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FINAL SAFETY EVALUATION REPORT
NAC INTERNATIONAL, INC.
MAGNASTOR® STORAGE SYSTEM
DOCKET NO. 72-1031
AMENDMENT NO. 10

Summary

By letter dated December 9, 2019 (Agencywide Documents Access and Management System [ADAMS] Accession No. ML19345E594), as supplemented on May 13, 2020 (ADAMS Accession No. ML20143A102), February 25, 2021 (ADAMS Package Accession No. ML21067A041), April 20, 2021 (ADAMS Accession No. ML21118A043), and September 2, 2021 (ADAMS Package Accession No. ML21251A529), NAC International (NAC or the applicant) submitted an application for Amendment No. 10 to the MAGNASTOR® storage system. The application proposes to add a (MSO) for the MAGNASTOR® storage system. In support of the application, the applicant submitted revised safety analysis reports (SARs), revision Nos. 19C, and 21A.

The U.S. Nuclear Regulatory Commission (NRC) staff reviewed the amendment request using guidance in NUREG-2215, "Standard Review Plan for Spent Fuel Dry Storage Systems and Facilities - Final Report," dated April 2020. For the reasons stated below and based on the statements and representations in NAC's application, as supplemented, and the conditions specified in the certificate of compliance (CoC) and technical specifications (TSs), the staff concludes that the requested changes meet the requirements of Title 10 of the *Code of Federal Regulations* (10 CFR) Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste."

Chapter 1 GENERAL INFORMATION EVALUATION

The objective of the review of this chapter is evaluate design changes made to the MAGNASTOR® storage system to ensure that NAC provided a description that adequately identifies pertinent features of the system, including the requested changes.

1.1 General Description and Operational Features

The MAGNASTOR® system is a spent fuel, dry storage system consisting of a storage overpack containing a welded, stainless steel transportable storage canister (TSC) which contains the spent fuel, and a transfer cask. There are two types of storage overpacks, a concrete cask or an MSO. In the storage configuration, the TSC is placed in the central cavity of the storage overpack. The storage overpack provides structural protection, radiation shielding, and internal airflow paths that remove the decay heat from the TSC surface by natural air circulation. The storage overpack also provides protection during storage for the TSC and the spent fuel it contains against adverse environmental conditions. The MAGNASTOR® system is designed to accommodate storage of up to 37 pressurized-water reactor (PWR) assemblies or 87 boiling-water reactor (BWR) assemblies.

The transfer cask is used to move the TSC between workstations during TSC loading and preparation activities, and to transfer the TSC to or from the overpack. There are two different designs for the transfer cask, the standard MAGNASTOR® transfer cask (MTC) and the passive MAGNASTOR® transfer cask (PMTC). The MTC provides shielding during TSC movements between workstations, the overpack, or the transport cask. It is a multiwall (carbon steel/lead/NS-4-FR/steel) design with retractable (hydraulically operated) bottom shield doors that are used during loading and unloading operations. There is a second version of the MTC, called the MTC2. The only difference from the MTC is that the MTC2 has stainless steel walls.

1.1.1 Storage Overpack

NAC proposed adding an MSO as an alternate storage overpack. The metal storage overpack is a cylindrical, structural shield wall formed with carbon steel inner and outer liners that encase the NS-3 neutron shielding material. The metal storage overpack has a carbon steel inner base. The NS-3 shield wall and steel liners provide the neutron and gamma radiation shielding for the stored spent fuel. The inner and outer liners provide the structural strength to protect the TSC and its contents. The metal storage overpack provides an annular air passage to allow natural circulation of air around the TSC to remove the decay heat from the contents. The lower air inlet and upper air outlet vents are carbon steel penetrations in the bottom weldment and inner liner, respectively. Each air inlet/outlet vent is covered with a screen. The weldment baffle directs the air upward and around the pedestal that supports the TSC.

1.1.2 Transportable Storage Canister

The TSC is unchanged from Amendment No. 9.

1.1.3 Transfer Cask

The transfer casks are unchanged from Amendment No. 9.

1.2 Drawings

In support of this application, NAC submitted the following 4 drawings for NRC review:
Drawing No. 71160-565, Revision 3P – “Body, Lid and Details, Metal Storage Overpack (MSO), MAGNASTOR;”
Drawing No. 71160-565, Revision 0NP – “Body, Lid and Details, Metal Storage Overpack (MSO), MAGNASTOR;”
Drawing No. 71160-567, Revision 0P – “Loaded MSO Metal Storage Overpack (MSO), MAGNASTOR;” and
Drawing No. 71160-567, Revision 0NP – “Loaded MSO Metal Storage Overpack (MSO), MAGNASTOR.”

1.3 Contents

There were no changes to the contents specified in appendix B to Amendment No. 9 of the certificate, however, with the new MSO, NAC added footnote 2 to table B2 2, “PWR Fuel Loading Patterns” in the SAR. The addition of footnote 2 limits the maximum decay heat for the MSO to 35.5 kW and a uniform loading pattern (i.e., preferential loading is not authorized) and limited fuel contents for use with the MSO to Westinghouse (WE) 14×14, Combustion Engineering (CE) 16×16, and WE17×17 fuel assembly types.

1.4 Evaluation Findings

Based on the NRC staff's review of information provided for the Amendment No. 10 to the MAGNASTOR® system, the staff determined the following:

F1.1 A general description and discussion of Amendment No. 10 to the MAGNASTOR® system is presented in chapter 1 of the SAR, with special attention to design and operating characteristics, unusual or novel design features, and principal safety considerations, and the description is sufficient to familiarize a reviewer or stakeholder with the design.

F1.2 Drawings for structures, systems, and components (SSCs) important to safety presented in section 1.8 of the SAR were reviewed. Details of specific SSCs are evaluated in sections 3 through 12 of this SER.

Chapter 2 PRINCIPAL DESIGN CRITERIA EVALUATION

The changes associated with principal design criteria for the addition of the new MSO are discussed and evaluated in subsequent chapters of this SER.

Chapter 3 STRUCTURAL EVALUATION

The staff reviewed the proposed changes to the MAGNASTOR® system for spent fuel storage to verify that the applicant has performed an acceptable structural evaluation demonstrating that the system, as proposed, meets the requirements of 10 CFR Part 72. The staff's structural review focused on the addition of the MSO, which adds another variant to the six MAGNASTOR® concrete storage cask variants in providing additional structural strength and shielding for the previously approved TSC for spent nuclear fuel.

The design of the TSC was not changed in this amendment, and the design of the TSC was not considered separately as part of the review. However, the staff did review the interactions of the MSO and TSC and whether the addition of the MSO challenged the structural design of the TSC.

3.1 Addition of the Metal Storage Overpack (MSO)

3.1.1 Description of the Structure

Revision 19C to the MAGNASTOR® system SAR includes Drawing 71160-565, "MSO Body, Lid, and Details," and Drawing 71160-567, "Loaded MSO," which depict the design details of the MSO. The MSO consists of an inner steel liner and an outer steel liner with a layer of NS-3 shielding between the liners. The MSO is closed by a lid assembly that is bolted to the top of the inner steel liner. This lid assembly consists of carbon steel and NS-3 shielding enclosed by top and inner plates of carbon steel.

The content of the MSO is limited to two sizes of TSCs that are uniformly loaded with undamaged PWR spent fuel assemblies.

3.1.2 Design Criteria

The applicant classified the MSO assembly as important to safety Category B in accordance with the guidelines of NUREG/CR-6407, “Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety.” The applicant listed the structural design criteria for the MSO in table 2.1-1 of the SAR. Table 2.1-1 states that the MSO is designed in accordance with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code Section III, Division 1, Subsection NF. The previously approved design criteria for environmental conditions and natural phenomena are described in section 2.3 of the SAR and remain applicable to the MAGNASTOR® system with the MSO.

The staff reviewed the design criteria and determined that the design of the MSO is consistent with the design codes and standards and NRC guidance in section 4.5.2 of NUREG-2215, “Standard Review Plan for Spent Fuel Dry Storage Systems and Facilities.” In particular, NUREG-2215 provides guidance on the use of ASME B&PV Code Section III, Division 1, Subsection NF for the steel components of metal overpacks.

The load combinations for the MAGNASTOR® system with the MSO are presented in table 2.3-2 of the SAR. The staff reviewed the load combinations and determined that they are consistent with American National Standards Institute (ANSI)/American National Standard (ANS)-57.9, “Design Criteria for an Independent Spent Fuel Storage Installation (Dry Type),” and NRC guidance on acceptable load combinations in NUREG-2215.

Based on the consistency of the structural design criteria of the MSO with the guidance on acceptable design criteria in NUREG-2215, the staff finds that the design of the MSO meets the requirements of 10 CFR 72.236(b).

