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

SAFETY EVALUATION REPORT
Docket No. 71-3100
Model No. MX-6P
Japanese Certificate of Competent Authority J/2037/AF 96
Revision 0

SUMMARY

By letter dated October 18, 2021 (Agencywide Documents Access and Management System {ADAMS} Accession No. ML21319A053), as supplemented on July 27, 2022 (ML22298A201), and October 3, 2022 (ML22298A219) the U.S. Department of Transportation (DOT) (the applicant thereafter) requested that the U.S. Nuclear Regulatory Commission (NRC) staff performed a review of the Japanese Certificate of Approval J/2037/AF-96, Revision 0, for the Model No. MX-6P transport package and make a recommendation concerning the revalidation of the package for import and export use.

The NRC (the staff thereafter) reviewed the application, as supplemented, against the requirements in International Atomic Energy Agency (IAEA) Specific Safety Requirements, No. SSR-6, 2012 Edition, “Regulations for the Safe Transport of Radioactive Material,” (SSR-6). In support of this request, the DOT provided the following documents for review with its letter dated January 12, 2022:

1. Japanese Certificate of Competent Authority J/2037/AF 96, Revision 0,
2. Mitsubishi Nuclear Fuel, Ltd. application “Safety Analysis Report for MX-6P,” as supplemented, and
3. Mitsubishi Nuclear Fuel, Ltd Fundamental Policy of Quality Management.

Based upon the NRC review of the statements and representations contained in the documents listed above, and for the reasons stated in this safety evaluation report (SER), the NRC recommends revalidation of Japanese Certificate of Competent Authority J/2037/AF 96, Revision 0, for the MX-6P package with no additional conditions.

1.0 GENERAL INFORMATION

The Model No. MX-6P is a Type A fissile package designed for the transport of unirradiated pressurized-water reactor (PWR) fuel.

1.1 Packaging

The packaging consists of five items: the main body, closure lid, basket, and top and bottom impact limiters (shock absorbing covers). The main body is a cylindrical shell with a bottom plate welded onto it. The cylindrical shell is constructed from rolled plate which is closed with a full penetration weld. Stiffeners are welded normal to the plate. The outside of the body has vertical plates welded onto the stiffeners to form the outer shell. The volume between the inner and outer shell formed by the stiffeners is filled with resin. The bottom consists of resin embedded into a stainless steel plate and covered by a stainless steel plate. The stainless steel plate is welded onto the bottom of the cylindrical shell. Six trunnions are bolted onto the cylindrical body, four at the top and two at the bottom.

Enclosure

The disk-shaped closure lid, like the bottom, is a composite of metal and resin. The lid is bolted to the upper flange of the body. The body-lid combination is sealed by a double O-ring groove in the upper flange, into which ethylene propylene diene monomer rubber (EPDM) gaskets are installed. The lid has ports for sampling the cavity gas and leak testing the O-rings seal.

The basket consists of stainless steel and aluminum alloy disks and tubes (lodgments) to hold the fuel. The lodgments are constructed of borated stainless steel. Aluminum spacers are located between the cylindrical inner shell and the basket.

Attached to the top and bottom end of the main body and the package's lid are shock absorbing covers. The shock absorbing covers consist of a stainless steel skin, gussets, and wood and are bolted onto the top flange and bottom.

1.2 Contents

The package is designed to hold up to eight, 14×14 PWR fresh fuel assemblies. The contents are limited to a Type A quantity of radioactive material.

1.3 Criticality Safety Index

The criticality safety index (CSI) for the package containing PWR fuel is 0.0.

2.0 STRUCTURAL EVALUATION

The objective of the structural evaluation is to verify that the structural performance of the MX-6P package meets the requirements of IAEA SSR-6. The applicant presented the structural analysis of the package in Section II-A of the MX-6P Safety Analysis Report (SAR).

2.1 Package Description

The applicant provided a description of the package in section I-C.2 of the SAR. Figures I-C.1 through I-C.4 depict the package, which consists of a body component, a lid, an internal fuel basket, and shock absorbing covers on each end. The applicant listed the dimension of the package in table I-C.3 and the weights in table I-C.4 of the SAR. The center of gravity is shown in figure II-A.1 of the SAR.

