UNITED STATES
NUCLEAR REGULATORY COMMISSION
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SAFETY EVALUATION REPORT
Certificate of Compliance No. 9796
Model No. M-290 Package
Revision No. 0

SUMMARY

By application dated May 13, 2013, as supplemented on March 31, May 20, and June 30, 2014, the Department of Energy, Division of Naval Reactors (Naval Reactors or the applicant) requested approval of the Model No. M-290 spent fuel package as a Type B(U)F-96 package. The M-290 is designed to transport a variety of spent fuel types, including A1W fuel modules.

Naval Reactors submitted the “Core Independent M-290 Safety Analysis Report for Packaging” (M-290 SARP) on May 13, 2013, to the U.S. Nuclear Regulatory Commission (NRC) for NRC review of the key packaging components that are independent of the contents. On March 31, 2014, Naval Reactors submitted the "A1W Spent Nuclear Fuel in the M-290 Safety Analysis Report for Packaging," (A1W SARP) for NRC review and approval of the components that change with differing contents.

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

REFERENCES

"Core Independent M-290 Safety Analysis Report for Packaging," dated May 13, 2013.

"A1W Spent Nuclear Fuel in the M-290 Safety Analysis Report for Packaging," dated March 31, 2014.

Supplements dated May 20 and June 30, 2014.

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 contain spent fuel 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 M-290 contents is comprised of A1W spent fuel and associated activated corrosion products (crud), and some residual water (up to 7 gallons) assumed to be contaminated with activated corrosion products contained in an A1W canister. Authorized fuel loadings, internals assembly, and other loading restrictions are specified in the A1W SARP. A1W spent fuel modules decay heat shall not to exceed 14,730 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 SARP. Internals assemblies and fuel modules for the A1W spent fuel are constructed and assembled in accordance with drawings in Appendix 1.3.3 of the A1W SARP.

1.4 Evaluation Findings

A general description of the M-290 package is presented in Section 1 of the application, with special attention to design and operating characteristics and principal safety considerations. Drawings for structures, systems, and components important to safety are included in the application.

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.

2.1 Description of Structural Design

2.1.1 Discussion

The M-290 core-independent transportation packaging 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 and a canister-based loading.

The principal structural core-dependent components of the M-290 transportation package are the restraint plate assembly, canister shell, closure head with port plug and dust cover, intermediate and top region spacer plates, control region spacer plates, bottom transition and support plates, dowel rods, tie rods, cylindrical and rectangular spacers, tie rod spacers and fastening hardware, and the A1W spent fuel modules.

2.1.2 Design Criteria

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

The design criteria are established based on the safety function and consequence of failure of each component. The design of the A1W canister and internals serves to maintain the containment boundary, confine the spent fuel within the canister, 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.

2.1.2.1 Allowable Stresses and Strains

Allowable stress and strain limits are summarized in Table 2.1-1 of the M-290 SARP for the core-independent components and Table 2.1-1 of the A1W SARP for the canister and its internals. The A1W canister 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

Applicable load combinations are summarized in Table 2.1-2 of the M-290 SARP and Table 2.1-2 of the A1W SARP. These loading configurations are in accordance with Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material."

2.1.3 Weights and Centers of Gravity

Tables 2.1-3 and 2.1-4 of the M-290 SARP summarize several content configurations with varying weights and center of gravity locations. Tables 2.1-3 through 2.1-8 of the A1W SARP summarize the weights and centers of gravity for the A1W canister, internals and the spent fuel modules.

2.1.4 Codes and Standards

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

The majority of the A1W M-290 internal 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 ASME B&PVC Section III, Division I, Subsection NB (2004) is applied to the materials, fabrication and installation, examinations, and testing of the A1W canister shell assembly. The remaining A1W M-290 internal components are designed and fabricated to alternate specifications, identified on the applicable drawings in Chapter 1 of the A1W SARP and in Tables 2.2-1 through 2.2-8 of the A1W SARP.

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.

2.2 Materials

2.2.1 Mechanical Properties of Materials

The staff reviewed the materials selected and determined that they are acceptable and provide reasonable assurance for safety of the package. Specifications and temperature dependent mechanical properties, including yield strength, tensile strength, allowable strength, modulus of elasticity, density, and coefficient of thermal expansion conform to ASME Code, Section II, Part D.

2.2.2 Chemical, Galvanic, or Other Reactions

Section 2.4.4 in both the M-290 SARP and the A1W SARP demonstrates that M-290 components are fabricated from materials not susceptible to unacceptable chemical or galvanic reactions and are fabricated from corrosion-resistant materials.