3.1.3 Structural Evaluation

The applicant evaluated the MAGNASTOR® system with the MSO using both hand calculations and finite element analyses. The applicant included three calculation packages to support the structural analysis: Calculation Package 30082-2603, “Metal Storage Overpack Structural Evaluation,” Calculation Package 30082-2604, “Evaluation of the MAGNASTOR Metal Storage Overpack for a 24-inch Drop,” and Calculation Package 30082-2605, “Tip-Over Analysis for the MAGNASTOR Metal Storage Overpack.” The applicant described the structural evaluations in section 3.11 of the SAR.

3.1.3.1 Lifting

The applicant described the lifting evaluation in section 3.11.1 of the SAR, which is supported by Calculation Package 30082-2603, “Metal Storage Overpack Structural Evaluation.” The MSO is lifted using two trunnions that insert into the liner forging and are held in place by fillet welds. The applicant performed hand calculations to demonstrate that the combined bending and shear stresses in the trunnions have factors of safety (FSs) of 3.95 for yield strength and 8.02 for ultimate strength. The calculations also demonstrated an FS of 4.72 for bearing of the trunnions against the MSO liner forging. These FSs are greater than the minimum FSs in NUREG-0612, “Control of Heavy Loads at Nuclear Power Plants,” to qualify the cask to be lifted as part of a special lifting device.

While lifting the MSO, the TSC rests on a pedestal on the bottom inside of the MSO. The applicant created a quarter symmetry finite element model of the pedestal using the finite element software ANSYS to evaluate the effect of the TSC on the pedestal during lifting. The finite element analysis considered a bounding TSC weight and an inertial acceleration of 1.1 g as a dynamic load factor per ANSI/ASME N45.2.15, “Hoisting, Rigging, and Transporting of Items for Nuclear Power Plants.” The stress evaluation showed the critical stresses occur in the support rails of the pedestal with an FS of 1.95 compared to the design stress intensity. This evaluation also shows a critical FS of 1.08 for the allowable stresses in the pedestal welds.

The inner liner and bottom weldment are also stressed when lifting the MSO with a loaded TSC. The applicant performed hand calculations to demonstrate that the critical FSs for these components are 8.90 for the inner liner side fillet weld and 2.97 for the bottom weldment side fillet weld. The lid assembly can be lifted separately using threaded bolts. The applicant evaluated this lift using hand calculations and demonstrated that the critical FS is 3.8 for allowable tensile stress in the bolts.

The staff reviewed the stress analyses for lifting of the MSO system and found the methodologies, including the applied dynamic load factors and use of finite element modeling, and determined safety margins were consistent with the guidance in NUREG-2215 for lifting of Metallic Storage Overpacks. Based on the safety margin determined by the stress analyses, the staff concludes that the lifting design of the MAGNASTOR® system with the MSO has sufficient structural capacity to withstand lifting and is therefore acceptable.

3.1.3.2 Normal Conditions

The applicant described the structural evaluation for normal conditions in section 3.11.2 of the SAR, which is supported by Calculation Package 30082-2603, “Metal Storage Overpack Structural Evaluation.” The applicant evaluated dead loads, live loads, loads from thermal expansion, wind loads, and normal handling loads. For the dead loads, the applicant considered the weight of the MSO with lid assembly. For the live load, the applicant considered the weight of the MAGNASTOR® transfer cask with the loaded TSC and transfer adapter.

For the loads from thermal expansion, the applicant performed hand calculations to determine the stresses caused by the thermal expansion of the NS-3 shielding material at the bounding bulk temperature of 275°F. For the wind loads, the applicant conservatively considered the tornado wind load, which is discussed in section 3.1.3.4.1 of this report. For normal handling loads, the applicant considered a bounding weight for the MSO with a loaded TSC acting upon the inner steel liner of the MSO.

The four load combinations considered for normal conditions in this evaluation are listed in table 2.3-2 of the FSAR and are discussed in section 3.1.2 of this report. The bounding stresses for each load combination for normal conditions are listed in tables 3.11.2-1 through 3.11.2-4 for the inner and outer liners of the MSO. The maximum combined stress from a load combination for normal conditions results in a critical FS of 5.29 compared to the allowable primary membrane plus bending stress for the MSO liners from the ASME B&PV Code Division 1, Subsection NF.

The staff reviewed the determination of the loads, the combinations of the loads, and the application of the ASME B&PV Code, and the staff concludes that the structural evaluation of the MAGNASTOR® system with the MSO under normal conditions is consistent with guidance in NUREG-2215. Based on the safety margin determined by the stress analyses, the staff

concludes that the MAGNASTOR® system with the MSO has sufficient structural capacity to withstand normal conditions. For these reasons, the NRC staff finds the structural evaluation of the MAGNASTOR® system with the MSO under normal conditions meets the requirements in 10 CFR 72.236 and is therefore acceptable.

3.1.3.3 Off-Normal Conditions

The applicant describes the structural evaluation for off-normal conditions in section 3.11.3 of the SAR, which is supported by Calculation Package 30082-2603, "Metal Storage Overpack Structural Evaluation." The applicant considered the dead load, live load, and loads from thermal expansion calculated for normal conditions to be applicable to off-normal conditions. Unique to off-normal conditions, the applicant evaluated off-normal handling loads. The off-normal handling load considered vertical and horizontal accelerations of the MSO with a loaded TSC acting upon the inner steel liner of the MSO.

The two load combinations considered for off-normal conditions in this evaluation are listed in table 2.3-2 of the FSAR and are discussed in section 3.1.2 of this report. The bounding stresses for each load combination for off-normal conditions are listed in table 3.11.3-1 and table 3.11.3-2 for the inner liner of the MSO. The maximum combined stress for off-normal conditions results in a critical FS of 4.72 compared to the allowable primary membrane plus bending stress for the MSO liner from the ASME B&PV Code (i.e., the stresses in the cask components from the off-normal loads are less than the ASME B&PV Code allowable stress).

The staff reviewed the determination of the loads, the combinations of the loads, and the application of the ASME B&PV Code, and the staff concludes that the structural evaluation of the MAGNASTOR® system with the MSO under off-normal conditions is consistent with guidance in NUREG-2215. Based on the safety margin determined by the stress analyses, the staff concludes that the MAGNASTOR® system with the MSO has sufficient structural capacity to withstand off-normal conditions. For these reasons, the NRC staff finds the structural evaluation of the MAGNASTOR® system with the MSO under off-normal conditions meets the requirements in 10 CFR 72.236 and is therefore acceptable.

3.1.3.4 Accident Conditions

The applicant describes the structural evaluation for accident conditions in section 3.11.4 of the FSAR, which is supported by Calculation Package 30082-2603, "Metal Storage Overpack Structural Evaluation," Calculation Package 30082-2604, "Evaluation of the MAGNASTOR Metal Storage Overpack for a 24-inch Drop," and Calculation Package 30082-2605, "Tip-Over Analysis for the MAGNASTOR Metal Storage Overpack." The applicant considered the dead load, live load, and loads from thermal expansion calculated for normal conditions to be applicable to accident conditions. Unique to accident conditions, the applicant evaluated the MAGNASTOR® system with the MSO for tornado winds and tornado-generated missiles, floods, earthquakes, a 24-inch drop, and a non-mechanistic tip-over.

3.1.3.4.1 Tornado Wind and Tornado-Generated Missile

The applicant describes the structural evaluation for tornado winds and tornado-generated missiles in section 3.11.4.1 of the FSAR, which the applicant supported with a series of hand calculations in Calculation Package 30082-2603, "Metal Storage Overpack Structural Evaluation." The applicant evaluated tornado wind loadings and a tornado-generated missile striking the MSO. The tornado wind and missile evaluations followed the same method that the

NRC previously approved for the other MAGNASTOR® overpack variants. The applicant stated that it determined the tornado wind speed from the design basis tornado characteristics discussed in Regulatory Guide 1.76, "Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants." The applicant stated that it calculated the design wind pressure for a tornado wind speed of 360 mph using the methodology and equations for determining wind loads from ANSI/American Society of Civil Engineers 7, "Minimum Design Loads for Buildings and Other Structures."

For the evaluation of tornado-generated missiles, the applicant considered three missiles defined in Regulatory Guide 1.76. These missiles are a massive high kinetic-energy missile corresponding to a 4,000 lb. automobile, an 8.0-inch diameter armor piercing artillery shell weighing 280 lb., and a 1.0-inch diameter solid steel sphere. All of these missiles were assumed to impact in a manner that produces maximum structural damage. The analysis showed that the missiles do not penetrate the outer steel liner of the MSO or the top plate of the MSO lid assembly. The applicant determined in the evaluation that the combined effects of the tornado wind loading and tornado generated missiles will not overturn the MAGNASTOR® system with the MSO with an FS of 2.46 for overturning.

The NRC staff reviewed the applicant's evaluation of tornado winds and tornado-generated missiles and finds that the applicant's methodology for determining a tornado windspeed, deriving a wind pressure, and selecting design basis tornado-generated missiles was consistent with the NRC guidance and industry codes mentioned above. The staff finds that the applicant's methodology, including the application of the guidance and codes mentioned above, is consistent with the guidance in NUREG-2215 on tornado winds and tornado missiles. Based on the applicant's demonstration that the tornado does not penetrate the cask or cause overturning, the NRC staff finds that the applicant has adequately evaluated tornado wind and tornado-generated missile accident conditions.