The body of the package is shown in Figures I-C.5 through I-C.7 of the SAR and consists of a cylindrical, stainless-steel inner shell with radial stiffeners welded to the outside connecting it to external plates and a top flange and bottom component welded to the ends of the inner shell and external plates. The space between the inner shell and external plates, separated by stiffeners, is filled with resin. The external plates have pressure regulating valves to release pressure in the shell part resin space during an accident. The stainless-steel bottom component includes a space filled with resin with a stainless-steel bottom resin cover. The staff reviewed the drawings of the package body and determined that no overall external dimension of the package is less than 10 centimeters, and the package meets the requirements of requirements of paragraph 636 of IAEA SSR-6.

The lid is depicted in Figure I-C.10 of the SAR. The lid is made of a titanium alloy shell with the hollow space filled with resin and a stainless-steel lid covering the resin. The lid is bolted to the top flange of the package body with double gaskets between them. The lid also features a quick connection for sampling of the internal gas in the packaging. The quick connection is protected by a bolted cover with a gasket.

The fuel basket is shown in figure I-C.11 of the SAR and consists of stainless-steel disks, aluminum-alloy disks, and eight borated stainless-steel lodgments containing the fuel content. Aluminum spacers separate the basket from the inner shell. The package contains fresh PWR fuel assemblies depicted in figures I-D.1 through I-D.3 of the SAR. Each fuel assembly is contained in a separate lodgment of the fuel basket. The fuel assembly consists of top nozzle, bottom nozzle, control rod guide thimbles, in-core instrument guide thimble, spacer grids and fuel rods. The fuel cladding is made of zirconium-based alloy.

The package employs shock absorbing covers bolted to the top and bottom ends of the package. The shock absorbing covers are depicted in figure I-C.12 and I-C.13 of the SAR and consist of a welded assembly of stainless-steel outer plates and gusset plates, wood, and a ring seat for bolt installation. The top shock absorbing cover provides a security seal and contains high-strength stainless steel plates and wood in the position of the lid's quick connection. The staff finds that the incorporation of the security seal is sufficient to meet the requirements of paragraphs 637 of IAEA SSR-6.

The package has four stainless steel trunnions bolted to the top flange and two to the bottom component for lifting. The trunnions are depicted in figures I-C.8 and II-A.2. As the shock absorbing covers fit over the trunnions, the package has handling belts installed onto the top and rear sides of the shell part used for horizontal lifting when the shock absorbing covers are installed. The handling belts are depicted in figure I-C.9 of the SAR.

Based on the applicant's description of the package as well as the structural analyses of the package's design discussed in the following sections of this report, the staff finds that the applicant designed the package considering its mass, volume, and shape and thus the package meets the requirements of paragraph 607 of IAEA SSR-6.

2.2 Structural Design Criteria

In section A.1.2 and table II-A.1 of the SAR, the applicant described the structural design criteria for the package, including the allowable stresses used in the stress analyses. The applicant summarized the load combinations used in the structural analyses in table II-A.2 of the SAR. The applicant summarized the conditions and analysis methods for the different structural analyses in table II-A.3. The design criteria for each of the structural evaluations are discussed in additional detail in the following sections of this report.

The staff reviewed the structural design criteria and finds they are appropriate for demonstrating that the package satisfies the requirements of IAEA SSR-6.

2.3 Lifting and Tie-down

The applicant presented the lifting evaluation in section A.4.4 of the SAR. The applicant performed a stress analysis of the trunnions and trunnion fixing bolts under lifting conditions to demonstrate that the stress intensities of these components were less than the yield stress. The applicant considered several bounding lifting configurations and a factor to account for rapid lifting. The applicant also conservatively used the total weight of the package, including the shock absorbing covers which would not be attached while lifting with the trunnions. The stress analysis of the trunnions and trunnion fixing bolts showed a safety margin greater than zero.

The applicant analyzed the handling belts using the finite element analysis software ABAQUS. The applicant included drawings used to develop the model in figures II-A.3 and II-A.4 and the mesh view of the model in figure II-A.5 of the SAR. The applicant relied on symmetry to model a quarter of the package and applied a loading factor in addition to the lifted weight. The model also included the connecting bolt that joins the upper and lower sections of the belts. The model results are shown in figure II-A.6 depicting deformations and figure II-A.7 depicting stress contours using Tresca stress criteria. The applicant presented the stress intensities and safety margin against yielding for various sections of the handling belt model in table II-A.6. The results of the finite element model of the handling belts showed safety margins greater than zero.