The staff concludes during normal operation the internals will not be subject to continuous or frequent exposure to moisture during transport. The number of and galvanic potential between the different alloys used in fabrication of the packaging is low. In addition, visual inspection during loading and off-loading are performed. Therefore, the conditions required to create chemical or galvanic reactions detrimental to form, fit, or function are minimal.

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 package meets the requirements of 10 CFR 71.43(a) for minimum size.

2.3.2 Tamper-Indicating Features

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. Damage to this security seal would indicate tampering, therefore, the requirements of 10 CFR 71.43(b) are satisfied.

2.3.3 Positive Closure

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. All of these structural components were shown to withstand the regulatory tests for hypothetical accident conditions, therefore, the requirements of 10 CFR 71.43(c) are satisfied.

2.4 Lifting and Tie-Down Standards for All Packages

2.4.1 Lifting Devices

Top dome threaded lift plate attachment holes were evaluated with closed form calculations. All margins were acceptable.

2.4.2 Tie-Down Devices

The package does not incorporate any structural feature that is used as a tie-down device, however, the applicant does evaluate components of the package that interact with the external tie down devices. All margins were acceptable.

The requirements of 10 CFR 71.45(b)(1) for lifting devices are met.

2.5 Normal Conditions of Transport

2.5.1 Heat

2.5.1.1 Summary of Pressures and Temperatures

The temperatures associated with the heat condition are summarized in Table 2.6-1 of the M-290 SARP and the applicant reported a maximum peak internal pressure of 40 psig. Table 2.6-1 through 2.6-3 of the A1W SARP summarizes the M-290 design temperatures developed based on thermal analysis in the M-290 SARP. The A1W SARP provides the peak calculated temperatures for the M-290 loaded with the A1W-R3 spent fuel modules cargo. The design temperatures established in the core-independent design are bounding for the A1W-R3 configuration.

2.5.1.2 Differential Thermal Expansion

Table 2-6.3 of the M-290 SARP and Table 2.6-4, Summary of Allowable Temperature Differences, of the A1W SARP compares the design temperature differences with the worst case temperature differences to illustrate the relative margin available prior to mechanical interference due to differential thermal expansion. No unacceptable interference occurs under the normal conditions of transport hot conditions. The applicant also demonstrated 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 entire package, including the containment cover and fasteners, the backing ring and fasteners, the shear ring and shear ring screws, the top dome and attachment hardware, the bottom dome and attachment hardware, the package, the internal components of the A1W canister, and the associated fasteners.

2.5.1.4 Comparison with Allowable Stresses

Stress results and comparison with allowable stresses are reported in tables on pages 2.6-10 to 2.6-14 of the M-290 SARP. All margins are shown to be positive for the core independent packaging. Table 2.6-5 of the A1W SARP summarizes the stresses in the M-290 during normal condition of transport for the A1W internal components for both hot and cold conditions. With two exceptions, all stresses associated with hot conditions are below the yield strength. The port plug and vent release cover bearing surfaces below the fastener heads could potentially yield as a result of the maximum preload condition. For both components, the applicant demonstrates that sufficient preload is maintained to prevent joint separation.

2.5.2 Cold

2.5.2.1 Differential Thermal Contraction

The applicant demonstrated that no component interference occurs for the package at the -40°F temperature for cold conditions and that all fastener preloads remained acceptable.

2.5.2.2 Stress Calculations

The applicant performed stress calculations under cold condition for all components of the A1W canister as well as the associated fasteners.

2.5.2.3 Comparison with Allowable Stresses

Table 2.6-5 of the A1W SARP summarizes the stresses in the M-290 during normal conditions of transport for the A1W internal components for both hot and cold conditions. All stresses associated with cold conditions are below the yield strength and meet the design criteria.

2.5.2.4 Brittle Fracture

Regulatory Guides 7.11, “Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m),” and 7.12, “Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Wall Thickness Greater than 4 Inches (0.1 m) But Not Exceeding 12 Inches (0.3 m),” do not apply to the use of stainless steels, which preclude brittle fracture under both normal conditions of transport and hypothetical accident conditions. The staff finds that by avoiding the use of ferritic steels, brittle fracture concerns are precluded; however there is limited use of ferritic steels in the Model M-290. Specifically, most primary structural packaging components are fabricated of dual certification stainless steel. Since this material does not undergo a ductile-to-brittle transition in the temperature range of interest (down to -40ºF), it is safe from brittle fracture. The staff states that in austenitic stainless steel metal, the force required to move dislocations, is not strongly temperature dependent and dislocation movement remains high (i.e., will deform more readily under load before breaking) even at low temperatures and the material remains relatively ductile. Regulatory Guide 7.11 states austenitic stainless steel is not susceptible to brittle facture at temperatures encountered in transport.