3.1.3.4.2 Flood

The applicant describes the structural evaluation for flooding in section 3.11.4.2 of the SAR, which the applicant supported with hand calculations in Calculation Package 30082-2603, "Metal Storage Overpack Structural Evaluation." The applicant evaluated a design basis flood for the MAGNASTOR® system with the MSO. To evaluate the stresses on the MSO induced by the design basis flood, the applicant considered a 15 ft/sec flow velocity acting on a fully submerged and conservatively empty MSO. The calculation of the stresses from the design basis flood conservatively considered the MSO as fixed at the bottom. The applicant included the stresses from the flood evaluation in the stress analysis for accident conditions in section 3.11.4.4 of the SAR, which is discussed in section 3.1.3.4.6 of this report. The applicant determined in the evaluation that a design basis flood would not overturn the MSO with an FS of 1.64 for overturning.

Based on the FS against overturning being greater than 1, the NRC staff finds the applicant has sufficiently demonstrated that the cask will not overturn during the flood accident conditions. The staff reviewed the evaluation of the design basis flood, including the applicant's identification of a critical water velocity and evaluation of the stresses and potential for overturning, and the staff finds that the applicant's design basis flood evaluation is consistent with NUREG-2215 and that the applicant has adequately considered the flooding accident condition.

3.1.3.4.3 Earthquake

The applicant describes the structural evaluation for the earthquake accident conditions in section 3.11.4.3 of the SAR, which the applicant supported with hand calculation in Calculation Package 30082-2603, “Metal Storage Overpack Structural Evaluation.” The applicant evaluated a design basis earthquake for the MAGNASTOR® system with the MSO. The evaluation of the design basis earthquake follows the same method that the NRC previously approved for the other MAGNASTOR® overpack variants. To evaluate the stresses in the MSO induced by the design basis earthquake, the applicant conservatively considered a 0.5 g horizontal acceleration and a 0.5 g vertical acceleration acting on the MSO with a loaded TSC. In calculating the stresses from the design basis earthquake, the applicant conservatively considered the MSO as a cantilever beam fixed at the bottom. The applicant included the stresses from the earthquake accident condition in the stress analysis for accident conditions in section 3.11.4.4 of the SAR, which is discussed in section 3.1.3.4.6 of this report.

The applicant calculated the overturning and restoring moments from the earthquake accident condition for both an MSO loaded with a TSC and an empty MSO without a stored TSC. The applicant determined in the evaluation that a design basis earthquake will not overturn the MSO by demonstrating that the restoring moment was greater than the overturning moment. The applicant demonstrated the FS is greater than 1.1 for overturning from the design basis earthquake.

Based on the FS against overturning being greater than 1.1, the NRC staff finds the applicant has sufficiently demonstrated that the cask will not overturn during the earthquake accident condition. The staff reviewed the structural analysis of the earthquake accident condition, including the applicant’s selection of horizontal and vertical accelerations and structural analysis to determine the stresses from those accelerations for a cantilever beam, and the staff finds that the structural analysis was consistent with the methodology that the NRC previously approved for the MAGNASTOR® system in, for example, Amendment 0 (ADAMS Accession No. ML090350509). Based on the staff’s review of the applicant’s structural analysis and calculation of the overturning moment from the earthquake accident conditions, the staff finds that the applicant’s evaluation is consistent with NUREG-2215 and that the applicant has adequately considered the earthquake accident condition.

3.1.3.4.4 24-inch Drop

The applicant describes the structural evaluation for the 24-inch drop accident in section 3.11.4.5 of the SAR, which the applicant supported with hand calculations in Calculation Package 30082-2603, “Metal Storage Overpack Structural Evaluation,” and a finite element analysis reported in Calculation Package 30082-2604, “Evaluation of the MAGNASTOR Metal Storage Overpack for a 24-inch Drop.” The applicant evaluated a drop of the MAGNASTOR® system with the MSO from the maximum lifted height of 24 inches. Section 4.3.1(h) of the technical specifications for the MAGNASTOR® system limits the lifting height of the MSO with loaded TSC to 24 inches.

To evaluate the 24-inch drop, the applicant performed a non-linear, dynamic finite element analysis on a half-symmetry model of the MSO with loaded TSC in the finite element analysis program LS-DYNA. The evaluation of the drop was primarily concerned with the impact of the bottom of the MSO and the accelerations experienced by the loaded TSC within the MSO. The applicant based the structural integrity at the bottom pedestal of the MSO on the ASME B&PV Code, Section III, Nonmandatory Appendix F. The evaluation analyzed the upper-bound weight

of the loaded TSC to assess maximum deformation of the pedestal and the lower-bound weight of the TSC to assess maximum accelerations of the TSC. The applicant accounted for the effects of material nonlinearities in the finite element analyses by defining strain-rate dependent material properties in Appendix E of Calculation Package 30082-2604.

The staff did not review the technical basis for the design criteria or the structural evaluation of the TSC or its internal components as part of the review for this amendment, as the applicant did not make changes affecting the TSC or this design criteria or the structural analyses of the TSC. The NRC previously approved the applicant's stress evaluation of the loaded TSC in a 24-inch drop, which subjected the TSC to a 60 g acceleration, and the applicant's use of the 60 g acceleration as a bounding criterion for evaluating the structural integrity of the TSC and its internal components. The applicant determined the maximum accelerations of the TSC inside the MSO with an applied dynamic load factor were less than the 60 g design acceleration of the TSC. Based on the accelerations of the TSC being bellow its design accelerations, the staff finds that the applicant has adequately demonstrated that the TSC, when loaded in the MSO, maintains structural integrity during the drop accident.

The applicant evaluated the strains in the MSO pedestal from the 24-inch drop analyses against triaxiality strain limits and an instability load limit in Appendix F of Calculation Package 30082-2604. The applicant evaluated the triaxial strains according to ASME B&PV Code Section VIII, Division 2, Part 5. The triaxial strain evaluation demonstrated that the MSO pedestal meets the triaxial strain criterion against local failure by calculating a minimum FS of 2.97, which compared the highest calculated plastic strains from the 24-inch drop finite element analyses to the calculated limiting triaxial strains. The applicant performed two additional finite element drop analyses with 40-inches and 34.4-inches drop heights to assess the instability load limit according to ASME B&PV Code Section III, Nonmandatory Appendix F. The additional drop analyses showed increasing stiffness of the pedestal with the increasing drop heights through the 40-inch drop. As the design basis 24-inch drop was less than 60% of the applied loads of the 40-inch drop, this stability evaluation demonstrated that the 24-inch drop was less than 70% of the instability load and the MSO pedestal meets the plastic instability load limit criterion against unbounded plastic deformation. Based on the applicant's demonstration that the MSO pedestal has sufficient margin against the limiting triaxial strain from ASME B&PV Code Section VIII, Division 2, Part 5 and the plastic instability load limit criterion from ASME B&PV Code Section III, Nonmandatory Appendix F, the staff finds that the applicant's strain evaluation has adequately demonstrated the structural integrity of the MSO pedestal in the 24-inch drop accident.

From the 24-inch drop finite element analysis results, the applicant evaluated the deformation of the air inlet at the bottom of the cask following the drop and determined that the deformation did not hinder the thermal performance of the TSC and was bounded by the off-normal thermal evaluation of the loss of one-half of the air inlets.

The NRC staff reviewed the applicant's finite element analysis and finds the analysis, as described above, is consistent with NRC guidance on computational modeling in NUREG-2215. The staff reviewed the evaluation of the 24-inch drop accident and finds that the evaluation is consistent with NRC guidance on the evaluation of a cask drop in NUREG-2215 and that the applicant has adequately considered the 24-inch drop accident condition. Based on the staff's review of the finite element analysis, the applicant's demonstration of the structural integrity of the MSO pedestal, the applicant's demonstration that deformations in the MSO pedestal are bounded by the off-normal thermal evaluation, the applicant's demonstration that the design acceleration of the TSC is not exceeded, and the consistency of the applicant's evaluation of the

drop accident with NRC guidance in NUREG-2215, the staff finds that the applicant has adequately demonstrated that the MSO with loaded TSC has adequate structural integrity to maintain the design basis shielding, geometry control, and confinement following the drop accident.

3.1.3.4.5 Tip-over

The applicant described the structural evaluation for the non-mechanistic tip-over accident condition in section 3.11.4.6 of the SAR, which the applicant supported with hand calculations in Calculation Package 30082-2603, “Metal Storage Overpack Structural Evaluation,” and a finite element analysis reported in Calculation Package 30082-2605, “Tip-Over Analysis for the MAGNASTOR Metal Storage Overpack.” The applicant considers the non-mechanistic tip-over as a hypothetical accident that presents a bounding case for the evaluation of accident conditions for the MAGNASTOR® system. The applicant performed evaluations to demonstrate that none of the existing, postulated design basis accidents result in the tip-over of the MSO as discussed in sections 3.1.3.4.1 through 3.1.3.4.3 of this report.