The applicant analyzed the lifting handles of the handling belts using a separate finite element analysis model in ABAQUS. The applicant included drawings used to develop the model in figures II-A.9 and the mesh view of the model in figure II-A.10. The applicant applied a loading factor in addition to the lifted weight. The staff finds the use of the loading factor sufficient to account for snatch lifting. The model results are shown in figure II-A.12 of the SAR depicting deformations and figure II-A.13 of the SAR depicting stress contours using Tresca stress criteria. The applicant presented the stress intensities and safety margin against yielding for various sections of the lifting handle in table II-A.7. The results of the finite element model of the lifting handle showed safety margins greater than zero.

The applicant performed a stress analysis of the lifting handle pins and connecting bolts under lifting conditions to demonstrate that the stress intensities of these components were less than the yield stress. The analysis accounted for the total weight of the package with a loading factor. The stress analysis of the lifting handle pins and connecting bolts showed a safety margin greater than zero.

The applicant performed fatigue analyses of the trunnions and handling belts in section A.4.4(2). For each component of the handling devices, the applicant’s analysis demonstrated that the calculated allowable number of cycles was sufficiently greater than the expected number of cycles for the package during transportation.

There are no tie-down attachments that are a structural component of the package. However, the applicant did evaluate the stresses in the package from transportation when mounted in the transport frame as depicted in figure I-C.1 of the SAR. The applicant created a half symmetry finite element model using ABAQUS and applied the acceleration and internal pressure for the normal conditions of transport (NCT). The applicant presented the stress intensities and safety margin against yielding for various sections of the packaging in table II-A.9. The results of the finite element model showed safety margins greater than zero.

Based on the staff’s review of the stress analyses described above, the staff finds that the applicant’s lifting and tiedown evaluations demonstrate that the structural design of the package meets the applicable structural of paragraphs 608, 609, and 638 of IAEA SSR-6.

2.4 Vibrations, Pressures, and Temperatures from Routine Conditions of Transport

The applicant evaluated the structural integrity of the packaging under the temperatures and pressures from routine conditions of transport in sections A.4.6 and A.5.1 of the SAR. The applicant calculated the differential thermal expansion of the various components of the packaging and determined that the package design provided sufficient clearances for the components and no stress would result from thermal expansion.

The applicant determined a bounding pressure differential for routine transport conditions and analyzed the applied pressure and bounding ambient temperatures in an ABAQUS finite element model. The applicant presented the results of this analysis in tables II-A.10 and II-A.11 of the SAR, which included calculated safety margins greater than zero for each of the packaging components. The results of these analyses demonstrated that stresses in the packaging remained below the stress limits and the lid maintained positive closure. The applicant also used the model to determine stresses in the lid bolts for a fatigue evaluation in section A.5.1.3(4) of the SAR. Based on the calculated allowable number of cycles, the applicant concluded the lid bolts had sufficient fatigue strength for the routine conditions of transport.

The applicant evaluated the structural integrity of the packaging under the vibrations from routine conditions of transport in section A.4.7 of the SAR. The applicant determined the natural frequency of the package when secured to the transport frame with an ABAQUS finite element model and the frequency of vibration of the package during transport. Comparing the frequencies, the applicant determined that the package would not experience resonance during routine transport. For vibrations on the packaging, the applicant also relied on the results of the stress analysis under the accelerations from the NCT using the ABAQUS model, which is described in the previous section of this SER. For vibrations on the lid bolts, the applicant concluded the initial tightening torque was sufficient to prevent vibrations from loosening the lid bolts.

Based on the staff's review, the staff finds that the applicant's structural evaluations of the package and closure mechanism sufficiently demonstrate that the package meets the applicable structural requirements for evaluating vibrations and pressures of paragraphs 613, 616, 641, and 645 of IAEA SSR-6.

2.5 Normal Conditions of Transport

In section A.5.2 of the SAR, the applicant notes that the external surfaces of the package are composed of stainless steel and will not deteriorate due to water spray. The applicant concluded that the water spray test will not impair the structural performance of the package. The staff finds that the applicant's assessment is consistent with the IAEA Specific Safety Guide No. SSG-26, "Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition)," and that the applicant's assessment has sufficiently shown that the package passes the water spray test through reasoned argument. Thus, the staff finds that the applicant has demonstrated that the package meets the requirements of paragraph 721 of IAEA SSR-6.