Brittle fracture was evaluated by categorizing materials as subject to brittle fracture or not subject to brittle fracture. Those materials (and components) that were classified as subject to brittle fracture were evaluated. In all cases except for the shear ring, brittle fracture was shown to be precluded. In the case of the shear ring, it was shown that brittle fracture was possible during hypothetical accident conditions. For those components, the applicant demonstrates the consequences of fracture are acceptable, and the ability of the package to meet 10 CFR Part 71 is not diminished.

2.5.2.5 Freezing of Residual or Accumulated Water

The amount of residual water remaining in the A1W canister can be up to 7 gallons. 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. If water was to migrate to the closure surfaces, canister closure components will maintain preload and the respective seals will remain intact under all normal conditions of transport.

2.5.3 Reduced External Pressure

The evaluated package design pressure of 40 psig bounds the effects of reduced external pressure (3.5 psia).

The requirements of 10 CFR 71.71(c)(3) are satisfied.

2.5.4 Increased External Pressure

The evaluated package design pressure of 40 psig bounds the effects of increased external pressure (20 psia) and furthermore the package is sufficiently robust to withstand 290 psig equivalent pressure from deep immersion (Section 2.7.7 of the SAR).

The requirements of 10 CFR 71.71(c)(4) are satisfied.

2.5.5 Vibration and Fatigue

2.5.5.1 Vibration

Vibration and shock loads are summarized in Table 2.6-7 of the M-290 SARP and Table 2.6-9 of the A1W SARP. Vibration of the M-290 transportation packaging, A1W canister, internals and cargo is driven by vibration of the M-290 railcar during transportation. The applicant performed analysis to evaluate the effects of vibration in 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 induced stresses. These analyses indicate that each of the relevant A1W canister, internals and cargo components are unaffected by resonant amplification. Where resonant amplification occurs, the applicant demonstrated that the resulting stresses are acceptable and meet the design criteria. Furthermore, no relative motion or joint separation occurs between the clamped members of joints as a result of vibratory loads. Some minimal local material yielding occurs as a result of axial shock, but this has no detrimental effects on the performance of the A1W canister assembly.

2.5.5.2 Fatigue

Fatigue could be driven by a number of phenomena including tensioning/detensioning, vibration, and thermal cycling. The applicant evaluated individual components by means of a usage factor. In all cases, the fatigue usage factor was less than the limiting value of 1.0 with the maximum reported value of 0.69 for the bottom dome due to vibratory and thermal loading.

2.5.6 Water Spray

Due to the materials of construction, including seals, the staff has determined that water spray is not a significant challenge to the structural design of this package.

The requirements of 10 CFR 71.71(c)(6) are satisfied.

2.5.7 Free Drop

The package was evaluated for a 1-ft drop on the bottom end and side orientations under hot and cold conditions. 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 SARP. In general, the results show minimal damage to the package components and does not affect the containment boundary. While any rearrangement of the A1W fuel modules or control rod withdrawal resulting from the 1-ft drop would be more severe than for other normal conditions of transport, such rearrangement is bounded by the limiting configurations resulting from the hypothetical accident conditions. Because a subcritical arrangement is maintained after the hypothetical accident conditions scenario and there is no significant rearrangement of the spent fuel, the staff concludes that a subcritical arrangement will be maintained for the 1-ft drop and that the geometric form of the package contents would not be substantially altered. The requirements of 10 CFR 71.71(c)(7) and 71.55(d)(2) are satisfied.

2.5.8 Corner Drop

The corner drop was not applicable to this package design. The requirements of 10 CFR 71.71(c)(8) are satisfied.

2.5.9 Compression

The compression drop test was not applicable to this package design. The requirements of 10 CFR 71.71(c)(9) are satisfied.

2.5.10 Penetration

The applicant subjected the package to a penetration test 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 consisted of a dent approximately 0.11 inches in depth and 0.75 inches in diameter. As such, this dent is 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 requirements of 10 CFR71.71(c)(10) are satisfied.

