UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION REPORT
Certificate of Compliance No. 9796
Model No. M-290 Package
Revision No. 1

SUMMARY

By application dated May 18, 2017, the Department of Energy, Division of Naval Reactors (Naval Reactors or the applicant) requested an amendment to Certificate of Compliance No. 9796 for the Model No. M-290 spent fuel package. The M-290 is designed to transport a variety of types of Naval Reactor spent fuel. The applicant requested addition of A1G spent fuel as authorized contents. Throughout this safety evaluation report (SER), the staff refers to the safety analysis report (SAR) under consideration (the A1G-configured M-290 transportation package) as the A1G SAR, the M-290 core-independent transportation package SAR as the M-290 SAR.

The NRC staff performed its review of the amendment to the M-290 package utilizing the guidance provided in NUREG-1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel."

1.0 GENERAL INFORMATION

1.1 Packaging

The M-290 is a right circular cylinder for transporting spent fuel. The package's approximate dimensions and weights are as follows:

Cavity diameter	71 inches
Cavity height	242 inches
Body outer diameter,	
upper section	92.15 inches
lower section	96.15 inches
Body steel wall thickness,	
upper section	10.6 inches
lower section	12.6 inches
Maximum outer diameter including domes	128 inches
Maximum height (including domes)	361.5 inches
Maximum weight (including contents)	520,000 pounds

The M-290 package body is fabricated primarily from dual-certified Type 304/304L stainless steel forgings, with the upper portion fabricated from a forging constructed of Nitronic 40. All forgings are joined via full-penetration welds. The upper inside wall of the package body includes two grooves. One for engagement of an internal retaining ring, and the other for engagement of a closure shear ring system. Between these grooves is a seating ledge for the closure head or canister restraint plate. The package bottom plate is approximately 11.56-inches thick. The thicker lower region of the package body is encircled by a set of 50, equally-spaced, thermal fins welded to the exterior surface. The upper and lower regions of the package body include exterior flanges into which impact mitigating, top and bottom domes are engaged during shipment.

The M-290 packaging body has no penetrations other than the main top opening, which is sealed during transport via a 5-inch thick, lid constructed of Nitronic 40. The lid includes three concentric O-rings, and is attached to the package body using 30 high-strength fasteners. Penetrations in the lid (for leak testing or venting operations) are plugged and sealed prior to transport.

Each end of the M-290 includes a large, impact mitigating dome that is also used for attachment of package handling hardware. The domes are fabricated from Type 304 stainless steel and are engaged in grooves in the packaging body. The top dome is attached via a set of 24 high-strength fastening pins; the bottom dome is attached via a set of 12 retention wedges, each of which is attached via two high-strength fasteners. The domes are custom-designed to reduce package loadings and protect the upper containment seals under accident conditions.

The M-290 is designed to be directly loaded with spent fuel and also spent fuel contained in a sealed canister. Direct-loaded spent fuel configurations include an internal assembly installed directly in the M-290 package body and held in place via an internal retaining ring (engaged in the package wall groove). Direct-loaded spent fuel shipments also include a thick closure head that seats on the internal package ledge and includes an access port for installation and removal of the spent fuel. The access port is closed and sealed via a bolted access plug. The head and plug each include supplemental O-ring seals.

Canistered configurations include a separate, sealed canister in which the spent fuel is located (within unique internals inside the canister). The canister is restrained within the M-290 utilizing a canister restraint installed in the same region occupied by the closure head for non-canistered configurations. The closure head (or canister restraint) is restrained and preloaded via a segmented shear ring that engages in the upper package body groove. The shear ring system is engaged in the groove and preloaded via a set of 28 shear ring jack screws. The shear ring is further prevented from disengagement via a backing ring bolted to the closure head or canister restraint.

Each M-290 is shipped at a 1-degree tilt (with the closure end upward) on a specially-designed railcar. The center of the package body sits within a custom shipping cradle (welded to the railcar deck), and cradle caps (which gird the upper portion of the body) provide vertical restraint. Two reaction pads (one at each end of the package) provide additional vertical support to the package.

1.2 Contents

The proposed contents for the M-290 is comprised of A1G spent fuel and associated activated corrosion products (crud), and some residual water (up to 8 gallons) assumed to be contaminated with activated corrosion products. Authorized fuel loadings, internals assembly, and other loading restrictions are specified in the A1G SAR. A1G spent fuel modules decay heat shall not exceed 58,484 Btu/hr per package at the time of canister draining.

1.3 Drawings

The packaging is constructed and assembled in accordance with the drawings in Appendix 1.3.3 of the M-290 SAR. Internals assemblies and fuel modules for the A1G spent fuel are constructed and assembled in accordance with drawings in Appendix 1.3.3 of the A1G SAR.

1.4 Evaluation Findings

A general description of the new contents in the M-290 package is presented in Section 1 of the application, with special attention to design and operating characteristics and principal safety considerations.

The staff reviewed the general design information. Based on its review, the staff concludes that the information presented in this section of the application provides an adequate basis for the evaluation of the M-290 package against the requirements in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 71 for each technical discipline.

2.0 STRUCTURAL EVALUATION

The objective of the structural review is to verify that the structural and materials performance of the package is adequately demonstrated to meet the requirements of 10 CFR Part 71, including the tests and conditions specified under normal conditions of transport and hypothetical accident conditions. The M-290 transportation package was previously approved by the NRC for transport of A1W spent nuclear fuel.

2.1 Description of Structural Design

2.1.1 Discussion

The M-290 core-independent transportation package is comprised of the packaging body, lid (containment cover) and fasteners, top and bottom impact limiter domes and attachment hardware, a shear ring with jack screw assemblies, and a backing ring assembly with fasteners. The evaluation of the core independent packaging considered two generic loading configurations which were spent fuel directly loaded into package cavity (A1G) and a canister-based loading (A1W).

The principal structural A1G core-dependent components in the A1G-configured M-290 transportation package are the closure head assembly, the internals retaining ring assembly, the internals assembly and the A1G spent fuel modules. The closure head assembly is the primary structural component that provides confinement of the A1G spent fuel. The internals retaining ring assembly secures the A1G internals assembly within the M-290 transportation package, the internals assembly provides the necessary structural support of the A1G fuel during shipment and facilitates the transfer of heat from the A1G spent fuel modules to the outside of the package. The A1G spent fuel consists of the fueled region as well as other structural components attached to the fuel in core. Additionally, a defueling grapple adapter (DGA), used to remove the fuel from the core, is attached on the top of the fuel assembly and remains with the assembly after removal from the core.

The applicant stated that the lead screw will fail due to brittle fracture as a result of a drop accident. A rod hold down device (RHD), if installed, shrouds the lead screw and limits control rod movement should the lead screw fracture. The applicant stated that a RHD will be installed based on the total burn-up of the core. At a given time in core life (effective full power hours or EFPH), the reactivity in the core is such that maximum withdrawal of the control rod due to failure of the lead screw will not result in criticality. For a core life greater than this, the addition of the RHD is not required to prevent criticality. For a core prior to this time in life, the RHD will be required to prevent control rod movement and possible criticality.

2.1.2 Design Criteria

The applicant used a combination of closed-formed, hand calculations, and finite element analysis to evaluate the A1G spent fuel in the M-290 package. In general, evaluations for normal conditions of transport were performed using primarily hand calculations and supplemented by finite element analysis. Conversely, evaluations for hypothetical accident conditions were performed primarily with elastic-plastic finite element analyses and supplemented by hand calculations. In addition, brittle fracture, fatigue, and buckling were also considered.

The applicant established the design criteria based on the safety function and consequence of failure of each component. The design of the A1G components serve to maintain the containment boundary, confine the spent fuel within transportation package; limit spent fuel module lateral or axial movement during hypothetical accident conditions and normal conditions of transport; while minimizing spent fuel structural damage, and limit control rod withdrawal during hypothetical accident conditions to maintain subcriticality. Table 2.1-1 of the SAR lists the specific design criteria for the major components of the A1G core-dependent package for normal conditions of transport and hypothetical accident conditions.

The staff reviewed Table 2.1-1 and concludes that the design criteria established by the applicant for the components of the A1G components are acceptable, because they are consistent with maintaining containment, shielding and subciticality of the A1G spent fuel.

2.1.2.1 Allowable Stresses and Strains

The applicant summarized the stress and strain limits in Table 2.1-1 of the M-290 SAR for the core-independent components and Table 2.1-1 of the A1G SAR for the core-dependent components of the package. The A1G components are generally designed to remain elastic during normal conditions of transport and stay below their uniform elongation true plastic strain limits during hypothetical accident conditions.