The applicant described the evaluation of the stacking test in section A.5.4 of the SAR. The applicant analyzed the stacking load in both a horizontal and a vertical orientation using ABAQUS finite element models. The applicant presented the deformations and stress contours in figures II-A.42 and II-A.43 of the SAR for the vertical orientation and figures II-A.45 and II-A.46 for the horizontal orientation. The applicant presented the stress analysis results in tables II-A.17 and II-A.18, which demonstrate that large safety margins exist for the package components compared to the yield stress. The applicant concluded that the structural integrity and shielding performance of the package will not be affected by the stacking test. The staff finds that the applicant's evaluation meets the requirements of paragraph 723 of IAEA SSR-6.

The applicant evaluated the penetration test in section A.5.5 of the SAR. The applicant considered the thinnest part of the external plate of the package as the bounding location for penetration. The applicant calculated the potential energy of the bar in the penetration test and the necessary energy for the bar to penetrate the external plate of the package. Comparing these energy calculations, the applicant concluded that the penetration test would not affect the structural integrity and shielding performance of the package. The staff finds that the applicant's evaluation meets the requirements of paragraphs 724 and 725(b) of IAEA SSR-6.

The applicant evaluated the free drop test for NCT in section A.5.5 of the SAR. The applicant evaluated the package for a 0.3-meter drop onto a rigid surface using the LS-DYNA finite element analysis software. The applicant created three, separate finite element models to evaluate the package body, the basket, and the fuel cladding.

As shown in figures II-A.29 and II-A.30 of the SAR, the applicant created a half symmetry model of the package to evaluate the package body for the free drop test of the NCT. The applicant analyzed the drop in five orientations: top-down vertical, bottom-down vertical, horizontal, top corner, and bottom corner. Figure II-A.32 depicts the deformation of the shock absorbing cover for each drop. Figure II-A.33 depicts the plastic strain contours that occurred in the horizontal drop. Table II-A.12 presents the plastic strains for various components and the stress evaluation of the bolts. The results showed that the safety margins in the bolts were greater than zero. For the vertical and corner drop orientations, the analyses showed no plastic strains or deformations in the package body. For the horizontal drop orientation, the analysis showed only small, localized strain in the stiffeners and flanges. From these results, the applicant determined that no deformations occurred that would have to be considered in other analyses and the structural integrity of the package body was maintained during the free drop test for NCT.

As shown in figures II-A.34 and II-A.35 of the SAR, the applicant created a finite element analysis model of a disk-shaped portion of the package to evaluate the basket. The applicant concluded that the horizontal drop resulted in a bounding structural response on the basket, because the total weight of the fuel bears on the basket in the horizontal drop. Since the basket is not circumferentially uniform, the applicant evaluated the drop test at three horizontal orientations with the impact occurring at the orientation of the package during shipping, and two additional orientations rotating the package about the longitudinal axis, as shown in figure II-A.37. As reported in table II-A.13, the analysis demonstrated that no plastic strains occur in the basket components. From these results, the applicant determined that no deformations occurred that would affect other analyses and the structural integrity of the basket was maintained in the free drop test.

As shown in figures II-A.38 of the SAR, the applicant created a finite element analysis model of a portion of a fuel rod. The applicant analyzed drops in the horizontal and vertical orientations. As reported in table II-A.16, the analysis showed that no plastic strain occurs in the fuel. From these results, the applicant concluded that the fuel cladding will not crack or rupture cladding during the free drop test.

The staff finds the orientations analyzed by the applicant in the free drop test analyses are sufficiently bounding to assess the maximum damage suffered by the package, as required by paragraph 722 of IAEA SSR-6. The staff finds the target considered in the analysis of the drop test meets the requirements of paragraph 722 of IAEA SSR-6. Based on a review of the analyses of the package body, basket, and fuel rods for the free drop test, the staff finds that the applicant's evaluation meets the requirements of paragraph 722 of IAEA SSR-6.

The staff reviewed the structural performance of the packaging under the NCT and concludes that there will be no substantial reduction in the effectiveness of the packaging that would prevent it from satisfying the requirements of paragraph 648 of IAEA SSR-6.

2.6 Accident Conditions of Transport

The applicant evaluated drop I in IAEA SSR-6 paragraph 727(a) of the mechanical test for accident conditions of transport (ACT) in section A.9.2(1) of the SAR. The applicant evaluated the package for the drop using the LS-DYNA finite element analysis software. The applicant used the finite element models from the free drop test for NCT to evaluate the package body, the basket, and the fuel cladding.