To evaluate the non-mechanistic tip-over, the applicant created a finite element model of a half-symmetry MSO, a concrete storage pad, and a typical soil sublayer in the finite element analysis program LS-DYNA. The evaluation of the non-mechanistic tip-over was primarily concerned with the impact of the MSO and the accelerations experienced by the loaded TSC within the MSO. The non-mechanistic tip-over analysis for the MSO followed the same methodology and used the same properties for the storage pad and soil that the NRC has previously approved for the tip-over evaluation of other MAGNASTOR® overpack variants.

The staff did not review the technical basis for the design criteria or the structural evaluation of the TSC or its internal components as part of the review for this amendment as no changes were made affecting the TSC or this design criteria. The NRC previously approved the applicant’s evaluation of the loaded TSC in a tip-over accident and the applicant’s use of the design basis accelerations as a bounding criterion for evaluating the structural integrity of the TSC and its internal components. The applicant determined the maximum accelerations for the fuel basket inside the TSC and the lid of the TSC with appropriate dynamic load factors. The maximum accelerations were less than the design basis accelerations of 35 g for the fuel basket and 40 g for the TSC and are thus bounded by previous evaluations.

Using the maximum accelerations from the LS-DYNA tip-over analysis, the applicant determined the maximum bending stresses in the outer steel liner of the MSO were less than the allowable stresses from the ASME B&PV Code.

The NRC staff reviewed the evaluation of the non-mechanistic tip-over accident and finds that the evaluation, as described above, is consistent with NRC guidance on tipover evaluations and computational modeling in NUREG-2215 and that the applicant has adequately considered the non-mechanistic tip-over accident condition. Based on evaluation of the maximum accelerations and bending stresses, the NRC staff concludes that the structural integrity of MSO, TSC, and the fuel basket is sufficient to maintain design basis shielding, geometry control, and confinement following the tip-over accident.

3.1.3.4.6 Combined Stresses

The applicant listed the six load combinations considered for accident conditions in this evaluation in table 2.3-2 of the FSAR. The load combinations for accident conditions are

discussed in section 3.1.2 of this report. The applicant listed the bounding stresses for each load combination for the accident conditions in table 3.11.4-1 through table 3.11.4-4 for the inner and outer liners of the MSO. The maximum combined stress for accident conditions occurred from the tip-over accident load combination and resulted in a critical FS of 4.16 compared to the allowable primary membrane plus bending stress for the MSO liners from Section III, Division 1, Subsection NF of the ASME B&PV Code.

Based on a review of the evaluations described above, the staff concludes that the structural evaluation of the MAGNASTOR® system with the MSO under accident conditions is consistent with NUREG-2215. Based on the maximum combined stress for accident conditions being below the allowable stresses, the staff finds that the MAGNASTOR® system with the MSO has sufficient structural capacity to withstand the accident conditions and maintain design basis shielding, geometry control, and confinement following. For these reasons, the NRC staff finds that the structural evaluation of the MAGNASTOR® system with the MSO under accident conditions meets the requirements in 10 CFR 72.236(l) and the MAGNASTOR® system with the MSO has adequate structural integrity to meet the requirements in 10 CFR 72.236(c), (d), (f), and (g) and is therefore acceptable.

3.2 Changes to Technical Specification

The staff reviewed the proposed changes to the technical specifications for the MAGNASTOR® system to accommodate the addition of the MSO. Importantly, the proposed technical specifications limit the content of the MSO to two sizes of TSC that are uniformly loaded with undamaged PWR spent fuel assemblies. The proposed technical specifications also limit the maximum lifting height of the loaded MSO to 24 inches. The staff concludes that the proposed changes to the technical specifications reflect the limitations of the structural evaluations supporting this amendment, and therefore, the staff finds the technical specifications acceptable.

3.3 Evaluation Findings

F3.1 The staff reviewed the structural performance of the important to safety SSCs designed to maintain subcriticality and concludes that these SSCs have adequate structural integrity to satisfy the criticality safety requirements of 10 CFR 72.124(a).

F3.2 The staff reviewed the structural performance of the important to safety SSCs designed to provide and maintain favorable geometry or permanently fixed neutron-absorbing materials and concludes that these SSCs have adequate structural integrity to satisfy the criticality control requirements of 10 CFR 72.124(b).

F3.3 The staff reviewed the design bases and design criteria of the important to safety SSCs and concludes that the applicant met the requirements of 10 CFR 72.236(b).

F3.4 The staff reviewed the structural performance of the important to safety SSCs designed to maintain the SNF in a subcritical condition under normal, off-normal, and accident conditions and concludes that these SSCs have adequate structural integrity to satisfy the subcriticality requirements of 10 CFR 72.236(c).

F3.5 The staff reviewed the structural performance of the important to safety SSCs designed to provide radiation shielding and confinement and concludes that these SSCs have

adequate structural integrity to satisfy the radiation shielding and confinement requirements of 10 CFR 72.236(d).

F3.6 The staff finds the storage cask is designed to store the spent fuel safely for the term proposed in the application and, therefore, meets the requirements of 10 CFR 72.236(g).

F3.7 The staff reviewed the structural evaluations of the storage cask and its important to safety SSCs and concludes that these evaluations considered appropriate tests and means acceptable to the NRC to demonstrate that they will reasonably maintain confinement of radioactive material under normal, off-normal, and credible accident conditions and, therefore, meet the requirements of 10 CFR 72.236(l).

F3.8 The staff finds that the applicant has considered the cask's compatibility with the removal of the stored SNF from a reactor site, transportation, and ultimate disposition by the Department of Energy in the design of the storage cask and, therefore, meets the requirements of 10 CFR 72.236(m).

The staff concludes that the evaluation of the structural design demonstrates that the MAGNASTOR® system with the MSO meets the requirements of 10 CFR Part 72 and provides adequate protection of the public health and safely. The NRC staff reached this finding based on the review described above, which considered the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

Chapter 4 THERMAL EVALUATION

The thermal review of Amendment No. 10 for the MAGNASTOR® cask system ensures that the cask components and fuel material temperatures will remain within the allowable values under normal, off-normal, and accident conditions. This review includes confirmation that the fuel cladding temperatures for fuel assemblies stored in the MAGNASTOR® cask system will be maintained below specified limits throughout the storage period to protect the cladding against degradation that could lead to gross ruptures. This portion of the review also confirms that the cask thermal design has been evaluated using acceptable analytical techniques and/or testing methods.

This review was conducted under the regulations described in 10 CFR 72.236, which identify the specific requirements for the regulatory approval, fabrication, and operation of spent fuel storage cask designs. The unique characteristics of the spent fuel to be stored in the MAGNASTOR® cask system are identified, as required by 10 CFR 72.236(a), so that the design basis and the design criteria that must be provided for the SSCs important to safety can be assessed under the requirements of 10 CFR 72.236(b).

This application was also reviewed to determine whether the MAGNASTOR® design fulfills the acceptance criteria listed in chapters 3, 5 and 16 of NUREG-2215.

The following change proposed under Amendment No. 10 to the MAGNASTOR® cask system is applicable to the thermal evaluation:

- adding a new MSO with a uniform loading pattern.

4.1 MAGNASTOR® System Thermal Model

The applicant used the ANSYS FLUENT computer-based analysis program to evaluate the thermal performance of the MAGNASTOR® spent fuel storage system. ANSYS FLUENT is a finite volume computational fluid dynamics (CFD) program with capabilities to predict fluid flow and heat transfer phenomena in two and three dimensions. Chapter 1 of the SAR provides a general description of the MSO and SAR section 4.11.1 provides a general description of the thermal model. The MSO has four inlet vents at the bottom and 26 outlet holes at the top. This unique design feature of the outlet holes at the top of the cask could affect the thermal performance because low-speed wind could act as a flow blockage by reducing the total air mass flow rate, which could affect the cask heat rejection capability. The staff's evaluation of low-speed wind in the cask thermal performance is provided in section 4.2 of this SER.

The applicant developed a two-dimensional (2-D) axisymmetric finite volume model to evaluate the thermal performance of the MSO and the TSC. The thermal model includes the MSO (including lid, liner, NS-3 wall, pedestal plate, stand and bottom plate), air inlet vents, the annulus, and the air outlet, TSC shell, lid and bottom plate, basket with spent fuel, and helium internal to the TSC. Boundary conditions and air flow characteristics were identical to previous analysis, as described FSAR, revision 0, chapter 4, (ADAMS Accession No. ML14176B275), which the staff previously reviewed and approved in CoC No. 1031, revision No. 0. The applicant assumed an ambient temperature of 76 °F. The staff noticed this ambient temperature could be nonconservative for sites where ambient temperature would be higher (including seasonal variations). For this case, a general licensee would need to demonstrate the cask thermal analysis assuming 76 °F bounds the ambient temperature at the site. Otherwise, site-specific analysis would need to be performed based on the site characteristics (using a maximum normal ambient temperature) to provide bonding results.