2.6 Hypothetical Accident Condition

2.6.1 Free Drop

The applicant developed 11 finite element models to evaluate the M-290 for hypothetical accident conditions. The first model was developed for the core-independent packaging and contains generic, canistered internals, and spent fuel. This model is used to generate the acceleration pulses that are then applied to the canister internals and contents. Three models were developed to evaluate the canister and internals and seven models were developed to evaluate the fuel modules. In many cases, a method called “clocking” is utilized in which the model is evaluated in 10-degree increments to determine the limiting drop orientation. In some analyses, specific components are modeled with elastic material properties such that the material continues to maintain its stiffness along the elastic modulus curve. This is done in specific cases in order to conservatively force more load into the component(s) of interest in that specific analysis case to prevent components in the load path from absorbing additional energy or reducing the loads on the component(s) of interest. Additionally, evaluations are completed for different acceleration pulses for hot (peak design temperatures) and cold (-20°F) conditions.

Specific evaluations were performed for the overall package response, and responses for the domes and attachment system, the package body, the containment cover and attachment system, and the shear ring and backing ring. The results demonstrated no loss of secondary containment, no contact of the closure head and the containment cover, no contact between top impact limiter and the containment cover, no top impact limiter breach, no failure of attachment components, and elastic behavior of the containment cover and fasteners.

The analytical modeling and scale drop testing in aggregate satisfy the requirements of 10 CFR 71.73(c)(1).

2.6.2 Crush

This evaluation is not applicable due to the package weight exceeding the minimum allowable of 1100 lbs.

The requirements of 10 CFR 71.73(c)(2) are satisfied.

2.6.3 Puncture

The applicant evaluated the package for a 40-inch puncture drop utilizing closed form calculations and finite element analysis. The closed form calculations demonstrated that the package exterior does not tear thereby breaching the containment boundary. The finite element analysis is performed to evaluated gross deformation of the package due to the puncture impact. Material thinning, gross geometry changes, and some minor component failures were reported. Overall the results demonstrate that the package function is not impaired due the puncture impact.

The requirements of 10 CFR 71.73(c)(3) are satisfied.

2.6.4 Thermal

The structural response (thermal stresses, differential thermal expansion, and stresses due to pressure differentials) of the packaging and contents to the fire test temperatures are based on a combination of closed-form calculations and finite element analysis. The applicant demonstrated that, with few exceptions, the A1W canister, internals, and cargo have no plastic deformation resulting from the fire test conditions. Additionally, the A1W canister, internals and cargo do not interfere with the M-290 core-independent hardware as a result of the fire test temperatures and have no effect on the M-290 containment boundary.

2.6.4.1 Summary of Pressures and Temperatures

The temperatures associated with the hypothetical accident conditions fire test are summarized in Table 2.7-2 of the M-290 SARP and the applicant reported a maximum peak internal pressure of 80 psig. Tables 2.7-4 through 2.7-7 of the A1W SARP summarize the A1W 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. These temperatures are used for the thermal-structural evaluations that are based primarily on temperature distributions and differences. Using the peak fire temperatures in Tables 2.7-4 and 2.7-5, the applicant demonstrated that 80 psig is bounding for the maximum fire internal pressure of the A1W canister assembly and is used for all applicable stress calculations.

2.6.4.2 Differential Thermal Expansion

The effects of differential thermal expansion were evaluated for individual package components based on the temperature values presented in Table 2.7-2 of the M-290 SARP. 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.

2.6.4.3 Stress Calculations

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

2.6.4.4 Comparison with Allowable Stresses

Stress results and comparison with allowable stresses are reported in Appendices 2.12.2, 2.12.11, and 2.12.12 of the M-290 SARP. All margins are shown to be positive. For the internal components, the bearing stress on the port plug surface below the fastener heads exceeds the yield strength of the material as was illustrated for normal conditions of transport. In addition, the radial bearing stress between the shear plate and the canister exceeds the yield strength of the shear plate material. Consequently, yielding may occur at these locations during a fire, which may result in a reduction of the sealing capability of the canister. Since the cladding temperature remains well below design temperatures, and secondary containment is provided by the packaging, which remains intact following a fire, the staff finds that the potential loss of the canister seal as a result of the fire is acceptable and does not affect the overall containment performance of the M-290.

2.6.5 Immersion – Fissile

Water exclusion was not necessary to meet criticality requirements. The requirements of 10 CFR 71.73(c)(5) are satisfied.

2.6.6 Immersion – All packages

The applicant demonstrated that the deep immersion evaluation bounds this requirement. The requirements of 10 CFR 71.73(c)(6) are satisfied.

The staff has reviewed the packaging structural performance under the hypothetical accident conditions and concludes the package has adequate structural integrity to satisfy the subcriticality, containment, shielding, and temperature requirements of 10 CFR Part 71.