2.1.2.2 Load Combinations

The applicant summarized the applicable load combinations in Table 2.1-2 of the M-290 SAR and Table 2.1-2 of the A1G SAR. These load combinations are consistent with Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material;" therefore, the staff finds them acceptable.

2.1.3 Weights and Centers of Gravity

Tables 2.1-3 and 2.1-4 of the M-290 SAR summarize several content configurations with varying weights and center of gravity locations. Tables 2.1-3 through 2.1-6 of the A1G SAR summarize the weights and centers of gravity for the A1G components and spent fuel modules as well as the M-290 loaded with the A1G spent fuel. Because the minimum and maximum calculated weights of the M-290 transportation package loaded with the A1G spent fuel are bounded by the M-290 SAR, the staff determines that the original evaluation of the M-290 transportation package is valid for transporting the A1G spent fuel.

2.1.4 Codes and Standards

For the design of the core-independent packaging, the applicant used the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (B&PV), Section III, Division 1, Subsection NB for the containment components, and ASME B&PV Code, Section III, Division 1, Subsection NF for the non-containment components. In certain cases, more restrictive requirements than ASME code requirements were utilized, such as the Naval Nuclear Propulsion Program requirements.

The majority of the A1G core-dependent package components are fabricated, examined, and tested in accordance with Naval Nuclear Propulsion Program and commercial industry requirements, including ASME, ASTM International, SAE International, and Military Standards specifications. The applicant applied the ASME B&PV Code, Section III, Division 1, Subsection NB to the materials, fabrication, welding, examinations and testing of the major components of the A1G closure head and internals retaining assemblies. The remaining A1G internal components were designed and fabricated to alternate specifications, identified on the applicable drawings in Chapter 1 of the A1G SAR and in Tables 2.2-1 of the A1G SAR.

The staff has reviewed the structural codes and standards used in package design and find that they are acceptable and therefore satisfies the requirements of 10 CFR 71.31(c). Additionally, the staff has reviewed the package structural design description and concludes that the contents of the application meet the requirements of 10 CFR 71.31(a)(1), (a)(2), and (c), as well as 10 CFR 71.33(a) and (b).

2.1.5 Analytical Approach

The applicant used the explicit finite element analysis (FEA) software LS-DYNA for the core independent M-290 analysis to determine deceleration values and the time-history response at various locations of the M-290 transportation package for the 1-foot drop and the 30-foot drop analyses. They used the explicit FEA software Abacus to evaluate the stresses and strains in key components of the A1G-configured M-290 based on the output of the LS-DYNA analysis and supplemented these solutions with closed form hand calculations. The applicant used 10 models of subassemblies to evaluate different components of the A1G-configured M-290 transportation package listed in the table below.

Model Name	Description	Components Evaluated	Event
I1	Internals Lateral Impact Model	Internals Assembly Internals Retaining Ring Assembly Simplified Cargo	1-foot drop 30-foot drop
I2	Internals Top Drop Model	Internals Internals Retaining Ring	30-foot drop
I3	Internals Bottom Drop Model	Internals Assembly Internals Retaining Ring	1-foot drop 30-foot drop
IRR	Internals Retaining Ring Lateral Impact Model	Internals Retaining Ring	30-foot drop

C1	Cluster Fuel Region Lateral Impact Model	Internals Support Plate Detailed Fuel Cross section Control Rod	1-foot drop 30-foot drop
C2	Cargo Top Drop Model	A1G Cell Assembly DGA/RHD Pedestal Assembly	30-foot drop
C3	Cargo Bottom Drop Model	A1G Cell Assembly DGA/RHD Pedestal Assembly	1-foot drop 30-foot drop
C4	Cargo Lateral Impact Model	Internals Internals Retaining Ring A1G Cell Assembly (excluding fuel) DGA/RHD	30-foot drop
CIC	Core Independent Model	M-290 Package A1G Closure Head Simplified Cargo	1-foot drop 30-foot drop
APF	Access Port Bolting Flange Fastener Models	Access Port Bolting Flange Large and Small Fasteners	30-foot drop

In general, the I1, I2, and I3 models were used to evaluate the effects of lateral and axial impacts on the A1G internals assembly. The IRR model focused on evaluating the response of the internals retaining ring to lateral impacts. The C2 and C3 models were used to evaluate the effects of axial impacts on the A1G cargo. The C1 and C4 models were used to evaluate the effect of lateral impacts on the A1G cargo. The CIC model was used to assess the response of the A1G closure head assembly to all potential impacts and the APF model was used to demonstrate acceptable brittle fracture performance of the closure head assembly access port fasteners.

The applicant provided a detailed description of the Abacus models in Appendix 2.12.13 of the SAR. The individual components were modeled based on nominal dimensions from the drawings in Chapter 1 of the SAR and included all features important to safety. Some features such as small chamfers, holes, alignment pins and lock-wire were omitted for model simplicity. The applicant provided a detailed list and description of all exceptions and analysis assumptions in Appendix 2.12.13 of the SAR. The majority of the components were meshed with reduce-integration, eight-node, linear hexahedral elements. Alternate elements types were identified in the SAR when they were used in the model. In many cases, the applicant used a method called "clocking" in which they evaluated the model at different incremental angles to determine the limiting drop orientation for the component under investigation. Evaluations were completed for different acceleration pulses due to the hypothetical drop accident for hot (peak design temperatures) and cold (-20°F) conditions.

The applicant defined the material properties used in the Abacus FEA models in Appendix 2.12.25 of the A1G SAR. The applicant used three primary material properties based on the component importance: elastic, elastic-plastic, and elastic-plastic with material damage. Additionally, the applicant created multiple sets of material properties based on temperature, strain rate, irradiation and hydrogen content. In some cases, the applicant used an elastic representation of a component to produce stresses that support a brittle fracture evaluation.

The staff determined that the applicant's Abacus models are consistent with the guidance established by the ASME B&PV Code Section III, Division 1 Special Working Group on Computational Modeling for Explicit Dynamics, and are therefore quality models. Because of these considerations, the staff determines that the applicant's analytical approach to impact analysis using LS-DYNA and Abacus FEA software, as well as supplemental hand calculations is acceptable and finds that application satisfies 10 CFR 71.41(a).

2.2 Materials Evaluation

The M-290 transportation packaging has been previously approved and that evaluation found M-290 packaging materials to meet and/or exceed the minimum requirements set forth in 10 CFR Part 71 and is designed and fabricated to meet Type B shipping container criteria therefore, the following materials evaluation concerns the addition of A1G spent fuel only. The staff notes that A1G fuel has been previously approved for transportation in the Model M-140 transportation package (Certificate of Compliance No. 9791.)

Section 2.4.4 of the application demonstrates that M-290 A1G spent fuel and components are fabricated from materials not susceptible to chemical or galvanic reactions and are fabricated from corrosion-resistant materials that form a protective, passive oxide layer. In addition, limits are placed on chloride content. The staff finds no significant material interactions or galvanic reactions are to be expected. The physical properties materials used for the A1G, particularly impact resistance, will not be adversely affected during the range of temperatures expected during normal shipping conditions.

2.3 General Requirements for All Packages

2.3.1 Minimum Package Size

The smallest overall dimension exceeds the specified requirement of 4 inches, therefore, the staff finds that the package meets the requirements of 10 CFR 71.43(a) for minimum size.

2.3.2 Tamper-Indicating Features

The applicant stated that a security seal is installed in one of the top dome attachment pin assemblies and must be destroyed in order to access the attachment pins and removed them. The staff reviewed the package closure description and determines that damage to this security seal would indicate tampering; therefore, the package satisfies the requirements of 10 CFR 71.43(b) for a tamper-indicating feature.

2.3.3 Positive Closure

The applicant asserts that access to the internal cavity of the M-290 package requires the removal of 24 attachment pin assemblies, removal of the top dome, and removal of the bolted containment cover. The staff reviewed the package closure system and the applicant's analysis for normal and accident pressure conditions and concludes that the containment system is securely closed by a positive fastening device and cannot be opened unintentionally or by a pressure that may arise within the package and therefore satisfies the requirements of 10 CFR 71.43(c) for positive closure.

2.4 Lifting and Tie-Down Standards for All Packages

2.4.1 Lifting Devices

The lifting evaluation was completed in the SER accompanying Revision No. 0 of this certificate of compliance. All margins were acceptable; therefore, the staff finds that the requirements of 10 CFR 71.41(a) are satisfied.