The applicant evaluated the package body for the “drop I” mechanical test in the following six orientations: top-down vertical, bottom-down vertical, horizontal, top corner, bottom corner, and a slap down orientation at a 30° angle. The applicant summarized the results of the drop orientations for the package body components in table II-A.21 of the SAR. The analysis resulted in plastic strains below the failure strain and showed that stresses in the lid bolts remained below the yield stress. From these results, the applicant concluded that the package body maintained structural integrity during the drops.

The applicant evaluated the basket for the “drop I” mechanical test in the same three horizontal orientations as the free drop test for the NCT. The applicant summarized the results of the drop orientations for the basket components in table II-A.22 of the SAR. The analysis resulted in small, local plastic strains in the lodgments and aluminum plates below the failure strains. From these results, the applicant concluded that the basket maintained structural integrity during the drops.

The applicant evaluated the fuel rods for the “drop I” mechanical test in the horizontal and vertical orientations. As shown in table II-A.23 of the SAR, the fuel cladding did not experience plastic strains. Thus, the applicant concluded that the fuel cladding did not rupture during the drops.

The applicant evaluated “drop II” in IAEA SSR-6 paragraph 727(b) of the mechanical test for accident conditions of transport in section A.9.2(2) of the SAR. The applicant evaluated the package for the drop by first performing a half-scale physical drop test to inform detailed finite element analysis of the package. The physical drop test resulted in penetration of the shock absorbing covers, denting to the lid resin cover, rupture of the external plates and stiffeners, and denting of the shell part. Following the physical drop test, the applicant performed a helium leak test and concluded that the containment boundary was maintained following the damage from the test.

The applicant created a finite element model in LS-DYNA, depicted in figure II-A.65, to perform a detailed evaluation of the internal components of the package during the drop II mechanical test. The applicant evaluated the drop test at three horizontal orientations with the impact occurring at the orientation of the package during shipment and two additional orientations rotating the package about the longitudinal axis, as shown in figure II-A.66. Figure II-A.67 of the SAR depicts the deformation in the basket, and figures II-A.68 through II-A.75 depict the plastic strain in the basket components. The finite element analysis resulted in significant damage to the aluminum plate at the impact location of the steel bar. However, the plastic strain in the adjacent plates was below the failure strain, and the applicant determined that the deformation would not affect the lodgment. The finite element analysis results showed the plastic strain in the lodgments was below the failure strain. Based on the finite element analysis, the applicant concluded the lodgments did not rupture and the fuel assemblies were not damaged.

The staff reviewed the analyses of the package for the mechanical test and finds that the applicant's evaluation meets the requirements of paragraph 727(a) and (b) of IAEA SSR-6

The applicant evaluated the thermal test in paragraph 728 of IAEA SSR-6 for ACT in section A.9.2(3) of the SAR. The applicant listed the temperatures for the package components evaluated in the thermal in table II-A.24. The applicant evaluated the package body for the thermal test using the same ABAQUS finite element model. The applicant used the model to evaluate the effects of the temperatures and pressures associated with routine conditions of transport. The model results are shown in figure II-A.76, which depicts the deformations, and figure II-A.77, which depicts the plastic strain contours of the inner shell. The inner shell experiences plastic strains less than the failure strain and does not rupture. No plastic strain occurs in the top flange, and the lid tightening bolts do not yield.

The applicant evaluated the basket for the thermal test by calculating the differential thermal expansion of the basket and the packaging body. First, the applicant determined the maximum temperature of the basket from thermal analysis and concluded that it was less than the upper limit of the material service temperature from section II, part D of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code. In the longitudinal direction, there is clearance between the basket and the shell part during the thermal test, and no additional stresses occur from constraint. In the radial direction, thermal expansion caused the basket's aluminum spacers to contact the inner surface of the shell part. However, the differential expansion is only slightly more than the clearance. The applicant concluded that the hollow aluminum spacers would deform, but no significant deformation would occur in the shell part or the aluminum plates of the basket.

The applicant evaluated the fuel cladding for the thermal test by calculating the stress in the fuel cladding caused by the increased internal pressure from the thermal test. First, the applicant calculated the internal pressure change due to the temperature increase of the thermal test. Then, the applicant calculated the circumferential, longitudinal, and radial stresses and the maximum stress intensity. The applicant demonstrated that the stress was less than the tensile strength and the fuel cladding would not rupture during the thermal test.