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

2.7.1 Deep Immersion

The package was evaluated with a combination of finite element analysis and closed form hand calculations. 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 remaining elastic and water tight for this evaluation. The requirements of 10 CFR 71.61 are satisfied.

2.8 Evaluation Findings

Based on review of the statements and representations in the application, as supplemented, the staff concludes that the structural design has been adequately described and evaluated and that the package has adequate structural integrity to meet the requirements of 10 CFR Part 71.

3.0 THERMAL EVALUATION

The purpose of this evaluation is to verify that the M-290 transport package provides adequate protection against the thermal tests specified in 10 CFR Part 71 and to verify that the package design meets the thermal performance requirements of 10 CFR Part 71 under normal conditions of transport and hypothetical accident conditions.

The applicant performed a thermal analysis of the M-290 package for normal conditions of transport and hypothetical accident conditions using the ABAQUS computer code. The thermal analysis was performed for the A1W fuel modules. The analysis assumed the contents were shipped dry with a maximum decay heat load of 14,730 Btu/hr.

3.1 Description of Thermal Design

The M-290 has been designed as a right circular cylinder with domes on both ends, and is shipped in a near-horizontal attitude on its railcar (view Figure 1.1-1 of Chapter 1 in the M-290 SARP). The M-290 is designed to hold either canistered or uncanistered fuel assemblies.

The fueled region of the spent fuel assemblies is located at the bottom half of the packaging (referenced from its vertical loading orientation) in the finned region. The decay heat is transferred to the package inner wall from the canister containing the basket and spent fuel modules by radiation and conduction through internal gas (air or water vapor). Conduction takes place through the package metal wall to the outside diameter and then to the ambient environment through the mechanisms of convection and radiation heat transfer. The lower half of the package enhances the heat transfer by the presence of annular fins welded to the outside of the package. The upper and lower domes, located at both ends of the package protect the package by deforming and absorbing energy during the hypothetical accident condition drop test and protect the lid from direct exposure to the fully engulfing fire.

3.1.1 Maximum Decay Heat

The maximum decay heat load was determined for the package based on an analysis of fuel blister and rupture temperature limits. The maximum decay heat was limited so that fuel blistering would not occur under normal conditions of transport and that rupture of the fuel cladding would not occur under hypothetical accident conditions. The applicant's analysis showed that the maximum decay heat load was limited to 14,730 Btu/hr based on the normal conditions of transport criterion to prevent fuel blistering.

The staff reviewed Section 3.1.2 of both the M-290 SARP and A1W SARP dealing with decay heat and reviewed the calculations and equations provided by the applicant. Based on staff's review, the staff finds reasonable assurance that the discussion on decay heat and the calculation for maximum decay heat are acceptable.

3.2 Normal Conditions of Transport

In analyzing the package for normal conditions of transport, the applicant assumed a 100°F ambient temperature, a maximum heat load of 14,730 Btu/hr, and the solar insolation given in the Insolation Data table in 10 CFR 71.71(c)(1). The maximum temperatures calculated for normal conditions of transport at various locations are listed below in Table 3-1.

Table 3-1: Maximum Temperatures for Normal Conditions of Transport

Component	**Calculated Temperature (°F)**
Lower Aluminum Fuel Region & Bottom Spacers	243
Containment Cover O-Ring	186
Fuel Cladding	336

The results of the applicant's analysis show that the seal region remained below 190°F, which is well below the acceptable service temperature for ethylene propylene 0-rings. The maximum temperature of the fuel modules did not exceed the fuel temperature limit. The calculated temperatures were within the limits for the package materials.

The M-290 package was also analyzed for a 100°F ambient temperature without insolation. The maximum temperature at any accessible point on the package surface was determined to be 124°F, which is less than 185°F and meets the requirement in 10 CFR 71.43(g) for maximum temperature for any accessible surface for exclusive use shipments.

The staff reviewed the calculations and methods used by the applicant to determine the temperatures at normal conditions of transport for various locations within the M-290 package. Based on the staff's review, the staff finds reasonable assurance that the regulations for normal conditions of transport were met and that package temperatures do not exceed allowable temperature limits.

3.3 Hypothetical Accident Conditions

In analyzing the M-290 package for hypothetical accident conditions, the applicant evaluated the package, simulating a 30-minute, 1475°F fire with no solar insolation and an internal decay heat load of 14,730 Btu/hr. The maximum temperatures calculated for hypothetical accident conditions at various locations are listed below in Table 3-2.