2.4.2 Tie-Down Devices

The tie-down evaluation was completed in the SER accompanying Revision No. 0 of this certificate of compliance. All margins were acceptable; therefore, the staff finds that the requirements of 10 CFR 71.45(b) are satisfied.

2.5 Normal Conditions of Transport

2.5.1 Heat

According to the applicant, the primary concerns of normal conditions of transport under hot conditions are thermal stresses due to the applied temperatures distribution, stresses due to the resulting internal pressure and the potential interferences from differential thermal expansion.

2.5.1.1 Summary of Pressures and Temperatures

The applicant addressed the effects of temperatures and stresses due to the cargo decay heat and solar insulation in Section 2.6.1 of the A1G SAR. Table 2.6-1 of the SAR provides the design temperatures of the M-290 package components from the core-independent SAR and the calculated temperatures of these components when loaded with A1G spent fuel under hot conditions. Table 2.6-2 provides the A1G internals and cargo peak design temperatures and calculated temperatures. Table 2.6-3 of the SAR provides the M-290 peak volume average design temperatures based on volumetric averages of components within the M-290 thermal model as well as the calculated temperatures when loaded with the A1G spent fuel. Table 2.6-4 of the SAR provides the maximum allowable temperature differences for various regions of the M-290 transportation package along with the calculated worst-case temperature difference when loaded with the A1G spent fuel. In addition, the applicant reported that the maximum peak internal pressure for the package is 40 psig.

In all cases, the calculated temperatures and temperature differences are less than the design temperatures and temperature differences; therefore, the staff finds these acceptable.

2.5.1.2 Differential Thermal Expansion

The applicant performed a thermal expansion and contraction evaluation of the A1G internal components in Appendix 2.12.2 of the A1G SAR. The analysis considered the stack-up of components and associated component temperatures for normal hot, cold, and transient conditions. The applicant also evaluated the fastener preloads accounting for the effects of differential thermal expansion and contraction. Table 2.6-5 of the A1G SAR summarizes the clearance/interface state between components as well as the limiting thermal condition. In most cases, clearance was maintained between A1G components. Where interference existed, the applicant evaluated the associated stress due to thermal expansion or contraction.

The applicant compared the M-290 design temperature differences with the worst case A1G temperature differences in Table 2.6-4 of the A1G SAR. Because the M-290 values bound the A1G values, the applicant determined that the analysis performed in the M-290 core-independent SAR remains bounding and that no unacceptable interference occurs under the normal conditions of transport hot conditions for the core-independent M-290 components.

The applicant also evaluated the acceptability of fastener preloads (accounting for the effects of differential thermal expansion) and canister closure system hardware.

2.5.1.3 Stress Calculations

The applicant performed stress calculations for normal conditions of transport hot conditions for the all of the A1G internal components in Appendix 2.12.2 of the SAR. The stress calculations combined the effects of fastener preload (including the changes in preload due to differential thermal expansion), internal pressure, differential thermal expansion, vibration and shock loading.

2.5.1.4 Comparison with Allowable Stresses

The applicant summarized the calculated combined stress values along with the allowable stress limits and the condition under which the maximum stress occurred for all components in Table 2.6-7 of the SAR. For the bounding hot conditions, the calculated stresses were less than the allowable stresses for all but the assembly tie rod. In this case, the applicant stated that the plastic strain that may be caused by exceeding the maximum allowed stress under hot conditions could result in a relaxation of the preload. Because the tie rods are not relied upon for transportation safety, the applicant stated that the reduction in preload in this joint is acceptable.

The staff reviewed the applicant’s evaluation of the package under hot normal conditions of transport and finds that the hot conditions of 10 CFR 71.71(b)(1) do not substantially reduce the effectiveness of the A1G-configured M-290 transportation package.

2.5.2 Cold

According to the applicant, the primary concern of the cold test for normal conditions of transport are the potential interferences due to differential thermal contraction, the potential for brittle fracture, and the effects of freezing of the limited water remaining within the package after draining.

2.5.2.1 Summary of Pressures and Temperatures

The applicant addressed the effects of temperatures and stresses due to the decay heat of the contents both with and without solar insolation in Section 2.6.1 of the A1G SAR. The applicant stated that at a reduced ambient temperature, the package temperatures and internal pressure are reduced. With the package at higher temperatures, the material strengths are reduced resulting in the hot conditions producing the limiting margin for the majority of the stresses summarized in Section 2.6.1 of the A1G SAR. The applicant identified the limiting stresses in terms of margin to the applicable stress limit regardless of temperature conditions in Table 2.6-7 of the A1G SAR.

2.5.2.2 Differential Thermal Contraction

The applicant performed a thermal expansion and contraction evaluation of the A1G internal components in Appendix 2.12.2 of the SAR. Since the calculations for differential thermal expansion and contraction utilize the same equations and assumptions, the applicant evaluated expansion and contraction and reported only the bounding conditions in the SAR. The staff discussed the combined expansion and contraction evaluations in Section 2.5.1.1 of this SER.

2.5.2.3 Stress Calculations

The applicant performed stress calculations for normal conditions of transport cold conditions for all of the A1G internal components in Appendix 2.12.2 of the SAR. The stress calculations combined the effects of fastener preload (including the changes in preload due to differential thermal expansion), internal pressure, differential thermal expansion, vibration and shock loading.

2.5.2.4 Comparison with Allowable Stresses

The applicant summarized the calculated combined stress values along with the allowable stress limits and the condition under which the maximum stress occurred for all components in Table 2.6-7 of the SAR. For the bounding cold conditions, the calculated stresses were less than the allowable stresses for all but the lead screw protector and lead screw protector insert. In this case, the applicant stated that a stress concentration factor of 2 was applied to the stress calculation because the axial length of the lead screw protector is smaller than the insert in the region of the interference fit. The applicant asserted that this resulted in high calculated stresses in the region near the edge of the interference fit of the components and were not representative of the stresses throughout the entire interference fit. When the applicant removed the concentration factor of 2, the combined stresses fell below the yield strength of the lead screw protector material. While some yielding at the edge of the interference fit may occur, the stresses in the majority of the interference fit were below the component yield strengths, and the applicant determined that this was acceptable.

The staff reviewed the results of the applicant's analysis of the normal conditions of transport cold conditions. All but one of the bounding conditions resulted in stresses less than the acceptance criteria. In the one case where the calculated stress exceeded the allowable stress, the applicant demonstrated that the high stress was localized and was not representative of the stress throughout the cross section of the component and that any yielding of the material in this region had no substantial impact on the structural performance of the component. Because of this, the staff finds that the cold conditions of 10 CFR 71.71(c)(2) do not substantially reduce the effectiveness of the A1G-configured M-290 transportation package.

2.5.2.5 Brittle Fracture

The applicant stated that brittle fracture was evaluated by categorizing materials as potentially subject to brittle fracture or not subject to brittle fracture. The applicant evaluated the A1G spent fuel materials (and components) that were classified as potentially subject to brittle fracture. For those components, the applicant's assessments demonstrate either brittle fracture will not occur or the consequences of failure due to brittle fracture are acceptable and accounted for in the evaluations for conditions of normal conditions of transport and hypothetical accident conditions.

The staff notes that the A1G fuel cluster was evaluated for zirconium hydrides, maximum fuel cluster hydrogen content at end of life and found to be below the amount considered detrimental. The staff finds A1G spent fuel modules are designed and fabricated from high quality materials designated by industry or military specifications. Extensive materials data characterization, including temperature dependence of physical properties provides reasonable assurance the A1G spent fuel is acceptable for transport, because the susceptibility of brittle fracture is low, and that A1G spent fuel and similar materials have been transported without failure for decades.

2.5.2.6 Freezing of Residual or Accumulated Water

The applicant stated, in the M-290 SAR, that the M-290 transportation package may contain up to 8 gallons of residual water. The M-290 SAR demonstrated that with the M-290 positioned on the railcar, this water will tend to remain near the bottom of the canister where freezing will not have an effect on the closure seals. In the A1G SAR, the applicant stated that the maximum amount of residual water in the M-290 package loaded with A1G spent fuel is less than that specified in the M-290 SAR. Additionally, the applicant asserted that the sealed closure head in the A1G internals protects against water reaching the containment closure head.

The staff reviewed the applicant's calculation of residual water in the A1G-configured M-290 package in Appendix 2.12.2.9.1 of the A1G SAR. Because the amount of residual water in the M-290 package loaded with A1G spent fuel is less than that analyzed in the M-290 SAR, and because the sealed closure head will prevent water from reaching the containment closure seals, the staff finds that the A1G-configured M-290 transportation package containment seals will not be affected by the potential for freezing residual water in the package.

