNASTOR System Integrity,” of Reference G.11-2, includes limiting condition for operation (LCO) 3.1.1 for canister maximum vacuum drying time, canister vacuum drying pressure, and canister helium backfill density. These LCOs create a dry, inert, leaktight atmosphere, which contributes to preventing the leakage of radioactive material.

As stated in Section 5.1.3.1, a post-transportation evacuated volume helium leak test will be conducted for each canister, as prudent measure, to confirm that a canister remains able to perform its safety function and is, therefore, acceptable for storage at the WCS CISF. Table G.11-1 identifies the accessible portions of the canister confinement boundary along with those portions that are inaccessible for the post-transportation leak test.

G.11.1 Undamaged and Damaged PWR Fuel

The confinement boundary of the TSC consists of the TSC shell, bottom plate, closure lid, inner vent and drain port covers, and the welds that join these components. The redundant closure of the TSC confinement boundary consists of the closure ring, the outer vent and drain port covers, and the welds that join these components to the TSC shell and closure lid. The confinement boundary is shown in Figure 7.1-1 of Reference G.11-1. The confinement boundary does not incorporate bolted closures or mechanical seals. The confinement boundary welds are described in Table 7.1-1 of Reference G.11-1.

G.11.1.1 Confinement Boundary

The confinement boundary of the MAGNASTOR system is described in detail in Section 7.1 of Reference G.11-1. Specific details for the confinement vessel, confinement penetrations, seals and welds, and closure are in Sections 7.1.1, 7.1.2, 7.1.3, and 7.1.4, respectively. In addition, a bounding evaluation in Section G.7.1.9 is presented to demonstrate that the confinement boundary for the NAC-MAGNASTOR canister does not exceed ASME Boiler and Pressure Vessel Subsection NB Article NB-3200 (Level A allowables) during normal conditions of transport to provide reasonable assurance that the confinement boundary is not adversely impacted by transport to the WCS CISF.

G.11.1.2 Requirements for Normal Conditions of Storage

The requirements for normal conditions of storage for the MAGNASTOR system are described in detail in Section 7.2 of Reference G.11-1. Specific details on the release of radioactive materials and pressurization of the confinement vessel are in Sections 7.2.1 and 7.2.2, respectively.

G.11.1.3 Confinement Requirements for Hypothetical Accident Conditions

The requirements for hypothetical accident conditions are described in detail in Section 7.3 of Reference G.11-1.

G.11.2 References

G.11-1 MAGNASTOR Final Safety Analysis Report, Revision 7, July 2015.

G.11-2 Amendment No.5 to Certificate of Compliance No. 1031 for the NAC International, Inc., NAC-MAGNASTOR System, June 29, 2015.

Table G.11-1
Canister Confinement Boundaries

Accessible Portions	***Inaccessible Portions***
NAC-MAGNASTOR TSC1 through TSC4 and GTCC-Canister-ZN	
• *Shell* • *Bottom Plate* • *Shell long seam welds* • *Shell circumferential welds, if present* • *Shell to Bottom Plate weld* • *Closure Lid (portion inside closure ring)*	• *Closure lid under the closure ring* • *Closure lid to shell weld* • *Port Covers (inner set)* • *Closure lid to port cover weld (inner set)*

APPENDIX G.12
ACCIDENT ANALYSIS
NAC-MAGNASTOR

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G.12 ACCIDENT ANALYSIS

The results of the analyses of the off-normal and accident events, including those identified by ANSI/ANS 57.9-1992, are presented in Chapter 12 of Reference G.12-1. Section 12.1 describes the off-normal events that could occur during the use of MAGNASTOR, possibly as often as once per calendar year. Section 12.2 addresses very low probability events that might occur once during the lifetime of MAGNASTOR or hypothetical events that are postulated because their consequences may result in the maximum potential effect on the surrounding environment. The detailed analysis of each evaluated event is presented in the appropriate technical chapters – structural, thermal, shielding, criticality, confinement, or radiation protection. In the analyses in those chapters, the bounding parameters (i.e., maximum concrete cask weight and center of gravity) are conservatively used, as appropriate, to determine the capability of MAGNASTOR to withstand the effects of the analyzed events.