The staff reviewed the analyses of the package for the thermal test and finds that the applicant's evaluation meets the requirements of paragraph 728 of IAEA SSR-6.

The applicant evaluated the structural capacity of the package for an external pressure of 150 kPa (21.7 psi) gauge for the water immersion test in section II-A.10.4 of the SAR. The applicant used the same ABAQUS finite element model from the evaluation of the temperatures and pressures associated with routine conditions of transport. The model results are shown in figure II-A, appendix 4.1, which depicts the deformations, and figure II-A, appendix 4.2, depicts the Tresca stress contours. Table II-A, appendix 4.1, lists the stresses in the package components and shows that all stresses are below the yield stress. The staff reviewed the analysis of the package for the water immersion test and finds that the applicant's evaluation meets the requirements of paragraph 729 of IAEA SSR-6.

The staff reviewed the structural performance of the packaging under the ACT and concludes that there will be no substantial reduction in the effectiveness of the packaging that would prevent it from satisfying the requirements of paragraphs 673 and 685 of IAEA SSR-6.

2.7 Evaluation Finding

Based on a review of the statements and representations in the application, the staff concludes that the MX-6P package has sufficient structural capacity to meet the requirements of IAEA SSR-6.

3.0 THERMAL EVALUATION

3.1 Review Objective

The review objective for model No. MX-6P radioactive material transportation package was to verify that the thermal performance of the package had been adequately evaluated for the tests specified under normal conditions of transport and accident conditions of transport and that the package design satisfies the thermal requirements of IAEA SSR-6. This case was also reviewed to determine whether the package fulfills the acceptance criteria listed in Section 3 (“Thermal Evaluation”) of NUREG-2216, "Standard Review Plan for Spent Fuel and Radioactive Material,” August 2020 (ADAMS Accession No. ML20234A651).

3.2 Description of the Thermal Design and Design Criteria

The MX-6P package is a passive thermal device having no mechanical cooling system or relief valves to aid in cooling the package. All cooling of the transport package is through free convection and radiation heat transfer. Several thermal design criteria are established by the applicant for the MX-6P package to ensure that the package meets all its functional and safety requirements, per the IAEA SSR-6 thermal requirements:

1. Thermal evaluation at an ambient temperature of 38°C (100°F) in still air, and insolation according to isolation data provided in Table 12 of SSR-6.

2. Thermal evaluation at an ambient temperature of -40°C (-40°F) in still air and shade.

3. Exposure of the specimen fully engulfed, except for a simple support system, in a hydrocarbon fuel/air fire of sufficient extent, and in sufficiently quiescent ambient conditions, to provide an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 800°C (1,475°F) for a period of 30 minutes, or any other thermal test that provides the equivalent total heat input to the package and which provides a time averaged environmental temperature of 800°C.

4. A package must be designed, constructed, and prepared for transport so that in still air at 38°C (100°F) and in the shade, no accessible surface of a package would have a temperature exceeding 50°C (122°F) in a nonexclusive use shipment, or 85°C (185°F) in an exclusive use shipment.

The applicant states that the contents are fresh fuel assemblies whose decay heat is negligible.

The staff reviewed the design features, design criteria, and the decay heat of the content for the MX-6P package. Based on the information provided in the application regarding these items, the staff determined that the application is consistent with guidance provided in section 3.3.1 (Description of the Thermal Design) of NUREG-2216. Therefore, the staff concludes that the description of the thermal design is acceptable because the description satisfies NUREG-2216 and therefore meets the requirement of SSR-6.

3.3 Summary Tables of Temperatures and Pressures

The summary tables of key package component temperatures for NCT were reviewed by the staff. The temperatures are consistently presented throughout the application for NCT. For ACT, the applicant presented the pre-fire, during-fire, and post-fire component temperatures. The staff verified that all components remain below their material property limits (specified in the application). The temperatures and design temperature limits for the package components under NCT and ACT were reviewed and found to be consistent throughout the application.

The applicant's calculated pressures are used in the calculation of stresses (as described in the SAR, chapter II.A). The structural analysis described in chapter II.A demonstrated that the stresses are below the acceptance criteria. Therefore, the structural integrity of the packaging will be maintained.

The staff reviewed the temperature and pressure design limits and calculated temperatures and pressures for the package and found them to be acceptable and consistent in the SAR.