2.5.3 Reduced External Pressure

The applicant stated that the M-290 SAR demonstrated that the M-290 containment boundary remained sealed under reduced external pressure and that no further evaluation was necessary for the M-290 loaded with A1G spent fuel.

The staff reviewed the M-290 SAR and corresponding SER and concludes that the reduced external pressure conditions of 10 CFR 71.71(c)(3) do not substantially reduce the effectiveness of the A1G-configured M-290 transportation package.

2.5.4 Increased External Pressure

The applicant stated that the M-290 core independent SAR demonstrated that the M-290 containment boundary remained sealed under increased external pressure and that no further evaluation was necessary for the M-290 loaded with A1G spent fuel.

The staff reviewed the M-290 SAR and the SER accompanying Revision No. 0 of this certificate of compliance and concludes that the increased external pressure conditions of 10 CFR 71.71(c)(4) do not substantially reduce the effectiveness of the A1G-configured M-290 transportation package.

2.5.5 Vibration and Fatigue

2.5.5.1 Vibration

The applicant summarized the vibration and shock loads in Table 2.12.2.10-1 of the A1G SAR. The applicant stated that vibration of the M-290 transportation packaging, A1G internals and cargo is driven by vibration of the M-290 railcar during transportation. The applicant performed analysis to evaluate the effects of vibration on individual parts, assemblies, and fastened connections within the package and contents including analysis of natural frequencies of components, the potential for resonant amplification and the resulting induced stresses. The applicant's analyses indicated that most of the relevant A1G, internals and cargo components were unaffected by resonant amplification. Where vibration amplification occurred, the applicant determined the transmissibility of the component and applied this to the vibration stress calculation. The applicant combined the stresses due to vibration and shock with the stresses from other normal conditions of transport loads to determine the combined stress in each internal component as evaluated in Sections 2.5.1 and 2.5.2 of this SER. The applicant also evaluated joints to determine if separation occurred between the clamped members of the joints due to the vibratory loads.

The applicant tested the fuel assemblies for susceptibility to vibratory loads for in-plant shipboard conditions using an Advanced Test Module (ATC) in accordance with Military Standard No. MIL-STD-167, "Mechanical Vibrations of Shipboard Equipment". The ATC is a mock up cell that is similar to the actual cell but with no fuel or poison. The applicant stated that the differences between the in-plant fuel assembly and the as-shipped fuel assembly cause the as-shipped assembly to have a higher stiffness and natural frequency. The A1G ATC passed all post-test inspections with no functional impairment. Because the testing in accordance with MIL-STD-167 bounds the M-290 vibration environment, and because the as-shipped fuel assembly is stiffer than the in-plant assembly, the applicant concluded that the A1G fuel cells will not be affected by vibratory loads under normal conditions of transport.

The applicant conducted shock testing of the A1G ATC in accordance with Military Specification MIL-S-901, for shock. This shock test measured accelerations from 4 g's to 38 g's, which is equal to or greater than the normal conditions of transport shock environment. The applicant stated that post-testing inspections revealed no significant or adverse effects, and therefore no structural degradation.

The staff reviewed the vibration and shock calculations in Appendix 2.12.2.10 of the A1G SAR and finds that no potential for resonance occurs in the A1G components and that no joint separation occurs between clamped joints as a result of vibration loads due to normal conditions of transport. The staff further finds that the in-plant A1G fuel assembly bounds that of the as-shipped fuel assembly (lower tolerance to shock and vibration) and that the testing standards of MIL-STD-1607 and MIL-S-901 bounds that of the normal conditions of transport environment, therefore, there is reasonable assurance that the fuel cladding will not be structurally degraded due to transportation shock and vibration and will continue to maintain primary containment. Additionally, the staff previously determined the acceptance of the stresses due to vibration and shock loads in Sections 2.5.1 and 2.5.2 of this SER. Because of this, the staff concludes that the structural performance of the A1G-configured M-290 transportation package is adequate under the vibratory normal conditions of transport loads.

2.5.5.2 Fatigue

According to the applicant, fatigue in the A1G-configured M-290 transportation package could be driven by a number of phenomena including tensioning/detensioning, vibration, and thermal cycling. The applicant evaluated individual components by means of a cumulative fatigue usage factor. The applicant lists the calculated fatigue usage factors for all A1G components for vibration, thermal, and tensioning/detensioning cycles as well as the cumulative fatigue usage factors in Table 2.6-11 of the A1G SAR.

The fatigue usage factor is basically the predicted number of cycles that a component is expected to endure over its life divided by the allowed number of cycles at the calculated level of stress for that component. A cumulative fatigue usage factor less than 1.0 indicates that fatigue will not influence the structural performance of the component. In Table 2.6-11 of the A1G SAR, all cumulative fatigue usage factors for the A1G internal components are less than 1.0; therefore, the staff determines that fatigue under normal conditions of transport loads will not substantially reduced the effectiveness of the A1G-configured M-290 transportation package.

Additionally, the vibration testing of MIL-STD-167 included endurance testing; therefore, the staff finds that the structural performance of the A1G fuel assemblies is also adequate for fatigue under normal conditions of transport loads.

2.5.6 Water Spray

Because the M-290 is a large shipping package, in accordance with Regulatory Guide 7.8, the staff finds that the water spray test of 10 CFR 71.71(c)(6) has no significance in the structural design of the A1G-configured M-290 transportation package.

2.5.7 Free Drop

The applicant stated that the M-290 transportation package was evaluated for a 1-ft drop on the bottom end and side orientations under hot and cold conditions in the M-290 SAR. The results and relative margins of safety (comparisons to deformation and strain limits) are presented and discussed in Section 2.6.7 of the M-290 SAR. The applicant asserted that, in general, the results show minimal damage to the package components and does not affect the containment boundary. The applicant used the methodology described in Section 2.1.5 of this SER to evaluate the components of the A1G-configured M-290. The applicant listed the calculated peak true plastic strain in the primary components of the A1G internal components and the A1G reactor cell assembly resulting from the 1-foot drop as well as the strain limits for each of the components in Tables 2.12.2.7-2 thru 2.12.2.7-6 of the SAR. The applicant reported that all strains were less than the strain limit for the internal assemblies. The peak plastic strain for the lower cell support housing of the A1G fuel assembly exceeded the strain limit; however, the applicant concluded that failure will not occur, because the strain is due to bearing and is localized.

The applicant asserted that the decelerations due to the 1-foot drop were less than those of the 30-foot drop. As a result, any rearrangement of the A1G fuel modules or control rod withdrawal resulting from the 1-ft drop are bounded by the limiting configurations resulting from the hypothetical accident conditions, which were shown to be acceptable.

Because the excessive strain in the lower cell support housing is localized, and because the strain in the rest of the component is well below the strain limit, the staff finds that the failure of the lower cell support housing will not occur. Additionally, because no significant fuel rearrangement occurs as a result of the hypothetical accident conditions scenario (see SER Section 2.6, below), the staff concludes that a subcritical arrangement will be maintained for the 1-ft drop and that the geometric form of the package contents will not be substantially altered.

Based on a results of the applicant's analysis, the staff has reasonable assurance to conclude that the free drop test of 10 CFR 71.73(c)(1) will not diminish the effectiveness of the A1G-configured M-290 transportation package.

2.5.8 Corner Drop

Because the A1G-configured M-290 transportation package is a large shipping package, in accordance with Regulatory Guide 7.8, the staff finds that the corner drop test of 10 CFR 71.71(c)(8) is not applicable and will not substantially reduce the effectiveness of the package.

2.5.9 Compression

Because the A1G-configured M-290 transportation package weighs more than 11,000 lbs, the staff finds that the compression test of 10 CFR 71.71(c)(9) is not applicable.

2.5.10 Penetration

The applicant analyzed the performance of the package for the penetration test in the M-290 SAR, which consisted of dropping a 13 lb steel bar, 1.25 inches in diameter from a height of 40 inches onto the package. The reported damage to the outer package and upper dome was minimal and was evaluated in the combined M-290 SAR. The damage was not sufficient in size to challenge the functional characteristics of the package; however, the shielding calculations for the M-290 take this dent into account.

The staff reviewed the M-90 SAR and the associated SER and finds that the penetration test of 10 CFR 71.71(c)(10) will not diminish the effectiveness of the A1G-configured M-290 transportation package.

The staff reviewed the structural performance of the packaging under the normal conditions of transport proscribed in 10 CFR 71.71 and concludes that there will be no substantial reduction in the effectiveness of the packaging that would prevent it from satisfying the requirements of 10 CFR 71.51(a)(1) for a type B package and 10 CFR 71.55(d)(2) for a fissile material package.