Table 3-2: Maximum Temperatures for Hypothetical Accident Conditions

Component	Calculated Temperature (°F)
Package Inner Wall	424
Package Body	276
Containment Cover O-Ring	280
Fuel Cladding	371

The thermal analysis for the M-290 transportation package showed that the maximum fuel temperature did not exceed the fuel temperature limit. The results of the applicant's analysis showed that the seal region remained below the maximum temperature of 300°F.

The staff reviewed the calculations and methods provided by and used by the applicant to determine the temperatures for hypothetical accident conditions for various locations within the M-290 package. Based on the staff's review, the staff finds reasonable assurance that the regulations for hypothetical accident conditions were met and that package temperatures do not exceed allowable temperature limits.

4.0 CONTAINMENT EVALUATION

4.1 Review Objective

This review is to verify that the package design satisfies the containment requirements of 10 CFR Part 71 under normal conditions of transport and hypothetical accident conditions. The containment review covers both M-290 SARP and A1W SARP.

4.2 Evaluation

4.2.1 Description of Containment System

The primary containment boundary of M-290 package consists of fuel cladding and weldments that extend over the entire surface area of the fuel and provide containment for the fuel and fission products. The M-290 packaging is comprised of the packaging body and the cover assembly (including O-ring) contains the crud which adheres to the fuel modules. The M-290 does not have valves or pressure relief devices for continuous venting.

The staff reviewed the M-290 containment design features presented in the M-290 SARP and finds that the design is adequately described. The staff therefore finds that the M-290 package meets the containment requirements of 10 CFR 71.33.

4.2.2 Residual Water and Hydrogen Limits

The M-290 SARP Section 1.2.5 identifies that the M-290 shipment must be made dry with less than 7 gallons of residual water for the A1W fuel in the M-290 package. The M-290 SARP states that the hydrogen generation will be below the limit of 5% hydrogen by volume. The pressure calculations conservatively assume a maximum of 5% hydrogen by volume. As described in the A1W SARP Appendices 2.12.2 and 2.12.28, the applicant calculated the amount of residual water (after draining), which is below the required water limit in the M-290 SARP, and that the time to generate 5% hydrogen by volume within the M-290 is greater than the 30-year limit on storage and the estimated shipment duration.

The staff reviewed the calculations in the A1W SARP Appendices 2.12.2 and 2.12.28 and agree that both residual water limit of 7 gallons in the M-290 SARP and hydrogen generation limit of 5% are met. The applicant evaluated the location and effects of freezing of 7 gallons of water in the A1W fuel canister during the cold conditions and determined that the sealing capability of the containment seals will not be compromised.

4.2.3 Containment under Normal Conditions of Transport

The applicant calculated a maximum pressure of 37.8 psig in the M-290 by considering the pressure of initial non-condensable gases at loading, the gas generation due to radiolysis of residual water, and the vapor pressure associated with the residual water in the package. The staff reviewed the pressure calculation shown in the M-290 SARP Appendix 2.12.2 and accepts that the bounding MNOP of 40 psig was used in the stress calculations for normal conditions of transport.

The applicant provided the peak normal conditions of transport temperatures of the containment O-ring seals for the M-290 in Section 3.3.1.3. The staff reviewed both M-290 SARP and A1W SARP and agrees that the containment O-rings remain within the allowable temperature limits under normal conditions of transport.

As described in the M-290 SARP, Sections 4.2 and 4.5.2, the applicant calculated an air leakage rate based on the crud source term from the fuel assembly to the shipping container under normal conditions of transport. The staff reviewed the calculations and confirms that the M-290 package, which meets the criteria for being leaktight in American National Standards Institute (ANSI) in ANSI N14.5-1997, "Radioactive Materials - Leakage Tests on Packages for Shipment," meets the containment criteria in 10 CFR 71.51(a)(1), since the leaktight criteria is less than the air leakage rate.

4.2.4 Containment under Hypothetical Accident Conditions

The applicant calculated the maximum internal pressure of 77.4 psig and adopted a bounding pressure of 80.0 psig for the M-290 package. The maximum pressure of 80 psig was used in the structural evaluation to evaluate package stresses during the tests for hypothetical accident conditions. The staff reviewed the applicant's calculations for the peak hypothetical accident conditions temperatures of the containment O-rings in the M-290 SARP and agrees that the maximum temperatures for package containing the A1W canister are below the limit.

The applicant calculated an air leakage rate for the crud source from the fuel assembly to the shipping container. The staff reviewed the calculations described in M-290 SARP Sections 4.2 and 4.5.2 and accepts that since the package leak rate after hypothetical accident conditions remains below the allowable limit, it will not allow a release of an A_2 per week. The staff agrees that the M-290 package meets the criteria required by 10 CFR 71.51(a)(2).