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

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

G.12.1 Undamaged and Damaged PWR Fuel

The following describes the off-normal and accident events evaluated for the MAGNASTOR system.

G.12.1.1 Off-Normal Events

Section 12.1 of Reference G.12-1 evaluates postulated off-normal events that might occur once during any calendar year of operations. The actual occurrence of any of these events is, therefore, infrequent.

The following off-normal events are evaluated. Beside each listed off-normal event is the location in Reference G.12-1 where the details of the analyses are presented.

1. Severe Ambient Temperature Events (106°F and -40°F) – Section 12.1.1
2. Blockage of One-Half of the Air Inlets – Section 12.1.2
3. Off-Normal TSC Handling Load – Section 12.1.3
4. Failure of Instrumentation – Section 12.1.4
5. Small Release of Radioactive Particulate from the TSC Exterior – Section 12.1.5
6. Crane Failure During Loaded Transfer Cask Movements – Section 12.1.6
7. Crane/Hoist Failure During TSC Transfer to VCC – Section 12.7

G.12.1.2 Accidents and Natural Phenomena

Section 12.2 of Reference G.12-1 presents the results of analyses of the design basis and hypothetical accident events evaluated for MAGNASTOR. In addition to design basis accidents, this section addresses very low-probability events, including natural phenomena that might occur once over the lifetime of the ISFSI, or hypothetical events that are postulated to occur because their consequences may result in the maximum potential effect on the immediate environment.

MAGNASTOR includes TSCs of two different lengths to accommodate two lengths of PWR fuel. In the accident analyses of this section, the bounding cask parameters (such as weight and center of gravity) are conservatively used, as appropriate, to determine the cask's capability to withstand the effects of the accidents. The results of these analyses show that any credible potential accident will result in a dose of ≤5 rem beyond the postulated controlled area. Consequently, MAGNASTOR is demonstrated to have a substantial design margin of safety, and will provide protection to the public and to site operations personnel during storage of spent fuel.

The following accidents and natural phenomena are evaluated. Beside each listed event is the location in Reference G.12-1 where the details of the analyses are presented.

1. Accident Pressurization – Section 12.2.1
2. Failure of All Fuel Rods with a Ground-level Breach of the TSC – Section 12.2.2
3. Fresh Fuel Loading in the TSC – Section 12.2.3
4. 24-Inch Drop of the Concrete Cask – Section 12.2.4
5. Explosion – Section 12.2.5
6. Fire Accident – Section 12.2.6
7. Maximum Anticipated Heat Load (133°F Ambient Temperature) – Section 12.2.7
8. Earthquake Event – Section 12.2.8
9. Flood – Section 12.2.9
10. Lightning Strike – Section 12.2.10
11. Tornado and Tornado-Driven Missiles – Section 12.2.11
12. Tip-Over of Concrete Cask – Section 12.2.12
13. Full Blockage of the Concrete Cask Air Inlets – Section 12.2.13

G.12.1.3 Concrete Cask Non-Mechanistic Tip-Over Analysis

Tip-over of the concrete cask is a non-mechanistic, hypothetical accident condition that presents a bounding case for evaluation. Existing postulated design basis accidents do not result in the tip-over of the concrete cask. Functionally, the concrete cask does not suffer significant adverse consequences due to this event. The concrete cask, TSC, and basket maintain design basis shielding, geometry control of contents, and contents confinement performance requirements.

For a tip-over event to occur, the center of gravity of the concrete cask and loaded TSC must be displaced beyond its outer radius, i.e., the point of rotation. When the center of gravity passes beyond the point of rotation, the potential energy of the cask and TSC is converted to kinetic energy as the cask and TSC rotate toward a horizontal orientation on the ISFSI pad. The subsequent motion of the cask is governed by the structural characteristics of the cask, the ISFSI pad and the underlying soil.

The concrete cask tip-over analyses of the MAGNASTOR storage systemsat the Consolidated Interim Storage Facility (CISF) are performed using LS-DYNA.