The staff reviewed the applicant's description of the MAGNASTOR® storage system thermal model. Based on the information provided in the application regarding the thermal model, the staff determined that the application is consistent with guidance provided in NUREG-2215, Section 5.5.4 "Analytical Methods, Models, and Calculations". Therefore, the staff concludes that the description of the thermal model is sufficiently detailed, as the description is consistent with NUREG-2215, and satisfies the requirements of 10 CFR 72.236(b), 10 CFR 72.236(f), 10 CFR 72.236(g), and 10 CFR 72.236(h).

4.2 Thermal Evaluation for Normal Conditions of Storage

The applicant used the 2-D axisymmetric thermal model, described in section 4.11.1 of the SAR, to determine temperature distributions under long-term normal storage conditions. The preferential loading pattern shown in FSAR, revision 0, figure 4.1-2 is considered for the analyses for all storage conditions in the SAR for the MSO. NAC performed a sensitivity analysis using both uniform loading and preferential loading. The analysis results show the preferential loading pattern bounds the temperature results for uniform loading pattern, since the temperatures for the preferential loading pattern were slightly higher than the uniform loading pattern. All predicted temperatures (including the maximum fuel cladding temperature) remain below the allowable limits provided in section 4.1 of the SAR.

The maximum average helium temperature in the TSC when it is contained in the MSO is bounded by the maximum average helium temperature calculated in revision 0 of the FSAR section 4.4.4, "Maximum Internal Pressures for PWR and BWR TSCs," for the internal pressure calculation. Therefore, the maximum normal condition pressure for the TSC containing the

preferential loaded pattern shown in FSAR figure 4.1-2 is bounded by the maximum normal condition pressure calculated in revision 0 of the FSAR, section 4.4.4.

As stated in section 4.1of this SER, the unique design characteristics of the cask outlet vents could affect the cask thermal performance. In the response to request for supplemental information (RSI) dated May 13, 2020 (ADAMS Accession No. ML20143A102), the applicant stated that it determined this cask design is most likely going to be used inside an independent spent fuel storage installation (ISFSI) building or enclosure. The applicant also stated that casks inside a building are not susceptible to any sustained low-speed winds because it is an indoor ISFSI and not directly exposed to any environmental wind conditions. The staff determined the applicant's response to a first request for additional information (RAI) dated February 25, 2021 (ADAMS Package Accession No. ML21067A041), regarding the effect of a building, was not acceptable because the application did not include any additional evaluation for an indoor ISFSI or enclosure to justify the changes in the technical specifications. In its second RAI response dated September 1, 2021 (ADAMS Accession No. ML21251A532), the applicant stated that it has elected to address the first RAI on low-speed winds directly and to remove the proposed requirement that the MSO must be used in an indoor ISFSI or enclosure.

The staff's evaluation of the applicant's response to the second RAI indicated the following:

- Analysis results (no wind conditions) from the MSO 2-D axisymmetric model in SAR section 4.11.2 list a peak cladding temperature (PCT) of 724 °F while the results from table 1-1 of Calculation No. 30082-3603, Rev. No. 0, "Thermal Evaluation of the Wind Effect on the MAGNASTOR MSO," (3-D analysis results) lists a PCT of 734 °F. This shows that predicted results from the 2-D axisymmetric model are not conservative, as claimed by the applicant in the SAR.

- When the staff ran the applicant's ANSYS FLUENT analysis model for this case using the second order accurate numerical method, and the angular discretization for the Discrete Ordinates (DO) radiation heat transfer model is increased from 2×2 to 4×4, a PCT of 740 °F is obtained.

The applicant provided results based on a 3-D analysis of the MSO for the wind case. The results correspond to steady state cases analyzed for a no wind condition, and assuming wind speeds of 2 miles per hour (mph), 7 mph, and 15 mph. The applicant showed that the PCT decreased as wind speed increased.

However, even though the outlet vents are represented in the applicant's 3-D thermal model as discrete squared holes with an area equivalent to a rounded hole, the discrete inlet vents are not explicitly represented in the thermal model. Instead, they are modeled to cover the entire circumference. This assumption is not realistic, as it is not an exact representation and could lead to nonconservative results. Assuming a 360-degree inlet vent could under-estimate the effect of flow blockage and could overestimate the air flow at the inlet vents. This assumption could result in an unrealistic decrease in the PCT at low wind speeds. An analysis that is based on a 3-D thermal model that represents the location and exact flow area of the inlet vents would be necessary to capture the effect of low-speed wind to show the true effect on the cask thermal performance and subsequently on predicted PCT. However, based on the staff's evaluation of low-speed wind for other ventilated casks (NUREG-2174 "Impact of Variation in Environmental Conditions on the Thermal Performance of Dry Storage Casks", March 2016), the staff concludes that the increase in temperature will not result in a PCT exceeding the allowable limit. Therefore, the staff finds the analysis results acceptable for the boundary conditions and

parameters used in the thermal evaluation of the MSO. For subsequent changes in the boundary conditions (for example, any increase in cask heat load), the applicant would need to develop a 3-D thermal model that represents the location and exact flow area of the air vents to capture the effect of low-speed wind and no wind conditions; this is because of the relatively small temperature margin calculated by the staff's sensitivity study that was based on the applicant's 3-D thermal model.

The staff reviewed the applicant's thermal evaluation of the MAGNASTOR® storage system during normal conditions of storage for the addition of the MSO and heat load patterns to the TSC for PWR fuel. Based on the information provided in the application, as supplemented, regarding the thermal model and evaluation, the staff determined that the application is consistent with guidance provided in NUREG-2215, Section 5.5.4 "Analytical Methods, Models, and Calculations" and therefore, meets the requirements of 10 CFR 72.236(f).

4.3 Off-Normal and Accident Events

4.3.1 Off-Normal Events

The applicant evaluated the following off-normal storage events: severe ambient temperature and partial blockage of air inlets conditions. The off-normal event for an increase in the ambient temperature only requires a change to the boundary condition temperature. For the partial blockage of air inlets condition, the air inlet condition is modified to permit air flow through half of the inlet area. The applicant used the preferential loading pattern used for normal conditions of storage to perform these analyses since it is the bounding heat load pattern. The temperatures of cask components for off-normal storage conditions are provided in SAR section 4.11.3. All component temperatures remain below the allowable limits described in the SAR for off-normal conditions.

4.3.2 Accident Events

The applicant evaluated the following storage accident events: maximum anticipated ambient temperature, fire, and full blockage of air inlet vents. The applicant performed steady state analysis using the thermal model described in SAR section 4.11.1 but modified the thermal model accordingly to reflect the different event conditions. The temperatures of cask components for accident conditions during storage are provided in SAR section 4.11.4. All component temperatures remain below the allowable limits described in the SAR for accident conditions.

The staff reviewed the applicant's thermal evaluation during off-normal and accident events. Based on the information provided in the application regarding the applicant's thermal evaluation, the staff determined that the application is consistent with guidance provided in NUREG-2215, Section 5.5.4 "Analytical Methods, Models, and Calculations" and therefore, meets the requirements of 10 CFR 72.236(f) because the thermal models adequately represent the storage system, and the analysis results show component temperatures within allowable limits.

4.4 Confirmatory Analyses

The staff reviewed the applicant's thermal models used in the analyses, checking the code input in the calculation packages submitted and confirming that the proper material properties and boundary conditions were used. The staff verified that the applicant's selected code models and

assumptions were adequate for the flow and heat transfer characteristics prevailing in the MAGNASTOR® geometry for the analyzed conditions.

Engineering drawings were also consulted to verify that system geometry and dimensions were adequately translated to the thermal analysis models. The material properties presented in the SAR were reviewed to verify that they were appropriately referenced and applied. In addition, the staff performed (sensitivity analysis calculations by changing calculation options and parameters that could affect predicted temperatures to verify that applicant's predicted results provide bounding predictions for all conditions analyzed in the application.

4.5 Evaluation Findings

F4.1 Chapter 2 of the FSAR describes SSCs important to safety to enable an evaluation of their thermal effectiveness. Cask SSCs important to safety remain within their operating temperature ranges.

F4.2 The MAGNASTOR® storage system is designed with a heat removal capability having verifiability and reliability consistent with its importance to safety. The cask system (TSC, transfer cask and concrete overpack) is designed to provide adequate heat removal capacity without active cooling systems.

F4.3 The spent fuel cladding is protected against degradation leading to gross ruptures under long-term storage by maintaining the fuel assembly PCT below 752 °F (400 °C). Protection of the cladding against degradation is expected to allow ready retrieval of spent fuel for future processing or disposal.

F4.4 The spent fuel cladding is protected against degradation leading to gross ruptures under off-normal and accident conditions by maintaining the fuel assembly PCT below 1058 °F (570 °C). Protection of the cladding against degradation is expected to allow ready retrieval of spent fuel for future processing or disposal.