3.4 Material Properties and Component Specifications

The package application provided material thermal properties such as thermal conductivity, density, specific heat, and emissivity for all modeled components of the cask. The staff found these properties acceptable because the thermal properties used for the analysis of the package were appropriate for the materials specified and for the conditions of the package required by SSR-6 during NCT and ACT.

The application provided component thermal technical specifications for the all materials used in the MX-6P package. Thermal technical specifications are provided in terms of allowable service temperatures.

The staff reviewed the thermal properties used for the package analyses and determined that they were appropriate for the materials specified and for the package conditions required by the IAEA SSR-6 during NCT and ACT. The staff reviewed the component specifications for the MX-6P package and determined that the specifications were sufficiently clear to be evaluated as part of the thermal evaluation results.

3.5 Thermal Evaluation under Normal Conditions of Transport

SAR section B.4.1 provides an adequate description of the thermal model for the staff to determine the adequacy of the thermal model. The staff reviewed the applicant's description the MX-6P thermal model and based on the information provided in the application regarding the developed thermal model, the staff determined that the model described in the application is consistent with guidance provided in section 3.4.5 (Thermal Evaluation under Normal Conditions of Transport) of NUREG-2216. Therefore, the staff concludes that the description of the thermal models is acceptable.

The applicant used the developed thermal models to perform the analysis of MX-6P under the thermal conditions specified in section 3.2, above. All predicted temperatures (including surface temperature) remain below the allowable limits specified in the SAR. The applicant calculated the maximum internal pressure and used this pressure to obtain the stresses (calculated in chapter II.A). In their structural analysis in chapter II.A, the applicant, of the SAR and demonstrated that the stresses are below the acceptance criteria. Therefore, the structural integrity of the packaging will be maintained.

3.6 Thermal Evaluation under Accident Conditions of Transport

The applicant used the developed thermal models to perform the analysis of MX-6P under the thermal conditions specified in section 3.2 (fire). All predicted temperatures remain below the allowable limits specified in the SAR. The applicant used the results from normal conditions of transport including insolation as the initial condition for the fire analysis. Based on the requirements in SSR-6, a fire temperature of 1,475°F, fire emissivity of 0.9 and a period of 30 minutes are conditions considered for the fire conditions.

The applicant presented the pre-fire, during-fire, and post-fire component temperatures. The staff verified that all components remain below their material property limits (specified in the application). Thermal stresses for the MX-6P are calculated in chapter II.A of the SAR.

The staff reviewed the applicant's analysis of the MX-6P package during ACT. Based on the information provided in the application regarding ACT analysis, the staff determines that the application is consistent with guidance provided in section 3.4.6 (Thermal Evaluation under Hypothetical Accident Conditions) of NUREG-2216. Therefore, the staff concludes that the ACT analysis is acceptable because the analysis and results satisfy NUREG-2216 and therefore meets the requirements of SSR-6.

3.7 Thermal Tests

No thermal tests were performed for either NCT or ACT as the MX-6P package is analyzed using computer simulations.

3.8 Evaluation Findings

Based on review of the statements and representations in the application, the NRC staff finds that the MX-6P transportation package has been adequately described and evaluated to demonstrate that it satisfies the thermal requirements of SSR-6.

4.0 CONTAINMENT EVALUATION

4.1 Review Objective

The objective of the containment review was to verify that the containment performance of the MX-6P transportation package had been adequately evaluated for the tests specified under normal conditions of transport and accident conditions of transport and that the package design satisfies the containment requirements of the IAEA SSR-6. This application was also reviewed to determine whether the package fulfills the acceptance criteria listed in Chapter 4 ("Containment Evaluation") of NUREG-2216.

4.2 Description of the Containment System

The containment boundary of the MX-6P package (shown in figure I-C.4 of the SAR) consists of a body and lid, a lid gasket, and a quick connection cover gasket. The containment system is designed to assured leak-tightness (as described in section I-C of the SAR).

4.3 Containment Evaluation under Normal Condition of Transport

The entire containment system, including each penetration is designed to meet leak-tightness (as described in section I-C of the application). The structural and thermal analyses presented in chapters II.A and II.B respectively, demonstrate that the package remains leak-tight under any of the normal conditions of transport, which ensures there will be no release of radioactive material or ingress of water during transportation.