4.3 Findings

The staff has reviewed the containment sections of both the M-290 SARP and A1W SARP and concludes that (1) the M-290 package has been described and evaluated to demonstrate that it satisfies the containment requirements of 10 CFR Part 71, and (2) the package is leaktight and meets the requirements of 10 CFR 71.51(a)(1) for normal conditions of transport and 10 CFR 71.51(a)(2) for hypothetical accident conditions.

5.0 SHIELDING EVALUATION

The objective of this review is to verify the M-290 shielding design meets the regulatory dose rate limits prescribed in 10 CFR 71.47 and 71.51 for the package under normal conditions of transport and hypothetical accident conditions.

5.1 Radiation Sources

The radiation sources of the contents include gammas and neutrons. The gamma sources include gammas emitted from the fission products as well as the activated hardware. The neutron sources include spontaneous fission of transuranics, alpha-neutron interactions with the isotopes in the fuel and structure materials, and subcritical neutron multiplication in the spent fuel. A neutron multiplication factor of 0.95 was used in accounting for subcritical multiplication of the neutron population. The source term values were determined for the maximum core life and the highest burnup fuel element in the core.

The fuel assembly burnup was determined using a core follow code, which provides accurate data for the fuel burnup and hence the source term calculations. Burnup profile was explicitly modeled in the shielding model in order to accurately reflect the peaking of the source distribution.

5.2 Computer Code and Evaluation

The package configuration was modeled with the PARTISN computer code for the shielding analyses for both gamma and neutron sources. PARTISN is a three dimensional S_N transport theory based code. This code has been benchmarked against measurement data and the calculated results are 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.

The applicant used a flux-to-dose-rate conversion factor that is less conservative in comparison with the American National Standards Institute/American Nuclear Society, (ANSI/ANS) 6.1.1-1977, “Neutron and Gamma-Ray Flux-to-Dose Conversion Factors.” The applicant studied the impact by comparing these two sets of factors and determined that the maximum difference is about 12% in the radial direction.

In addition, the shielding model used materials densities that are slightly lower than the values from standard material handbook. The applicant noted that this discrepancy might affect the results of the shielding analyses.

In order to compensate the uncertainties and non-conservative data used in the shielding analyses, the applicant used a “Design Assurance Factor” of 1.3 to increase calculated dose rates for normal conditions of transport.

Based on its analyses, the dose rates of the package with design basis contents are at fractional levels of the dose rate limits prescribed in 10 CFR 71.47 and 71.53. The actual package design basis dose rates were much less than the limits of 200 rem/hr on the package surface and 10 mrem/hr, 2 meters from the package surface, respectively. The applicant provided pre-shipment dose rate measurement data for a similar package to confirm the results of the shielding analyses for the M-290 package.

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 and finds them acceptable. 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 applicants for an exclusive use shipment.

5.3 Evaluation Finding

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 and finds that with reasonable assurance the package meets the shielding performance requirements of 10 CFR Part 71.

6.0 CRITICALITY EVALUATION

This review utilizes the A1W SARP to ensure that the proposed use of the M-290 shipping container to transport A1W naval spent nuclear fuel is performed in accordance with the criticality requirements specified in 10 CFR Part 71 for both normal conditions of transport and hypothetical accident conditions.

6.1 Model Evaluation

The applicant used an in-house Monte Carlo neutron transport theory computer program for all criticality calculations. This program allows for explicit representation of the fuel geometry and accurately models fuels, poisons, and accounts for self-shielding. This program also uses standard material definitions consistent with ASME and ASTM International standards. Neutron cross-sections are derived from Naval Reactors benchmarks and industry standard sources. All models utilized appropriately conservative assumptions for fuel loading and dimensional tolerances, and accounted for all biases and uncertainties.

Depleted nuclide inventories were calculated using a three-dimensional diffusion theory program and transferred into the Monte Carlo calculations as nuclide compositions to account for fission product inventories. A range of effective full power hours (EFPH) were evaluated to determine the most reactive bounding end of life depletion for the A1W cores. A subset of nuclides consisting of the principal isotopes and fission products were explicitly depleted, with the remaining fission products lumped as a function of the fission densities. For all calculations, the lumped fission products are used at a reduced percentage of their densities to conservatively account for reductions in the actual lumped fission product cross-sections after shutdown of the core.