F4.5 The staff finds that the thermal design of the MAGNASTOR® storage system complies with the design requirements in 10 CFR 72.236 and that the applicable design and acceptance criteria have been satisfied. The evaluation of the thermal design provides reasonable assurance that the cask will allow for safe storage of spent nuclear fuel. This finding is reached based on a review that considered NRC requirements, guidance, applicable codes and standards, and accepted engineering practices.

Chapter 5 CONFINEMENT EVALUATION

In MAGNASTOR® Amendment No. 10, the changes proposed in the SAR did not change the confinement design/function of the TSC, which is tested to leaktight criteria, in accordance with ANSI N14.5, "American National Standard for Leakage Tests on Packages for Shipment of Radioactive Materials".

Since the structural and thermal evaluations of the TSC within the MSO show that the TSC maintains its confinement capability, the NRC staff finds that the safety and regulatory compliance conclusions remain unchanged, thus the TSC remains in compliance with 10 CFR Part 72 and that the applicable design and acceptance criteria continue to be satisfied.

Chapter 6 SHIELDING EVALUATION

The shielding review evaluates the ability of the proposed shielding features to provide adequate protection against direct radiation from the dry storage system contents. The shielding features must limit the dose to the operating staff and members of the public so that the total dose remains within regulatory requirements during normal operating, off-normal, and design-basis accident conditions, including natural phenomena. The review seeks to ensure that the shielding design is sufficient and reasonably capable of meeting the operational dose requirements of 10 CFR 72.104 and 72.106 in accordance with 10 CFR 72.236(d). The staff's shielding review evaluated whether the MAGNASTOR system, with the proposed change, will provide adequate protection from the radioactive contents of the spent fuel. This review evaluated the methods and calculations employed by NAC to determine the total dose from gamma and neutron radiation at locations near the MSO surface and at specific distances away from the MSO.

6.1 Shielding Design Description

6.1.1 Design Features

Amendment No. 10 to the MAGNASTOR® dry storage system consists of a metal cask containing a stainless-steel canister (TSC) with a welded closure to safely store the spent fuel. The MAGNASTOR® system also includes a transfer cask as a shielded lifting device designed to hold the canister during loading operations, transfer operations, and unloading operations.

Amendment No. 10 adds the MSO with existing TSCs, basket, and contents. The MSO structural walls consist of carbon steel with a nominal outside diameter of 114.2 inches, 8-5/8 inches thick, and a height of 224 inches, with the outer and inner walls of the MSO encasing NS-3 shielding material. The carbon steel lid has a thickness of 9.73 inches with NS-3 encapsulated between ¾-inch-thick carbon steel and bolted to the top of the MSO. The NS-3 shield wall and carbon steel provide radiation shielding for neutron and gamma for stored spent fuel. Design characteristics and nominal values of the materials used in the MSO are given in the SAR in table 1.3.1 and Drawing Nos. 71160-565 and 71160-567.

6.2 Source Specification

The allowable contents for MSO are Westinghouse (WE) 14×14, Combustion Engineering (CE) 16×16, and WE17×17 fuel assemblies with a maximum heat load of 35.5 kW and uniform loading. Non-fuel hardware or damaged fuel is not allowed in the MSO. The source terms for uniform loading in this SAR for the PWR fuel assemblies are unchanged and calculated using the methodology in sections 5.2 and 5.8.1 of the FSAR[1].

6.3 Shielding Model

No changes were made to the shielding design of the TSC for the MAGNASTOR® dry storage system as a result of this amendment. The MSO is used as an overpack in this amendment in place of concrete overpacks in the previous shielding design evaluations. In its application, the applicant used the same computer codes, MCNP-5, that the staff previously found acceptable in

[1] Section 5.2 can be found in revision 5 of the FSAR (ADAMS Accession No. ML17132A265). FSAR Section 5.8.1 can be found in revision 0 of the FSAR ((ADAMS Accession No. ML091030364).

revision 8 of the FSAR for the shielding analyses, and the staff finds that the MCNP-5 code continues to be acceptable for this amendment application. The staff's determination is based upon NRC prior approvals, and because it is cited as a well-established code commonly used for spent fuel dry storage system shielding evaluations that the staff has found to be acceptable in Section 6.5.4 of NUREG-2215, "Shielding Analyses," and Section 4.3 of NUREG/CR-6802, "Dose Rate Estimation."

6.3.1 Shielding Model Specification

The applicant used the same MCNP model for the fuel assemblies, fuel tube, basket, and TSC from previously approved amendments, since these items remain unchanged in this amendment. The MSO dimensions from the drawings and NS-3 density and materials composition from design fabrication replaced the concrete cask overpack in the MCNP model. The canister lid also changed to carbon steel per design of the MSO. The applicant used the nominal density of the NS-3 of 1.76 g/cm^3 per the vendor data sheet. NS-3 neutron shield composition is temperature dependent. NAC adjusted the NS-3 composition in the MCNP model to account for weight loss due to thermal and radiation degradation, consistent with the data provided by NAC in its supplements dated April 20, 2021, and September 1, 2021.

Chapter 12 of the SAR discusses the potential off-normal conditions and their effect on the MAGNASTOR® system. The applicant concludes in SAR section 5.12.1 that none of the off-normal or accident conditions have a significant impact on the shielding analysis. Based on the staff's review of the model and resulting analyses, it confirmed that the off-normal and accident conditions are bounded by dose rates calculated in revision 8 of the FSAR for the MAGNASTOR® system.

6.3.2 Shielding Model Specifications—Configuration of the Shielding and Source

The staff reviewed the MCNP model of the MAGNASTOR® storage system as depicted by MCNP VisEd in SAR figures 6.12 through figure 6.19 in Calculation Package No. 30082-5601, revision 0, "MAGNASTOR MSO PWR Shielding Evaluation," and found NAC modeled it in sufficient detail to accurately represent the MSO. The cross-section of MSO is depicted in Figures 5.12.4-1 and 5.12.4-2 of the SAR. The design dimensions of MSO are shown in table 5.12.4-1 of the SAR. The model for the fuel assemblies, 37-assembly PWR basket, and TSC described in previous amendments (71160-5022 Rev. 1.) were the same as those used in previous amendments, except that TSC lid was modeled as stainless steel rather than carbon steel. The density of carbon steel is used for the pedestal plate of the MSO in place of stainless steel. This is a conservative assumption since the density of carbon steel is lower than stainless steel.

The NS-3 and its steel shell are not considered in the evaluation of outlet vent dose rates. The axial and outlet vent dose rates are evaluated for CE 16×16 since it is 7 inches taller than WE 14×14, and therefore result in higher dose rates in the axial direction and outlet vents. The insulation of the MSO lid is modeled as a void, which is a conservative assumption. The staff evaluated the applicant's shielding model and found it acceptable because the dimensions and material specifications of the components in the model represent the design shown the licensing drawings for the MAGNASTOR® storage system. The shielding model provides reasonable assurance that the MAGNASTOR® storage system will meet the applicable dose limits in 10 CFR 72.236(d).

6.3.3 Material Properties

The staff reviewed SAR chapter 5.12.4.3 for the composition of the NS-3 neutron shield material used in the shielding evaluation for the MAGNASTOR® MSO.

In the supplement dated April 20, 2021 (ADAMS Accession No. ML21118A043), the applicant provided three documents for the NS-3 neutron shield to provide more detailed information on the material properties and its qualification testing. The staff verified that the material properties of NS-3 used to represent this material in the shielding evaluation are consistent with the weight loss due to thermal and radiation degradation.

6.4 Shielding Evaluation

The applicant calculated dose rates for the MSO using the MCNP5 computer code. These dose rates and source terms were for a uniform heat load of 35.5 kW. The evaluation is specific to these three fuel types, therefore the technical specifications limit loading of fuel in the MSO to these three fuel types.

Using the dose-response method discussed in revision 0 and 1 of the FSAR (ADAMS Accession Nos. ML091030628 and ML21147A112, respectively), the applicant calculated dose rates from the MSO for all allowed cooling times, assembly average burnup, and initial enrichment fuel type combinations.

Tables 5.12.1-1 through 5.12.1-3 of the SAR shows the maximum dose rates for the uniform loading of WE14×14, CE16×16, and WE17×17. The maximum dose rates on the side and top are of the MSO are 322.3 mrem/hr. and 352.9 mrem/hr., respectively. These dose rates are bounded by the dose rates on the side and top of the concrete cask of 434 mrem/hr. and 430 mrem/hr., respectively. The MSO dose rates used to calculate occupational dose are also bounded by the concrete cask dose rates.

The average dose rates on the side and top of MSO are 52.9 and 67.0 mrem/hr., respectively. The shielding analysis for site boundary and occupational exposure are based on 40 kW and average dose rates for side and top of the concrete cask of 56.7 mrem/hr. and 134.7 mrem/hr. FSAR, revision 8 that bound the dose rates from the MSO. Since the cask dose rates used to calculate offsite dose FSAR, revision 8 and worker dose exceed the dose rates for the MSO, no further evaluation is necessary for site boundary and occupational exposure. In addition, since the MSO dose rates are bounded by the approved concrete cask dose rates specified in FSAR, revision 8, the measurement locations and dose rates in technical specification 3.3.1, “CONCRETE CASK or MSO Maximum Surface Dose Rate,” are adequate to ensure offsite dose can be met.