LS-DYNA is an explicit finite element program for the nonlinear dynamic analysis of structures in three dimensions. The objective of these evaluations is to confirm that the maximum amplified accelerations of the top of the basket and the canister for the five systems at the CISF are bounded by the accelerations used in the structural evaluation of the five systems for the original license basis of each system. The LS-DYNA reevaluation of the cask tip over is required, since the concrete pad and soil conditions at the CISF differed from the original license basis.

G.12.1.3.1 Concrete Cask Finite Element Model For Tip-Over Evaluation

The half-symmetry finite element model of the loaded VCC, concrete pad, mudmat, and soil sublayers are constructed of solid brick elements. The details of the finite element model set-up are shown in Figure G.12-2.

G.12.1.3.2 Material Models/Properties

The material properties used in the analysis are given below:

The modulus of elasticity of concrete is calculated using the following equation:

$$E_c = 33\,(w_c)^{1.5}\sqrt{f_c'}$$

Where,

E_c = Modulus of elasticity of concrete, psi

W_c = Unit weight of concrete, lb/ft3

f_c' = Compressive strength of concrete, psi

G.12.1.3.3 Concrete Pad

Mass density, ρ = 148 pcf = 2.217 E-4 lb-sec^2/in^4

Modulus of elasticity, E = 4.602E6 psi

Poisson's ratio, υ = 0.2

Shear modulus, G = 1.918E6 psi

Compressive strength, f_c' = 6000 psi

G.12.1.3.4 Mudmat

Mass density, ρ = 146 pcf = 2.187 E-4 lb-sec^2/in^4

Modulus of elasticity, E = 2.604E6 psi

Poisson's ratio, υ = 0.2

Shear modulus, G = 1.085E6 psi

Compressive strength, f_c' = 2000 psi

G.12.1.3.5 Soil

The properties of soil at various depths are given in Table G.12-1.

Table G.12-1
Soil Properties

G.12.1.3.6 VCC Concrete

The concrete properties used for VCC are given Section G.12.1.3.12.1 for the MAGNSTOR storage system. The densities of VCC and other components used account for the total weight of non-structural components that are not modeled.

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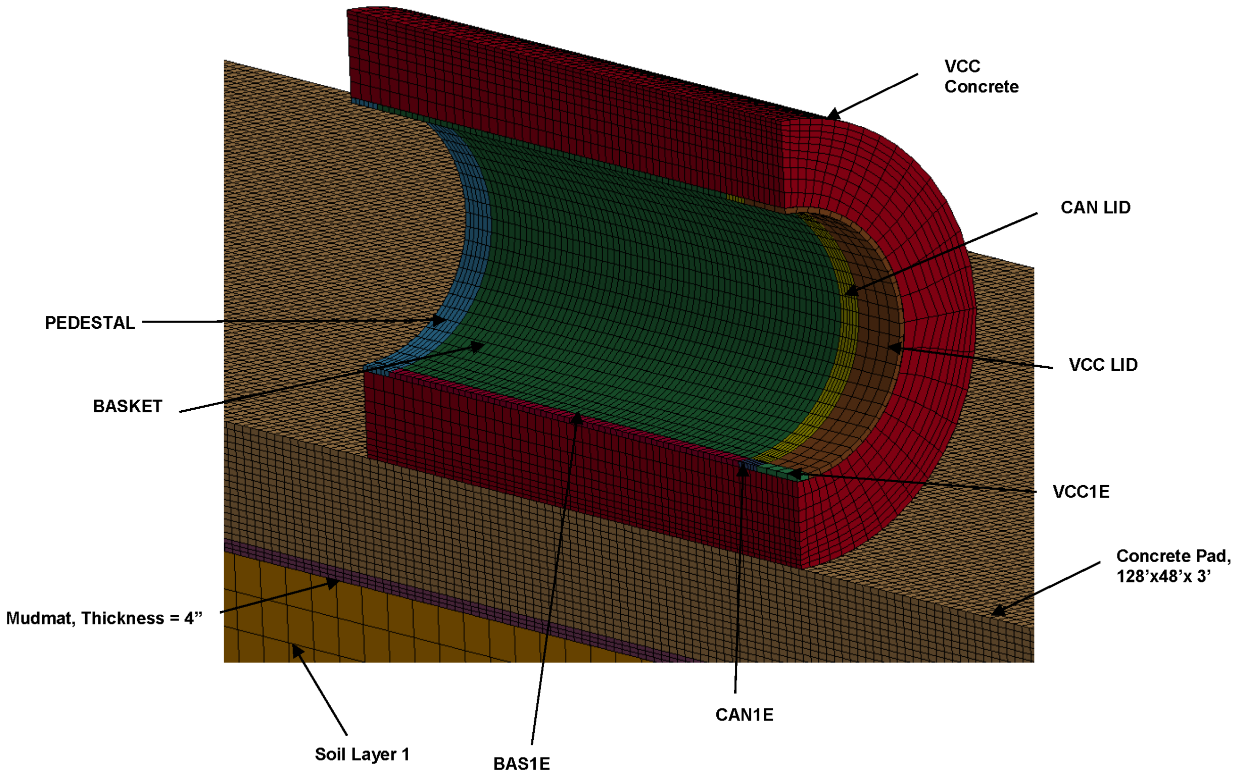