2.6 Hypothetical Accident Conditions

2.6.1 Free Drop

The applicant used the 10 finite element models described above in Section 2.1.5 of this SER to evaluate the A1G-configured M-290 for the free drop event in the sequence of tests for the hypothetical accident conditions. To determine the worst case result for each of the key features or components under consideration, the applicant evaluated the A1G internals and cargo for a flat top drop, flat bottom drop, side drop, bottom corner drop, top corner drop, top slapdown drop (top impacts first, followed by the bottom at a higher velocity), and a bottom slapdown drop. The applicant performed specific evaluations for the closure system response;

the internals retaining ring response; the internals response; the DGA, RHD and pedestal assembly response; the A1G cell assembly response; and the A1G cluster response.

The applicant identified that brittle fracture of the lead screw and tie rod is possible during a drop accident if a defect of sufficient size were present at a region of high stress in the lead screw. If this happens, control rod withdrawal is limited by the remaining portions of the lead screw, or the RHD. To conservatively bound the movement of the control rod without an RHD, the applicant assumed that the lead screw fractures into four equal length pieces. The applicant's basis for this assumption is that no more than four pieces of the lead screw can fit within the inner diameter of the scram spring, and maximum withdrawal is achieved when the four pieces are of equal length. The applicant calculated the control rod withdrawal as a result of brittle fracture of the lead screw in Appendix 2.12.27 of the SAR for an A1G fuel module both with and without an RHD installed.

The applicant summarized the results of the 30-foot drop in Section 2.7.1.8 of the SAR. In general, the applicant reported that the A1G spent fuel is confined within the M-290 cargo area during all drop accidents. Most of the components remained elastic with some portions undergoing local plastic strain that remained below the strain limit. For those components (including fasteners) that experienced plastic strain above the limit, the applicant used material damage models to determine their structural acceptability.

The applicant assumed the lead screw and tie rods fail during the free drop, but control rod withdrawal was limited by the remaining portions of the lead screw or RHD when installed. The control rod remained intact with some material damage in the hafnium region, but the applicant concluded that this is not significant for structural, shielding or criticality safety performance of the package. Additionally, the applicant reported that no fuel damage or cladding breach occurred and that the A1G fuel cluster remained intact with no potential for separation or rearrangement of the fuel.

The staff reviewed the finite element analysis and supplemental hand calculations in the appendices of Chapter 2 of the SAR as well as the applicant's conclusions with respect to the structural response of the A1G-configured M-290 transportation package. Based on the applicant's design criteria, the staff has reasonable assurance to conclude that the free drop test of 10 CFR 71.73(c)(1) will not diminish the structural performance of the M-290, A1G contents. With respect to the lead screw failure, the staff finds that the assumed control rod withdrawal is conservative. See Chapter 6 of this SER for the criticality evaluation as a result of the lead screw failure.

2.6.2 Crush

Because the weight of the A1G-configured M-290 transportation package is greater than 1100 lbs, the staff determines that the crush test proscribed by 10 CFR 71.73(b)(2) is not applicable.

2.6.3 Puncture

The applicant evaluated the package for a 40-inch puncture drop utilizing closed form calculations and finite element analysis and reported local denting of the M-290. The closed form calculations in the M-290 SAR demonstrated that the package exterior does not tear thereby breaching the containment boundary. In Appendix 2.12.10 of the A1G SAR, the applicant evaluated the effects of the puncture on the A1G internals and cargo. The applicant stated that the potential local reduction in package diameter produced some interference in the non-fuel region of the internals, but the performance of the affected components was acceptable. The local reduction in package diameter did not produce any interference within the fuel-bearing regions of the A1G cargo; therefore, the applicant concluded that there was no potential for fuel damage due to deformation.

Based on a review of the applicants analysis in Appendix 2.12.10 of the A1G SAR, as well as the M-290 SAR and the SER accompanying Revision No. 0 of this certificate of compliance, the staff has reasonable assurance to conclude that the puncture test of 10 CFR 71.73(c)(3) will not diminish the structural performance of the A1G-configured M-290 transportation package.

2.6.4 Thermal

The applicant used a combination of closed-form calculations and finite element analysis to determine the structural response (thermal stresses, differential thermal expansion, and stresses due to pressure differentials) of the packaging and contents due to the fire test temperatures of 10 CFR 71.73 (c)(4). In Appendix 2.12.2.13, the applicant demonstrated that, with few exceptions, the A1G internals and cargo have no plastic deformation resulting from the fire test conditions. Additionally, the A1G internals and cargo did not interfere with the M-290 core-independent hardware as a result of the fire test temperatures and had no effect on the M-290 containment boundary.

2.6.4.1 Summary of Pressures and Temperatures

The applicant summarized the temperatures of the components of the M-290 package associated with the hypothetical accident conditions fire test in Table 2.7-2 of the A1G SAR. Tables 2.7-3 through 2.7-5 of the A1G SAR summarize the A1G-configured M-290 peak temperatures due to the fire test, the peak accident component temperatures, the peak volume average temperatures and the allowable temperature differences during the fire test. The applicant used these temperatures for the thermal-structural evaluations that were based primarily on temperature distributions and differences. Using the peak fire temperatures in Tables 2.7-3 and 2.7-4, the applicant demonstrated that the internal pressure is bounding for the maximum fire internal pressure of the A1G assembly and was used for all applicable stress calculations.

2.6.4.2 Differential Thermal Expansion

The applicant evaluated the effects of differential thermal expansion for individual package components based on the temperature values presented in Table 2.7-2 of the A1G SAR. The results indicated that there were some individual cases where mechanical interference occurred but subsequent evaluations demonstrated that the interference was sufficiently small as to not result in component or functional failures. Additionally, the applicant determined that the cap screws for the internals retaining ring, the DGA and the RHD will expand more than the clamped members, which will reduce the preload and result in joint separation. The applicant assessed that this reduction in preload did not affect the safety of the package.

2.6.4.3 Stress Calculations

The applicant used a combination of closed form and finite element analysis to determine the combined stresses due to thermal expansion.

2.6.4.4 Comparison with Allowable Stresses

The applicant reported the stress results and comparison with allowable stresses in Appendix 2.12.2.13 of the A1G SAR. The applicant determined that the bearing stress between the access port bolting flange small fasteners and the access port bolting flange exceeded the yield strength of the material of the flange, but remained below the ultimate strength. The applicant further stated that this would cause local material coining, strain hardening and relaxation of the joint preload, but the that large fasteners provided sufficient clamping force to preclude movement of the access port bolting flange; therefore, local yielding under the small fasteners was acceptable. All other calculated stresses were less than the yield strength of the respective material.

The staff reviewed the applicant's evaluation of the package under the thermal test in 10 CFR 71.73(c)(4) and finds that the thermal test conditions do not substantially reduce the effectiveness of the A1G-configured M-290 transportation package.

2.6.5 Immersion – Fissile

In Chapter 6 of the A1G SAR, the applicant determined that the A1G-configured M-290 transportation package remains subcritical under the conservative assumption of an optimally moderated package along with bounding contents and control rod translation; therefore, the staff finds that water exclusion is not necessary to meet criticality requirements and the test of 10 CFR 71.73(c)(5) has no relevance.

2.6.6 Immersion – All packages

The applicant demonstrated that the deep immersion evaluation bounds this required evaluation of 10 CFR 71.73(c)(6); therefore, the staff concludes that this test requirement is satisfied.

The staff has reviewed the structural performance of the packaging under the hypothetical accident conditions proscribed in 10 CFR 71.73 and concludes that the packaging has adequate structural integrity to satisfy the subcriticality, containment, and shielding requirements of 10 CFR 71.51(a)(2) for a type B package and10 CFR 71.55(e) for a fissile material package.

2.7 Special Requirements for Type B Packages Containing More than 10^5 A_2

2.7.1 Deep Immersion

The applicant evaluated the M-290 transportation package for deep immersion in the M-290 SAR. The applicant demonstrated that there were no adverse effects including collapse or buckling due to the applied 290 psig pressure. Furthermore, the applicant demonstrated that the package and all relevant containment boundary elements remained elastic and water tight for this evaluation.

The staff reviewed the packaging structural performance of the M-290 in the M-290 SAR under an external pressure of 290 psi for not less than 1 hour, as well as the SER accompanying Revision No. 0 of this certificate of compliance, and finds that package does not buckle, collapse or allow the in leakage of water and therefore satisfies the requirements of 10 CFR 71.61.