6.5 Confirmatory Review and Analysis

The staff reviewed the applicant’s shielding analysis and found it acceptable because the maximum offsite dose rates meet the limits in 10 CFR 72.236(d). The staff reviewed the radiation shielding evaluations, including the calculations of the sources, and the dose rates for the MSO. The staff independently calculated source terms for the bounding PWR fuel assemblies using combinations of different enrichments, burnups, and cooling times. The staff also performed confirmatory analyses of the dose rates with the MSO. The staff finds the applicant’s determination of the bounding dose rates for WE14×14, CE16×16, and WE17×17 PWR fuels as defined in table 5.12.4-1 to be acceptable and finds that the offsite doses with the

design basis fuel will be within regulatory limits. The staff concludes that the applicant has demonstrated that the MAGNASTOR® dry cask storage system with the MSO meets the radiation protection requirements of 10 CFR 72.104 and 72.106 as referenced in 10 CFR 72.236(d).

6.6 Evaluation Findings

Based on the NRC staff's review of information provided for the MAGNASTOR® application, the staff finds the following:

F6.1 Chapter 5 of the MAGNASTOR® SAR describes shielding structures, systems, and components important to safety in sufficient detail to allow evaluation of their effectiveness.

F6.2 Chapter 5 of the MAGNASTOR® SAR provides reasonable assurance that the radiation shielding features are sufficient to meet the radiation protection requirements of 10 CFR Part 20, 10 CFR 72.104, and 10 CFR 72.106.

F6.3 Operational restrictions to meet dose and ALARA requirements in 10 CFR Part 20, 10 CFR 72.104, and 10 CFR 72.106 are the responsibility of the general licensee. The MAGNASTOR® shielding features are designed to assist in meeting these requirements.

Based upon its review, the staff has reasonable assurance that the design of the shielding system for the MAGNASTOR® system, including the MSO, the transfer cask, and the TSC comply with 10 CFR Part 72 and that the applicable design and acceptance criteria have been satisfied. The evaluation of the shielding and radiation protection design features provides reasonable assurance that the MAGNASTOR® system will provide safe storage of spent fuel in accordance with 10 CFR 72.236(d). This finding is based on a review that considered regulatory requirements, the appropriate guidance, applicable codes and standards, the applicant’s analyses, the staff’s confirmatory analyses, and acceptable engineering practices.

Chapter 7 CRITICALITY EVALUATION

In MAGNASTOR® Amendment No. 10, NAC did not make any changes to the contents or TSC. Since the structural and thermal evaluations of the TSC within the MSO show that the TSC, its basket and fuel inside remain unchanged after normal, off-normal and accident conditions, the NRC staff finds that the safety and regulatory compliance conclusions remain unchanged, thus the criticality safety of the MAGNASTOR® system remains in compliance with 10 CFR Part 72 and that the applicable design and acceptance criteria continue to be satisfied.

Chapter 8 MATERIALS EVALUATION

The staff evaluated the materials performance of the new MSO to ensure that it meets the requirements of 10 CFR Part 72. The MSO is designed to hold the TSC with PWR fuel during long-term storage.

8.1 Materials of Construction

As described in SAR sections 3.1.2 and 8.1, SAR table 4-1, and the licensing drawings, the MSO is a structural steel cylinder that incorporates a layer of cementitious shielding material (NS-3). The internal cavity is lined by ASTM International (ASTM) A350 Grade LF2 carbon

steel, and the outer shell is constructed of ASTM A516, Grade 70 carbon steel. NS-3 shielding, consisting primarily of Portland cement and fire-retardant alumina trihydrate, is sandwiched between a welded cavity formed by the outer shell, the inner liner, the top plate, and the bottom weldment. The bottom and base plate weldments are fabricated to ASTM A516, Grade 70 carbon steel, except for the ASTM A36 carbon steel shield bars. Eight carbon steel gussets reinforce the inner liner and bottom weldment. Standoffs, fabricated with ASTM A36 or A992 carbon steels, are welded to the cask inner liner and are responsible for guiding the TSC into the MSO. The MSO lid assembly is constructed of NS-3 encased in carbon steel plate (a welded cavity between the NS-3 ring, the lid base plate and the lid top plate). The MSO is lifted using two ASTM A696 Grade C carbon steel trunnions that are welded into the inner liner forging.

8.2 Codes and Standards

As described above, all structural steels conform to appropriate ASTM standards. The staff notes that the cited standards are consistent with NRC guidance in NUREG-2215, which states that structural components of the overpack may be constructed of ASTM materials. Therefore, the staff finds the MSO codes and standards for the metallic materials to be acceptable. The staff's review of the NS-3 material, for which there is no applicable standard, is documented below in SER section 8.10.

8.3 Drawings

The staff reviewed MSO licensing drawings and verified that the applicant provided an adequate description of the materials of construction, dimensions, fabrication (welding) specifications, and post-weld examinations. The steels used in the fabrication of the MSO are specified in the bill of materials. In addition, the drawings establish the minimum density and hydrogen content of the NS-3 shielding material. The staff finds that the drawings provide sufficient information to describe the MSO materials and fabrication criteria and are, therefore, acceptable.

8.4 Material Properties

For the new MSO design, the applicant used the same steel materials (with one exception) as those used to construct the previously approved overpacks and transfer cask. Consequently, the applicant used the same mechanical properties and thermal properties previously used in the structural analysis and thermal analyses of the MAGNASTOR® system. One new steel material introduced in the MSO design was the option to use ASTM A992 carbon steel as an alternative to ASTM A36 carbon steel for the construction of the overpack standoffs. However, in its structural analysis of the MSO in a tip-over accident, the applicant used the properties of the A36 steel, and its lower strength and similar elastic properties relative to A992; these properties provide a bounding analysis. The applicant also added SAR tables 8.3-34 and 8.3-35 to provide the mechanical and thermal properties of the NS-3 material. The staff reviewed the material properties and verified that they are consistent with the values provided in the BISCO Products NS-3 Specification Sheet (BISCO, 1986). Therefore, the staff finds the mechanical and thermal properties of the MSO materials to be acceptable.

8.5 Fracture Toughness

The fracture toughness of the MSO inner shell material is established by its ASTM A350 material specification, which includes requirements to perform Charpy impact tests to ensure adequate notch toughness. The ASTM A696 Grade C trunnion steel specification does not

include a specific requirement for toughness testing; however, as described in SAR section 8.1.1, the applicant will impact test the trunnion steel per ASME B&PV Code Section III, Division 1, Subsection NF (Supports), Subarticle NF-2300. In addition, although the trunnion steel will be tested to ensure adequate fracture performance at -40 °C (-40 °F), the lifting of the MSO is restricted to occur when the surrounding air temperature is greater than -18 °C (0 °F). Therefore, based on the use of the ASTM and ASME impact testing criteria, the staff finds the applicant's approach to ensure adequate fracture performance of the inner liner and trunnions steels to be acceptable.

The SAR does not include fracture testing of the ASTM A516, Grade 70 outer shell and top lid plate steel; however, the staff considers the overpack's performance in the tornado missile and tipover impact events to be adequately addressed by the applicant's structural analyses of these components, which includes significant safety margins. The missile penetration evaluation in SAR section 3.11.4.1 found that the outer shell and lid plate thickness had a minimum 3.7X and 2.5X factor of safety, respectively, even when neglecting the backing support by the underlying cement shielding and carbon steel layers. For the non-mechanistic tip-over event, the calculated stress on the outer shell is approximately 25% of the material's typical yield strength, as summarized in SAR tables 3.11.4-3 and 3.11.3-4. Given these safety margins and the fact that that the steels are required to be tested to meet minimum ductility requirements per their ASTM specification, the staff finds there is reasonable assurance that brittle fracture will not compromise the missile penetration and tip-over performance of the overpack in these impact events.

8.6 Corrosion Reactions

In SAR section 8.10, the application evaluated the materials used in fabrication of the MSO to determine whether chemical, galvanic or other reactions among the materials and environment would occur. The applicant stated that the exposed carbon steel surfaces of the MSO inner and outer shells, lid, and the air inlets and outlets are coated to provide protection from weather-related moisture and the coatings are formulated for use in continuous high temperature environments. As a result, the applicant concluded that no potential chemical, galvanic or other reactions could adversely affect the integrity of the MSO.

The staff reviewed the MSO materials and noted that the MSO is constructed of similar carbon steels to those of the previously approved MAGNASTOR® components (e.g., transfer cask) and all exposed surfaces are coated to provide protection from the operating environment. Further, the accessible external carbon steel surfaces of the MSO are inspected annually to verify the integrity of corrosion-inhibiting coatings. The coatings are reapplied, as necessary, for repair in accordance with manufacturer's instructions. Therefore, the staff finds the applicant's activities to preclude chemical, galvanic corrosion or other reactions to be acceptable.