6.2 Single Package Evaluation and Normal Conditions of Transport

The M-290 is designed to remain leak tight under normal and accident conditions and utilizes several conservative design features to maintain the A1W fuel in a subcritical state for both a single package and package arrays. The package under normal conditions of transport is evaluated for flooding under the requirements of 10 CFR 71.55(b), utilizes the most reactive credible fuel configuration, and accounts for any potential fuel assembly movement within the constraints of the package. This evaluation bounds the single package evaluation required by 10 CFR 71.55(d).

The M-290 is also evaluated in a close-packed hexagonal array with optimal moderation under normal conditions of transport in accordance with 10 CFR 71.59(a)(1).

6.3 Hypothetical Accident Conditions

The M-290 package is also evaluated under hypothetical accident conditions under the requirements of 10 CFR 71.55(e), and is modeled using the most reactive fuel assembly configuration with the maximum amount of credible moderation under flooding conditions. All required damaged conditions are evaluated to account for any potential movement of the fuel assemblies.

Arrays of packages under hypothetical accident conditions are performed in accordance with 10 CFR 71.59(a)(2) and modeled as a close-packed hexagonal array with optimum moderation. The Criticality Safety Index for the M-290 package was calculated using 10 CFR 71.59(b) and found to be zero, allowing any number of packages to be shipped together.

6.4 Evaluation Findings

The staff reviewed the description of the M-290 package and the allowable contents as they related to criticality safety and found them to be acceptable. Based on its review, the staff determined that the methods used in the criticality analyses are consistent with accepted industry practices and standards, and that the results are acceptable. The maximum multiplication factors for all postulated credible bounding analyses are below those allowed for commercial spent fuel packages.

Based on its review of the statements and representations in the application, as supplemented, the staff concludes that the M-290 shipping container has been adequately described and evaluated, and that the package meets the standards for shipment under 10 CFR Part 71.

7.0 OPERATING PROCEDURES

Chapter 7, "Operating Procedures," in the M-290 SAR summarizes the procedures that are independent of the contents whereas the procedures specific to the A1W fuel assemblies are summarized in Chapter 7 of the A1W SARP. Specific procedures are included for preparing the package for loading, loading and unloading the package, and preparing an empty package for transport.

The package is inspected for damage prior to loading as discussed in Chapters 7 and 8. The package is prepared for loading and the spent fuel is loaded in accordance with procedures in the A1W SARP. The canister is closed, drained and prepared for transport, including inspection of the containment cover, O-rings and sealing surfaces for damage and debris, as discussed in Section 8.2.3. The package is leak tested, protective domes are installed, radiation and contamination surveys are performed, and security seals are installed.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

Section 8.1 of the application describes the acceptance tests to be performed prior to first use of each packaging. These tests include: visual inspection and measurements; inspection of the package welds in accordance with the ASME B&PV Code; a 5X visual inspection of the external cooling fin welds; a pressure test that meets AMSE B&PV Code requirements at a pressure that is 2.5 times the MNOP; a structural proof-test load of the top dome lifting feature equivalent to five times the package weight; and ultrasonic tests to ensure shielding integrity.

The M-290 package will be tested to leak-tight criteria ($1x10^{-7}$ ref-cm^3/sec) for the fabrication, periodic and pre-shipment leak rate tests. Periodic leak rate tests will be performed on the containment cover middle O-ring and vent plugs within the 12-month period prior to each use of the package, and for the maintenance leakage rate test prior to the package returning to service.

Section 8.2 of the application describes the maintenance program for the package. The maintenance program consists of inspections of numerous parts of the packaging prior to each shipment and at periodic intervals for damage.

CONDITIONS

The following conditions are included in the certificate of compliance:

1. In addition to the limitations above, the A1W fuel is limited to:
   (a) The A1W modules are packaged with internals inside one A1W canister in the M-290 packaging.
   (b) Shipment shall be made no earlier than 730 days after shutdown.
   (c) The A1W canister draining shall occur no earlier than 805 days after shutdown, or at a time after shutdown as determined from applicable safety analyses.
   (d) Module Installation Lifting Adapters must be installed on all A1W modules and Control Rod Locking Devices must be installed in all modules with control rods.
   (e) The A1W core age must be per Section 1.2.5 of the A1W SARP.
   (f) The loaded A1W canister inside the M-290 shipping container must not be sealed for greater than 30 years.
   (g) The package must contain no more than 7 gallons of residual water.

2. Failed fuel or fuel with defective cladding is not authorized for shipment.

3. The package must be prepared for shipment and operated in accordance with the Operating Procedures of Chapter No. 7 of the application.

4. Each packaging must meet the Acceptance Tests and Maintenance Program of Chapter No. 8 of the application.

5. Transport by air of fissile material is not authorized.

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. 0, on December 12, 2014.