2.8 Evaluation Findings

Based on review of the statements and representations in the application, the NRC staff concludes that the structural design has been adequately described and evaluated and that the A1G-configured M-290 transportation package has adequate structural integrity to meet the requirements of 10 CFR Part 71. In addition, the staff finds that the M-290 transportation package containing A1G spent fuel meets the regulatory requirements of 10 CFR Part 71 for normal conditions of transport and hypothetical accident conditions temperatures, for mitigating galvanic or chemical reactions, and is constructed with materials and processes in accordance with acceptable industry codes and standards.

3.0 THERMAL EVALUATION

The applicant requested an amendment to the certificate for the M-290 package for the inclusion of A1G spent nuclear fuel.

3.1 Description of Thermal Design

Section 3.1 of the application provides a description of the thermal design of the M-290 by referencing specific sections of the M-290 SAR. The A1G spent fuel is evaluated in the application; heat is transferred from the fuel through the inner materials by conduction and radiation to the outer circumference, and then to ambient by convection and radiation. The components and geometries of the A1G internals assembly are described in Section 3.1.1.2.1 of the application and detailed figures of the components are provided. The components and geometries of the A1G spent fuel module are described in Section 3.1.1.2.2 of the application and detailed figures of the components are provided. Section 3.1.1.2.2.3.1 of the application describes the detailed and simplified A1G spent fuel modules that are included in the thermal model; figures and justification are also provided in the application to demonstrate that the simplified modules do not adversely affect the component temperatures. The staff reviewed Section 3.1 of the application and finds that the discussion of the thermal design satisfies the thermal requirements of 10 CFR Part 71.

3.1.1 Content Decay Heat

Section 3.1.2 of the application described that the decay heat used in the thermal analysis is conservatively higher than the decay heat for each A1G module at the time of loading. Section 3.1.2 of the application also described adjustments in the design power history used in the generation of the decay heat, as well as factors to account for uncertainties in the prediction of the decay heat which are applied to all cells. In addition, a safety factor is applied to fission product decay heat calculations using the ANS/ANSI 1994, “Decay Heat Power in Light Water Reactors.” The staff reviewed Section 3.1.2 of the application and finds that the discussion on the maximum decay heat satisfies the thermal requirements of 10 CFR Part 71.

3.1.2 Maximum Temperatures

Tables 3.3-1 and 3.3-2 of the application show that component temperatures are lower than their design temperatures during normal conditions of transport. Tables 3.4-1 and 3.4-2 of the application show that the O-ring does not exceed its continuous use temperature limit during hypothetical accident conditions. The calculated peak fuel temperatures during normal conditions of transport and hypothetical accident conditions produce no fuel damage that would compromise the fuel cladding and there is no concern with fuel usage or blistering.

3.1.3 Maximum Pressures

Section 2.12.2.1 of Appendix 2.12.2 of the application shows that all pressures in the M-290 containing A1G are within the bounds of the core independent M-290 SAR.

3.2 Material Properties and Component Specifications

Thermal material properties (conductivity, density, specific heat, and emissivity) are referenced from the M-290 SAR. The thermal conductivities for the A1G fuel and poison plate were provided in Section 3.2 of the application. Materials of construction for all A1G M-290 components and detailed material properties are provided in Section 2.2 of the application. The application references Appendix 3.5.2 of the M-290 SAR for a discussion of fuel blistering and usage calculations.

3.3 Normal Conditions of Transport

The A1G configuration is evaluated using a 3D, 360-degree Abaqus thermal model. The application describes the application of the decay heat and types of heat transfer between components. The ambient temperature is 100°F and the application of solar insolation is described in Section 3.3.0.1 of the application. The comparison of component temperatures to their design values is described in Section 3.3.1.1 of the application and shown in Tables 3.3-1 and 3.3-2 of the application; all component temperatures for the M-290 and A1G internals are below their applicable design limits. Section 3.3.1.2 of the application describes that the package accessible surface temperature is below 185°F for an exclusive use shipment and therefore meets 10 CFR 71.43(g).

Section 2.12.2.1 of Appendix 2.12.2 of the application identifies that based on the less-limiting temperatures, the normal conditions of transport pressure of the A1G spent fuel loaded in the M-290 package is bounded by the normal conditions of transport design pressure in the M-290 SAR. Section 2.4.4.2 of the application concludes based on the analysis in Appendix 2.12.28 of the application that the hydrogen concentration will remain below 5 percent for the time that the M-290 containing A1G spent fuel is sealed; in addition there is a loading restriction to ensure the package is not sealed for a time greater than a specific time period.

Section 3.3.3.1 of the application shows that if the design fuel temperature limit is conservatively assumed to remain constant for 1 year, the cumulative usage shows that there will be no fuel blistering and that infinite dry time is met at a specific value of days after shutdown. In addition, two sensitivity studies described in Section 3.3.3.2 of the application show the calculated increases in peak fuel and peak spacer plate temperatures are accommodated by the margins between the baseline calculated temperatures and the design values.

Section 2.6.1 of the M-290 SAR summarizes the stresses, including the thermal stresses, under normal conditions of transport and demonstrates that all applicable structural limits are met and the secondary containment boundary which includes the seal formed by the containment cover O-rings is not compromised as a result of the temperatures. The thermal stresses for the A1G M-290 closure head, internals, and A1G contents are evaluated in Section 2.6, and Appendices 2.12.2 and 2.12.11 of the application.

The staff reviewed the analysis modeling approach for the normal conditions of transport evaluation and finds that the thermal analysis demonstrated that component temperature limits were not exceeded for the limiting decay heat for the A1G contents during normal conditions of transport consistent with the tests specified in 10 CFR 71.71.

3.4 Hypothetical Accident Conditions

For hypothetical accident conditions the applicant evaluated the M-290 with A1G fuel, in a 30 minute, 1475°F fire with no solar insolation. The initial conditions for the hypothetical accident conditions is normal conditions of transport temperatures at 100°F ambient with solar insolation; solar insolation is also applied during the post-fire cooldown. These described conditions meet 10 CFR 71.73(c)(4). The analyses of the fire accident used the same model as the normal conditions analyses with the top dome replaced with the deformed version. The deformed version of the top dome is described in Section 3.4.2.3 of the M-290 SAR.

Section 2.12.2.1 of Appendix 2.12.2 of the application identifies that based on the less-limiting temperatures the hypothetical accident conditions fire, the internal pressure of the A1G spent fuel loaded in the M-290 package is bounded by the M-290 hypothetical accident conditions pressure.

Tables 3.4-1 and 3.4-2 of the application show the maximum hypothetical accident conditions temperatures of the M-290 A1G internals, A1G Cargo, and M-290. Section 3.4.3.1 of the application shows that the O-rings are below their continuous use temperature limit. Section 3.4.6.1 of the application shows that the fuel temperature will not result in blistering; the usage during the fire accident is determined using the same methodology described in Section 3.3.3.1 of the application. Post-fire steady-state maximum temperatures can be affected by a deformed top dome, fuel movement, spacer plate separation, package wall deformation from puncture, missing top dome attachment pins, and fin crush which are discussed in Sections 3.4.3.2.1 through 3.4.3.2.4 of the application, or in Section 3.4.2.3 of the M-290 SAR. The hypothetical accident conditions peak fuel temperature takes into account increases due to puncture dent, fuel movement, internal plate separation, and additional margin. The structural damage that the M-290 package experiences during the hypothetical accident conditions test sequence (drop(s), puncture(s), fire) is described in Section 2.7 of the M-290 SAR and shows no predicted breach of containment for the M-290 package or containment cover. The structural damage that the A1G M-290 closure head, internals, and A1G spent fuel experiences during the hypothetical accident conditions accident sequence is described in Section 2.7 of the application. In summary, no damage or breach of any A1G fuel cladding is predicted from the thermal effects from decay heat, insolation, or fire, or appropriate combination of events.

Section 2.7.4 of the M-290 SAR summarizes the stresses, including the thermal stresses, under hypothetical accident conditions and demonstrates that all applicable structural limits are met, the secondary containment boundary which includes the seal formed by the containment cover O-rings, is not compromised as a result of the temperatures. The thermal stresses for the A1G M-290 closure head, internals, and A1G cargo are evaluated in Section 2.7, and Appendices 2.12.2 and 2.12.11 of the application.

The staff reviewed the analysis modeling approach for the hypothetical accident conditions evaluation and the temperature limits prescribed by the applicant for the performance of the contents, and finds that the limits were not exceeded for the hypothetical accident conditions fire exposure and the hypothetical accident conditions are consistent with the tests specified in 10 CFR 71.73.