Figure G.12-2
CISF Configuration - Finite Element Model Set-Up (Continued)

G.12.1.3.7 Boundary Conditions

The VCC, liner, concrete pad, mudmat and soil sublayers are modeled using solid elements. The bottom surface of the soil is constrained in the vertical direction. To represent the unlimited expanse of adjacent soil, non-reflecting boundary conditions are applied to the three vertical planes of the soil. Symmetry boundary conditions are applied to the symmetry plane of VCC, concrete pad, mudmat and soil. The bottom of the soil column is vertically restrained. Contact modeling between VCC, liner, basket and canister is modeled using the Surface Contact options available in LS-DYNA.

G.12.1.3.8 Weight of Loaded VCC

The body load due to the gravity (1 g) of the loaded VCC is considered in the analysis and is conservatively applied as a step load. The weights of various loaded VCC systems are given in Table G.12-2.

G.12.1.3.9 Tip-Over Velocity

The tip-over condition is simulated by applying angular velocity to the loaded VCC. The angular velocity is calculated by equating the potential energy of VCC due to change in the position of center of gravity (CG) with the kinetic energy due to rotation of the VCC (while standing on its corner with the CG directly over it) as shown below:

Potential Energy = Rotational Kinetic Energy

$$mgh = (I\omega^2)/2$$

Where,

m = Total mass of the loaded VCC, lb-sec^2/in

g = Acceleration due to gravity, 386.4 in/sec^2

w = mg, Total weight of the loaded VCC, lbs

h = Change in height of CG of VCC, in

I = Total mass moment of inertia of loaded VCC about the pivot point, lb-sec^2-in

ω = Angular velocity of loaded VCC, rad/sec

The diagram is shown below:

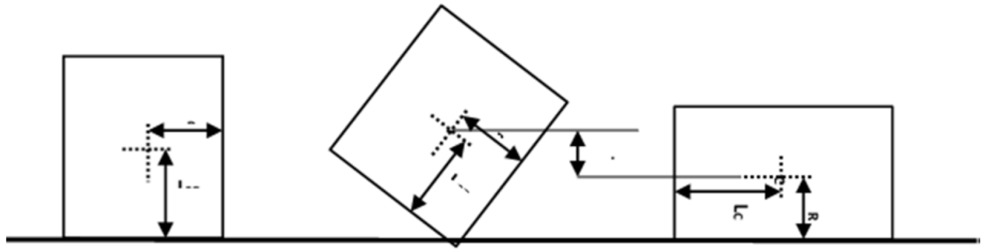

Figure G.12-3
Schematic Representation of the Change in Height of CG of VCC

The change in height of CG of VCC:

$$h = \sqrt{R^2 + {L_{CG}}^2} - R$$

Where,

R = Radius of VCC, in

LCG = Distance of CG from base of VCC, in

Therefore, the angular velocity is given by,

$$\omega = \sqrt{\frac{2mgh}{I}}$$

The angular velocities for various VCC systems are given in Table G.12-2.