8.7 Protective Coatings

In the MSO design, the applicant used the same coatings that have been previously approved for use in the MAGNASTOR® system to mitigate atmospheric corrosion of carbon steel, and the staff finds that those coatings continue to be effective. Therefore, the staff finds the coatings to be acceptable.

8.8 Weld Design

In SAR section 8.4, the applicant stated that weld design, procedures, and qualification processes for the MSO will be consistent with the criteria previously approved for the transfer cask. The weld design will be in accordance with ASME B&PV Code Subsection NF, and the welding procedures, processes, and welder qualifications will be in accordance with either ASME B&PV Code Section IX, "Qualification Standards for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators," or ANSI/American Welding Society (AWS) D1.1, "Structural Welding – Steel." In SAR section 10.1.1 and 10.1.2, the applicant stated that visual examination of the MSO structural welds will be performed in accordance with ASME B&PV Code, Section V, "Nondestructive Examination," or ANSI/AWS D1.1, and the critical load-bearing welds of the trunnions shall be magnetic particle or liquid penetrant examined per ASME B&PV Code, Section V. The staff notes that the applicant's use of the cited ASME and AWS codes for the design, fabrication, and examination of the MSO welds is consistent with the guidance in NUREG-2215. Therefore, the staff finds the welding criteria to be acceptable.

8.9 Bolt Applications

As described in the SAR section 8.5, the MSO lid is retained by six commercial-grade stainless steel bolts. The applicant stated that commercial-grade bolts are sufficient since only negligible forces are applied to the lid connections during normal operations or off-normal and credible accident events. The staff notes that the lid bolt requirements for the MSO are identical to the bolts previously approved for the lid of the MAGNASTOR® concrete overpack that experience similar loading conditions and service environments; therefore, the staff finds them to be acceptable.

8.10 Radiation Shielding

Carbon steel and NS-3 provide gamma shielding that is used for both the radial shell and top lid of the MSO. NS-3 provides neutron shielding. NS-3 is a commercially available cementitious shielding material that is designed for gamma and neutron shielding. It is currently used in the top shield plugs in the concrete overpacks for the NAC-MPC and NAC-UMS storage system designs, Certificate of Compliance Nos. 1025 and 1015, respectively. The staff evaluated the material properties (e.g., density) and radiation absorption characteristics used in the shielding analysis to ensure that the properties are adequately validated by test data.

For the carbon steels, the staff notes that the properties used in the MSO shielding analysis are identical to those previously reviewed for the existing shielding analysis of the concrete cask. The staff verified that those properties continue to be adequate for the analysis of the MSO, as the steel density values used in the shielding analysis are consistent with those of the materials of construction. In addition, the staff notes that the shielding performance of the steels are not expected to degrade over the licensing term, as the steels are found to have adequate corrosion resistance (as described in SER section 8.6) and they are not affected by the gamma and neutron radiation exposures in spent fuel storage systems (as documented in NUREG-2214, "Managing Aging Processes in Storage (MAPS) Report," section 3.2.1.9). Therefore, the staff finds that the applicant is using appropriate materials properties for the carbon steels in the shielding analysis.

For NS-3, as stated above, NAC currently employs this material in the concrete overpacks for the NAC-UMS and NAC-MPC storage systems. The new MSO is the first application of NS-3 in

the MAGNASTOR® design. The staff evaluated the NS-3 properties used in the shielding analysis, including whether use of this material in the MSO introduces service conditions that may be more severe than those already considered in the previously approved designs. As described in SAR section 5.12.4.3, both temperature and radiation exposure may lead to a loss of density and hydrogen content (in the form of loss of water vapor) that must be considered in the NS-3 shielding analysis. In support of the shielding properties used in the shielding analysis, the applicant provided proprietary test reports on the effects of temperature and radiation exposure in the application supplements dated April 20, 2021, and September 2, 2021. The staff reviewed the provided test data on the NS-3 material and verified that the material properties used in the shielding analysis account for the potential material changes due to prolonged temperature and radiation exposure during normal, off-normal, and accident conditions. Therefore, based on the above discussion, the staff finds that the applicant is using appropriate materials properties for NS-3 in the shielding analysis.

8.11 Evaluation Findings

F8.1 The applicant has met the requirements in 10 CFR 72.236(b). The applicant described the materials design criteria for SSCs important to safety in sufficient detail to support a safety finding.

F8.2 The applicant has met the requirements in 10 CFR 72.236(g). The properties of the materials in the storage system design have been demonstrated to support the safe storage of spent fuel.

F8.3 The applicant has met the requirements in 10 CFR 72.236(h). The materials of the spent fuel storage container are compatible with their operating environment such that there are no adverse degradation or significant chemical or other reactions.

F8.4 The applicant has met the requirements in 10 CFR 72.234(b). Quality assurance programs and control of special processes are demonstrated to be adequate to ensure that the design, testing, fabrication, and maintenance of materials support SSC intended functions.

The staff concludes that the MAGNASTOR® design adequately considers material properties, environmental degradation and other reactions, and material quality controls such that the design is in compliance with 10 CFR Part 72. This finding is reached on the basis of a review that considered NRC requirements, guidance, applicable codes and standards, and accepted engineering practices.

<u>References</u>

BISCO Products, Inc. “NS-3 Specification Sheet.” (ADAMS Accession No. ML110730731), June 23, 1986.

Chapter 9 OPERATING PROCEDURES EVALUATION

NAC revised the operating procedures to incorporate the MSO by replacing the term “concrete cask” with “storage cask,” as appropriate, to include both concrete casks and MSO. Since both the MSO and the concrete casks are handled similarly, no other changes were proposed or are necessary.

Chapter 10 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM EVALUATION

The acceptance tests demonstrate that the storage cask was fabricated in accordance with the design criteria to ensure that it complies with regulatory requirements.

10.1 Acceptance Tests

NAC incorporated the MSO into the acceptance tests to clarify when tests apply to either the concrete cask, MSO, or both. Consistent with the drawings, principal design criteria, and the structural and materials evaluations, NAC specified the ASME B&PV Code along with associated code criteria (ASME or AWS) inspections for non-destructive examination of the MSO welds. NAC also proposed a load test for the trunnions by applying a vertical load of 150% of the maximum MSO weight to the trunnions for a minimum of 10 minutes. After the load test, accessible portions of the trunnions and the adjacent areas will be visually examined to verify no deformation, distortion, or cracking occurred. Critical load-bearing welds of the trunnions will undergo magnetic particle examination in accordance with ASME B&PV Code, as documented in the staff's review of the weld design in SER section 8.8, "Weld Design.

10.2 Maintenance Program

NAC incorporated the MSO into the maintenance program to clarify when specific maintenance items apply to either the concrete cask, MSO, or both.

The only maintenance program inspections that are specific to the MSO are the visual inspection and repair or recoating of MSO accessible coated carbon steel surfaces, which is discussed in section 8.7 of this SER and the visual inspection of MSO identification markings. Both tests are performed annually.

10.3 Findings

F10.1 The MSO will be designed, fabricated, erected, tested, and maintained to quality standards commensurate with the importance to safety of the function of the MSO. Chapter 2 of the SAR identifies the principal design criteria and safety importance of the MSO in accordance with 10 CFR 72.234(b) and 10 CFR 72.236(b), (g), (j) and (l).

Chapter 11 RADIATION PROTECTION EVALUATION

Since the average dose rates around the cask for normal, off-normal and accident conditions, when loaded with the three fuel types at 35.5 kW are bounded by the dose rates in revision 5 of the FSAR, the revisions requested by NAC do not alter the staff's previous evaluation of radiation protection of the MAGNASTOR® system. Therefore, as discussed in section 6.4, above, the staff did not reevaluate this area for this revision request.

Chapter 12 ACCIDENT ANALYSES EVALUATION

NAC incorporated the MSO into the evaluation of accidents. NAC noted that the radiological effects of the MSO are evaluated in chapter 5 of their SAR. NRC evaluation of the radiological effects are given above in chapter 11, "Radiation Protection Evaluation." Therefore, the revisions requested by NAC do not affect the accident analysis evaluation for the system and do not alter the staff's previous evaluation of the accident analyses for the MAGNASTOR® system.

Chapter 13 TECHNICAL SPECIFICATIONS AND OPERATING CONTROLS AND LIMITS EVALUATION

NAC incorporated the MSO and its associated contents into the technical specifications. The staff reviewed the technical specifications and the operating controls and limits of the technical specifications to ensure they meet the requirements of 10 CFR Part 72. The staff evaluation of the adequacy of the technical specifications is provided in chapters 2 through 8, above.

Chapter 14 QUALITY ASSURANCE PROGRAM EVALUATION

There were no requested changes to NAC's quality assurance program and none of the changes requested by NAC affect the quality assurance program.

Issued with Certificate of Compliance No. 1031, Amendment No. 10,
on December 19, 2022

AMENDMENT NO. 10 TO CERTIFICATE OF COMPLIANCE NO. 1031 FOR THE MAGNASTOR® STORAGE SYSTEM DATE December 19, 2022

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