3.5 Appendices

Appendices in Chapter 3 of the application were provided that discussed the computer analysis codes used for the thermal analyses, and the component temperature changes when the ambient conditions abruptly change from normal conditions of transport temperature for the heat test to -40°F.

3.6 Conclusions

Based on its review of the statements and representations in the application, the staff concludes that the thermal design has been adequately described and evaluated, and that the thermal performance of the package meets the thermal requirements of 10 CFR Part 71 for the A1G spent fuel.

4.0 CONTAINMENT EVALUATION

The applicant requested an amendment to the certificate for the M-290 package for the inclusion of A1G spent nuclear fuel.

Section 4.1 of the application demonstrated that the analyses and conclusions of the M-290 SAR are applicable or bounding for the shipment of A1G spent fuel in the M-290. Chapter 2 normal conditions of transport and hypothetical accident condition structural evaluations do not predict failure of the primary containment boundary. Chapter 3 of application does not predict temperatures that would result in degradation of the primary containment boundary. Table 4-1 of the application provides key containment parameters of the M-290 SAR and the A1G SAR values. Table 4-1 of the application shows that the A1G values are equivalent or less limiting than the M-290 SAR values. Therefore the conclusion from the M-290 SAR that the M-290 transportation package meets all 10 CFR Part 71 release limits under normal conditions of transport and hypothetical accident conditions remains valid for the shipment of the A1G spent fuel in the M-290.

The leakage rate testing and acceptance criterion of the secondary containment boundary described in the M-290 SAR remain applicable for the shipment of the A1G spent fuel in the M-290.

The A1G closure head assembly establishes an operational containment boundary between the cargo and the upper portion of the M-290 package interior. Although the A1G closure head assembly is not part of the primary or secondary containment boundary, leakage rate testing of the A1G closure head assembly is described in Section 8.1.4 of the application.

4.1 Conclusions

Based on its review of the statements and representations in the application, the staff concludes that the containment design has been adequately described and evaluated and that the package design meets the containment requirements of 10 CFR Part 71 for the M-290 containing A1G spent fuel.

5.0 SHIELDING EVALUATION

5.1 Review Objective

The objective of this review is to verify that the shielding design of the M-290 radioactive material transportation package meets the regulatory dose rate limits as prescribed in 10 CFR 71.47 and 10 CFR 71.51 from radiation directly coming from the contents of the package. The following sections of this SER documents the staff's evaluation of the shielding design of this package. The staff followed the guidance provided in NUREG-1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel" (the SRP thereafter) in performing its safety evaluation of this package shielding design.

5.2 Package Shielding Design Features

The M-290 package is designed to transport spent naval reactor fuel and associated non-fuel hardware. The packaging system consists of a cylindrical stainless steel shell, an aluminum alloy fuel basket, and a bottom and top plate to form the many body of the cask. The packaging system include closure lid components to form the containment boundary and support the structural functions of the package under normal conditions of transport and hypothetical accident conditions as prescribed in 10 CFR 71.71 and 10 CFR 71.73. The package includes two large stainless steel dome shape impact limiters as sacrificial devices to absorb impacts under normal conditions of transport and hypothetical accident conditions to protect the contents.

The applicant provided a summary table for the dose rates of the package under normal conditions of transport and hypothetical accident conditions in the SAR. The applicant also provides graphical figure to show the distributions of the calculated dose rates around the surface and at 2 meters from the surface of the package. The maximum calculated dose rates are 33.08 mrem/hr on the surface and 6.61 mrem/hr at 2 meters from the surface of the package under normal conditions of transport. For the package under hypothetical accident conditions, the maximum dose rate at 1 meter from the surface of the package is 717 mrem/hr. The maximum dose rate in the normally occupied space is 0.594 mrem/hr. The calculated dose rates demonstrate that the shielding design of the package meets the requirements of 10 CFR 71.47 and 10 CFR 71.51.

The package is designed for exclusive use in accordance to the definition of 10 CFR 71.4. In accordance with the regulation of 10 CFR 71.47(b), there is no limit on the transport index for the package.

5.3 Radiation Sources

The radiation sources considered in shielding design include gammas and neutrons from the contents of the package. The gamma sources include gammas emitted from the fission products and actinides produced during irradiation of the fuel, as well as the activated hardware. The neutron sources include spontaneous fission of transuranic materials and fission neutrons produced by subcritical neutron multiplication in the spent fuel.

The applicant determined the gamma and neutron sources from the fuel based on the actual core operation history and assembly depletion data for each fuel assembly with detailed axial and radial neutron flux distribution over time. The applicant determined the gamma sources from the non-fuel hardware also based on the actual core operation history and component exposure data for each component with detailed axial and radial neutron flux distribution over time.

The applicant calculated the neutron and gamma source terms based on an assumed full power continuous operation of the reactor. The applicant assumed that there was no down time and the lower power operation periods are all converted to a full effective power equivalent operation times. This is a significant conservatism in the source term calculations because it neglected the decays of the source in the low power operation and/or down time periods. As a result, the calculated sources are higher than the actual sources.

The applicant also considered the neutron sources from subcriticality multiplication. The applicant adjusted the neutron source from the fuel with the well-known subcriticality neutron population equation $S^* = S/(1-k_{eff})$. Where S^* is the actual neutron source n/cm^3/second, S is the number of neutrons emitted by the fuel per unit weight and per second, and k_{eff} is the neutron multiplication factor of the package, which is determined in criticality safety analysis for this package design.

The staff reviewed the applicant's calculation of the neutron and gamma sources from the spent fuel and non-fuel hardware and determined that the applicant method for calculation of the source terms is reliable and conservative. On this basis, the staff finds that the results are acceptable.

The applicant did not include beta particles as source in the dose rate calculations. The staff finds this acceptable because the packaging system does not use heavy metal shielding materials such as lead. Therefore, there is no concern with the secondary gamma generated by Bremsstrahlung reactions between high energy beta particles and heavy metal.

5.4 Model Specification

The applicant modeled the package under normal conditions of transport as well as hypothetical accident conditions consistent with the damage conditions under the tests prescribed in 10 CFR 71.71 and 10 CFR 71.73, respectively.

Under normal conditions of transport, the applicant modeled the package with source geometry as loaded. For package under hypothetical accident conditions, the applicant analyzed the dose rates at 1 meter from the surface of the damaged package with various scenarios of hypothetical source relocation.

The staff reviewed the applicant's models for the package under normal conditions of transport and hypothetical accident conditions and finds that the applicant's models and assumptions for the sources and shielding structure are conservative and consistent with the damages from the tests prescribed in 10 CFR 71.71 and 10 CFR 71.73. On this basis, the staff finds the applicant's modeling of the package for shielding safety analysis acceptable.

In the shielding models, the applicant used material properties that are consistent with ASME and ASTM standard data. The staff finds this consistent with common practice and therefore acceptable.

The applicant calculated the dose rates at the surface of the package and 2 meters from the surface of the package using the PARTISN code (discussed in the following section of the SER) for neutron and gamma sources separately.

The applicant used a set of flux-to-dose-rate conversion factors for neutron and gamma radiation that are different from the American National Standards Institute/American Nuclear Society, (ANSI/ANS) 6.1.1-1977, "Neutron and Gamma-Ray Flux-to-Dose Conversion Factors," which is recommended by NUREG-1617. The applicant studied the impact by comparing these two sets of factors and determined that the gamma dose rates calculated using the applicant's own flux-to-dose rate conversion factor that is comparable with the ANSI/ANS 6.1.1-1977 standard. To further confirm that the results of the shielding analyses for the M-290 package are conservative, the applicant compared the actual measured results of the dose rates with the calculated results for a package that is very similar to the M-290 design. The results show that the measured maximum dose rates for package under normal conditions of transport is about 35% of the calculated maximum dose rate. This comparison show that the applicant's method and assumptions produce conservative results. Based on this fact, the staff determined that the applicant modeling approach is reliable and conservative and therefore acceptable.

5.5 Computer Code Evaluation

The applicant used a computer code named PARTISN in the shielding analyses of the package for both gamma and neutron sources. PARTISN is a three dimensional, discrete ordinate, $S_{N,}$ transport theory based computer code. This code has been benchmarked against measurement data and the calculated results are also compared to the results of an MCNP model for the package. Although code-to-code comparison cannot be used as a substitute for benchmark experiments, comparing the results with a well-established code provides some additional confidence in the reliability of the code being used. Based on these facts, the staff determined that the PARTISN is adequate and appropriate for use as a shielding design analysis code for the M-290 package.