Table G.12-2
Total Weights and Tip-Over Angular Velocities of MAGNASTOR VCC System

Storage System	Loaded VCC		Tip-Over Angular Velocity (rad/sec)
	Weight (kips)	Mass ($lb\text{-}sec^2/in$)	
MAGNASTOR	323.5	837.2	1.522

G.12.1.3.10 Determination of Amplified Accelerations

The acceleration time histories are taken from the nodes at the top of the basket and the canister which would identify the maximum acceleration of the basket and the canister. The acceleration time histories from the LS-DYNA nodal acceleration file were filtered with a Butterworth filter frequency of 165 Hz. Details of the filter frequency calculation are contained in Reference G.12-2. The general pattern of the acceleration time history of both components is shown in the acceleration time history curve in Figure G.12-4. The initial spike has a duration (t1) of approximately 4 ms while the longer pulse duration (t2) is approximately 40 ms. The initial spike of duration t1 is associated with the initial crushing of the concrete and the equivalent static acceleration used for the basket and canister evaluation is determined using the Dynamic Load Factors (DLF) for a triangular shaped pulse. The DLF for the longer pulse (t2) is determined using the DLF for a sine shaped pulse. The DLF for the basket is dependent on each basket design and basket angular orientation. The DLF for the canister lid region of the TSC is considered to be 1 due to the rigidity of the lid.

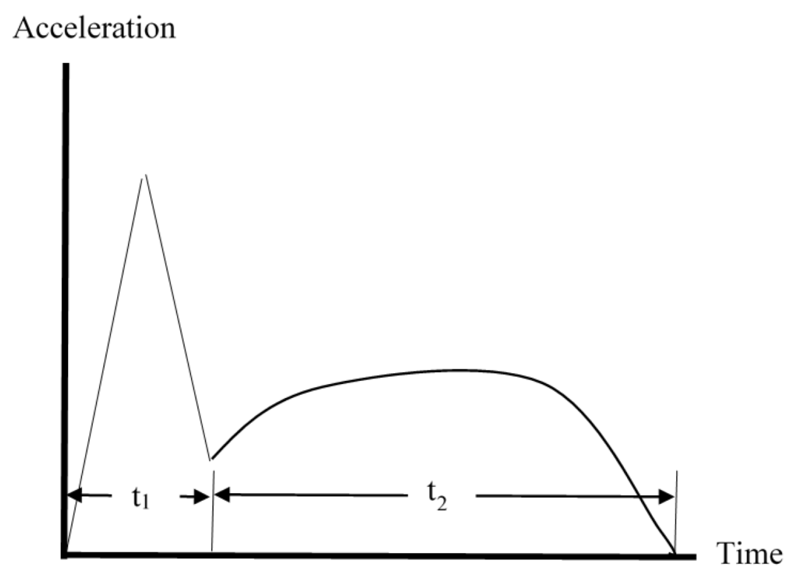

Figure G.12-4
Acceleration Time History

G.12.1.3.11 Cask Specific Evaluations

A model is used to evaluate the loaded concrete cask during tip-over conditions for the MAGNASTOR systems. The concrete pad represents the concrete pad properties at the CSIF site. The dimensions of the concrete pad are 128 feet (length) x 48 feet (width) with a thickness of 3 feet. The mudmat under the pad had a thickness of 4 inches. The subsoil used the length and width of the pad plus 4 feet on each side. The site soil properties were modeled to a depth of 98.7 feet. The mesh density and element aspect ratio of all the models are consistent.

G.12.1.3.12 MAGNASTOR

The total weight of the loaded MAGNASTOR VCC used in the analysis is equal to 323.5 kips. Half-symmetry model as discussed in Section G.12.1.3.1 is used in the analysis.

G.12.1.3.12.1 Material Properties of VCC

Material properties of VCC concrete used in the analysis are given below:

Mass density, ρ = 172.2 pcf = 2.579E-4 lb-sec^2/in^4

Modulus of elasticity, E = 4.716E6 psi

Poisson's ratio, υ = 0.22

Shear modulus, G = 1.933E6 psi

Compressive strength, f_c'= 4000 psi

G.12.1.3.12.2 Geometric Properties of VCC

Radius of VCC, R = 68 in

Distance of CG of VCC from base, LCG = 108.31 in

Change in height of CG, h = 59.9 in

The tip-over angular velocity of the VCC is calculated as per the methodology described in Section G.12.1.3.9 and is applied to the MAGNASTOR model in conjunction with the gravity. The deformed shape of the model is shown in Figure G.12-5. Further details regarding numerical and graphical results are contained in Reference 1.

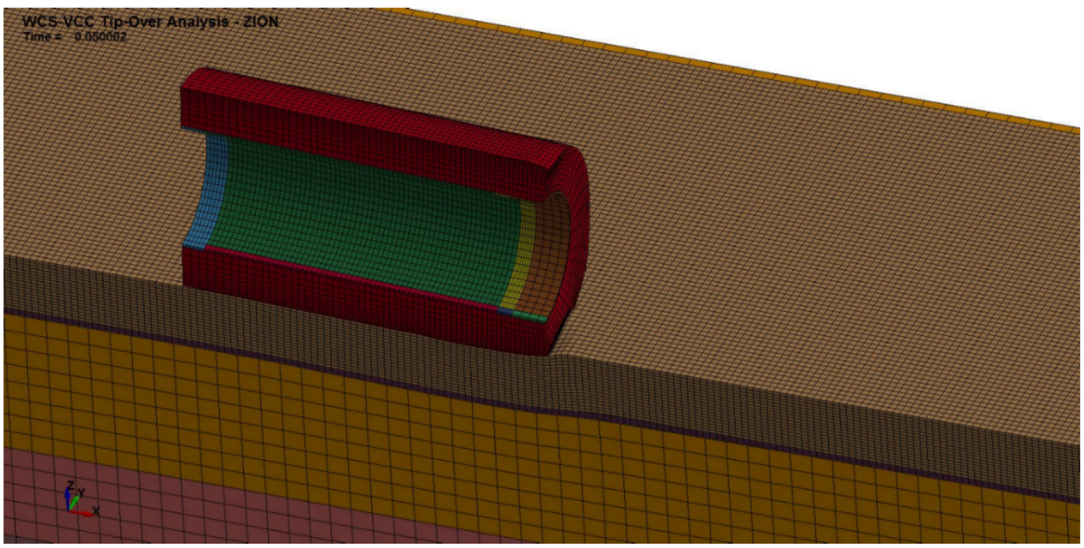

Figure G.12-5
Deformed Shape of MAGNASTOR VCC, Concrete Pad, Mudmat and Soil

The canister lid and attached canister shell peak acceleration is determined to be 28.8g, which would also correspond to the static acceleration to be applied to the model for the canister stress evaluation.

As indicated in Figure G.12-4, the acceleration time history shows two types of pulses. The DLF for the short pulse is based on a triangular shaped pulse. The DLF associated with the short pulse for the basket evaluation is dependent on the fundamental modal frequency of the MAGNASTOR basket and the time duration of the short pulse. Details of the modal analysis for the MAGNASTOR basket are contained in Reference G.12-3. The bounding DLF associated with the short pulse, which is dependent on basket orientation, is 1.05 resulting in an amplified acceleration for the short pulse of 29.2 g's. For the accelerations during the long pulse, the bounding DLF, for the sine pulse is 1.76, regardless of the fundamental modal frequency of the basket. The DLF of 1.76 for the sine pulse is conservatively applied to the peak transient analysis acceleration. The table below shows the basket acceleration obtained from the transient analysis, the maximum DLF, and the amplified accelerations. The acceleration used in the basket and canister evaluations for the MAGNASTOR system in Reference *G.12-1* was 35g's. The peak amplified basket acceleration, which is shown below, is 33.1 and the peak canister acceleration of 28.8, and both of these accelerations are bounded by 35g. Therefore, the basket and canister evaluations contained in Reference G.12-1 are bounding for the conditions at the CISF.

G.12.2 References

G.12-1 MAGNASTOR Final Safety Analysis Report, Revision 7, July 2015

G.12-2 NAC Calculation 30039-2010 Rev 0, "Concrete Cask Tip-Over Evaluation – WCS", NAC International, Norcross, GA

G.12-3 NAC Calculation 30039-2015 Rev 0, "Tip-Over DLF Calculation for WCS", NAC International, Norcross, GA