However, the applicant recognized that the computer code is not implemented to track the secondary particles generated by nuclear reactions, such as an (n, gamma) reaction, when performing the particle transport calculations. To assure the package shielding design calculations are conservative, the applicant used a "Design Assurance Factor" of 1.3 to scale up the calculated dose rates for the package under normal conditions of transport and hypothetical accident conditions. This means that the applicant added 30% safety margin to the calculated dose rates. In addition, the applicant added a 15% uncertainty to the calculated dose rates of the package under normal conditions of transport to account for the uncertainties of the shielding analysis model.

For package under hypothetical accident conditions, the applicant did not use the 15% uncertainty to adjust the calculated dose rate. However, the applicant used $k_{eff} = 0.95$ to calculate the subcriticality multiplication of neutron source and assumed that package is in a dry condition. Because $k_{eff} \leq 0.95$ is the limit for criticality safety of a flooded package, for shielding purposes, which assumes the package is not flooded, this assumption added substantial conservatism in the calculation of the neutron source, which in turn translates into conservatism in the calculated dose rates.

The staff reviewed the applicant's description of the shielding analysis computer code and finds that the neutron transport equation is accurately represented in the code and that the S_N method is a well-established solution method for the Boltzmann equation for uncharged particle transport. On this basis, the staff finds this code is appropriate for the shielding analysis.

The staff also noted that the applicant recognized that the limitation of the code for tracking the secondary particles generated by nuclear reactions when a particle traverses the contents and shielding layers and the Design Assurance Factor as discussed above is sufficient to account for not including the contributions to dose rates from the secondary particles in the shielding analyses. Based on engineering judgment and comparison with the measured dose rates for similar packages, the staff determined that the applicant's strategy to compensate the limitation of the code is sufficient and acceptable.

5.6 Evaluation Finding

The staff reviewed the description of the package design features related to shielding, the source terms for the design basis, fuel and the applicant's dose rate calculations. The staff also reviewed the measured dose rates for a similar package and confirmed that calculated dose rates are conservative with a large safety margin. Based on its review, the staff determined that the methods used in the shielding analyses are consistent with accepted industry practices and standards and the results are reliable. The maximum dose rates for normal conditions of transport and hypothetical accident conditions meet the regulatory limits imposed by the applicant for an exclusive use shipment.

Based on the staff's review of the statements and representations in the application, the staff concludes that the M-290 package design has been adequately described and evaluated. On these bases, the staff finds that with reasonable assurance that the M-290 package meets the shielding performance requirements of 10 CFR Part 71.

6.0 CRITICALITY EVALUATION

The applicant requested an amendment to the certificate of compliance for the M-290 package to add the A1G spent fuel as an allowable content. The objective of this review is to verify that the M-290 shipping container continues to meet the criticality safety requirements of 10 CFR Part 71 under normal conditions of transport and hypothetical accident conditions.

6.1 Description of Criticality Design

The package is designed to transport spent fuel modules and prevent in-leakage of water under normal conditions of transport and hypothetical accident conditions. The package internals maintain spacing between the spent fuel modules to reduce neutron interaction between modules, and the thickness of the M-290 package reduces neutron communication between packages in arrays.

6.2 Fissile Material Contents

The M-290 is designed to contain seven different types of A1G fuel modules in various positions within the package, as well as control rods, with the fuel and poison loadings varying based on module type. All of these fuel and poison configurations are analyzed using the most reactive time in life in core, including conservative reactivity allowances. Based on staff review of the parametric studies performed for the various assembly types, NRC staff confirmed that the applicant used the most reactive A1G fuel module types with the most reactive core in their calculations.

6.3 General Considerations for Criticality Evaluations

The applicant based the construction of the A1G spent fuel models to represent an accurate geometry model, with special importance given to aspects of the model that are important to criticality safety. Material data used in the evaluation include ASME, ASTM, and Naval Nuclear Propulsion Program documents. Calculations are performed using a Monte Carlo neutron transport theory computer program, and the model accurately represents the features of the fuel modules in complete detail, including fuel, poison, cladding, coolant channels, control rods and channels, and the structural material of the modules.

With respect to the potential for lead screw failure, control rod motion was conservatively overestimated by a significant degree to provide an additional margin of safety compared to the baseline withdrawal model. Withdrawal to such a degree is very unlikely and was conservatively bounded by the applicant's analysis.

The applicant demonstrated the maximum reactivity of the M-290 by evaluating various sensitivities and assumptions for the single package evaluation under flooding conditions, a single package under normal conditions of transport, a single package under hypothetical accident conditions, and packages in arrays under both normal conditions of transport and hypothetical accident conditions. Based on the application, the criticality safety index (CSI) was calculated for a close packed infinite array of loaded M-290 packages would yield a CSI of 0 in accordance with 10 CFR 71.59(a)(1) and 10 CFR 71.59(a)(2).

6.4 Single Package Evaluation

For the single package evaluation, staff confirmed that the applicant adhered to the applicable conditions of 10 CFR 71.55 and evaluated various flooded conditions as well as residual water left in the package. In all instances, the resulting calculated k_{eff} that was identified by the applicant was found to be less than 0.95, including all biases and uncertainties for both normal conditions of transport and hypothetical accident conditions.

6.5 Evaluation of Package Arrays Under Normal Conditions of Transport

For the array of packages under normal conditions of transport, a close packed hexagonal array was utilized to minimize spacing in an infinite array with the applicant modeling the M-290 with varying degrees of moderation in compliance with the applicable portions of 10 CFR 71.59. The applicant included a demonstration of determining maximum reactivity utilizing numerous parametric studies for all of the scenarios evaluated. In all instances, the resulting calculated k_{eff} that was identified by the applicant was found to be less than 0.95, including all biases and uncertainties.

6.6 Evaluation of Package Arrays Under Hypothetical Accident Conditions

For the array of packages under hypothetical accident conditions, a close packed hexagonal array was again utilized to minimize spacing in an infinite array, with the applicant modeling the M-290 with varying degrees of moderation in compliance with the applicable portions of 10 CFR 71.59. The applicant included a demonstration of determining maximum reactivity utilizing numerous parametric studies for all of the scenarios evaluated. In all instances, the resulting calculated k_{eff} that was identified by the applicant was found to be less than 0.95, including all biases and uncertainties.

6.7 Benchmark Evaluations

The applicant provided an extensive benchmark evaluation that compared calculational methods with experimental results to determine appropriate bias and uncertainties. The method employed complies with the requirements of 10 CFR 71.31(a)(2) and 10 CFR 71.35.

6.8 Evaluation Finding

Since the resulting k_{eff}s for the evaluated system under both normal conditions of transport and hypothetical accident conditions were confirmed through the applicant's analysis to be less than 0.95, staff concludes that the Model M-290 containing a full load of A1G fuel modules under the assumptions utilized by the applicant, and under the conditions listed in the certificate of compliance, continues to meet the criticality safety requirements in 10 CFR Part 71.

7.0 OPERATING PROCEDURES

In the application, Naval Reactors provided procedures that are specific to the A1G fuel assemblies for preparing the package for loading, loading the contents, and unloading the M-290 package, and preparing an empty package for transport. The A1G-specific procedures, along with those in the M-290 core independent SAR, provide the full set of operating procedures for operating the M-290 package containing A1G fuel modules.

The staff reviewed the Operating Procedures in Chapter 7 of the application to verify that the package will be operated in a manner that is consistent with its design evaluation. On the basis of its evaluation, the staff concludes that the combination of the engineered safety features and the operating procedures provide adequate measures and reasonable assurance for safe operation of the proposed design basis fuel in accordance with 10 CFR Part 71.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

The A1G SAR provides for acceptance tests for those packaging components specific to the A1G fuel modules. The specific acceptance tests include visual inspections and measurements; weld inspections; a pressure and leakage tests on the A1G closure head; and component and material tests. Based on the statements and representations in the application, the staff concludes that the acceptance tests for the packaging meet the requirements of 10 CFR Part 71.

CONDITIONS

The following conditions are included in the certificate of compliance:

Added conditions 5(b)(1)(ii) and 5b(2)(ii) to include A1G fuel modules.

Added condition No. 7 to add limitations on the A1G fuel modules

Previous item 7 was renumbered to item 8.

Previous item 8 was renumbered to item 9.

Previous item 9 was renumbered to item 10.

Previous item 10 was renumbered to item 11.

Previous item 11 was renumbered to item 12.

CONCLUSIONS

Based on our review, the statements and representations contained in the application, as supplemented, and the conditions listed above, we conclude that the Model No. M-290 package meets the requirements of 10 CFR Part 71.

Issued with Certificate of Compliance No. 9796, Revision No. 1,
on __3/16/18_____.