4.4 Containment Evaluation under Accident Conditions of Transport

The entire containment system, including each penetration is designed to meet leak-tightness (as described in section I-C of the SAR). The results of the structural and thermal analyses presented in chapters II.A and II.B, respectively, demonstrate that the package will remain leak-tight thus preventing ingress of water for all the ACT.

The staff reviewed the containment evaluation under NCT and ACT. Based on the review of the application the staff concludes that the MX-6P transportation package meets the confinement requirements of the IAEA SSR-6.

4.5 Findings

Based on review of the statements and representations in the application, the NRC staff finds that the MX-6P transportation package has been adequately described and evaluated to demonstrate that it satisfies the containment requirements of SSR-6.

5.0 SHIELDING EVALUATION

The applicant requested the revalidation of the certificate of compliance for the Model No. MX-6P package for transportation of unirradiated PWR fuel assemblies containing uranium dioxide (UO_2) enriched up to 5.0 weight percent (wt.%) uranium-235 (^{235}U) to the requirements of IAEA SSR-6. Fuel assembly contents may have previously been stored in a spent fuel pool, and therefore may also include residual contamination.

5.1 Description of shielding design

The shielding design of the MX-6P package consists of the borated stainless steel basket guide tubes, cavity inner steel shell, radial resin in the cask body, package external steel plates, inner shell bottom steel plate, bottom resin, titanium alloy lid, lid resin, and steel lid resin cover. The geometric arrangement of shielding components is shown in figures I-C.5 through I-C.7 of the SAR for the package body, figure I-C.10 of the SAR for the lid, and figure I-C.11 of the SAR for the basket. Table I-C.1 of the SAR provides the materials of all of the shielding components with the exception of the resin, and the associated standard for each material. The resin component consists of the materials and weight ratios shown in table I-C.2 of the SAR.

5.2 Radioactive materials and source terms

The radioactive source for the MX-6P package consists of the unirradiated fuel source, and the contamination source from being stored in a spent fuel pool. The fuel source consists of the radionuclides shown in table II-D.1 of the SAR, including ^{235}U, ^{238}U, ^{232}U, ^{234}U, ^{236}U, and trace technecium-99 (^{99}Tc). This fuel composition is consistent with that of unirradiated light water reactor fuel and represents a Type A quantity of radioactive material. The gamma source from the fuel component is shown in table II-D.2 of the SAR. The corresponding neutron source from the fuel is negligible since it is unirradiated. The applicant stated that there is additionally a contamination source due to the fuel assemblies having been stored in a spent fuel pool with pool water contamination. To estimate this source, the applicant conservatively assumed that a 1.0 millimeter (mm) film was present on every exposed surface of the fuel assembly. The film was assumed to contain the maximum activity associated with the spent fuel pool water, to be confirmed by measurement prior to loading in the package per the operating procedures. All contamination activity is conservatively assumed by the applicant to be cobalt-60 (^{60}Co) for the purposes of the shielding analysis. The resulting contamination gamma source intensity is determined as shown in table II-D.3 of the SAR. With the maximum pool water activity being confirmed by measurement along with procedures requiring removal of excess water from and decontamination of the fuel prior to loading and recognizing the adhering contamination will not be entirely ^{60}Co, the staff finds that the applicant has conservatively estimated the radioactive materials and source terms present in the package for the shielding analysis.

5.3 Shielding model and model specifications

The applicant's shielding model specifications are described in section II-D.3 of the SAR. The applicant modeled the minimum thickness of borated stainless steel guide tube inside the basket aluminum spacer discs. The applicant homogenized the fuel assembly material in five axial regions: top nozzle, upper plenum, active fuel length, lower gap, and bottom nozzle. Only the active fuel length region contains the fuel source, while the contamination source is modeled in all five axial regions, consistent with the fuel assembly surface area in each region. The source term is homogenized within each axial region, as shown in figures II.D-1 through II.D-4. The applicant modeled the fuel assemblies shifted in the basket guide tubes such that the top nozzle region contacts the inner surface of the package lid, in order to simulate potential fuel assembly movement within the basket. The applicant conservatively assumed that the basket structural material below the basket guide tubes is replaced with air. The package design also includes a top and bottom steel and wood impact limiter, but only the spacing provided by these components for determining external dose rates is credited, and the materials are replaced by air in the shielding model. The number densities for each material modeled by the applicant in the shielding model are listed in table II-D.4 of the SAR.

The applicant modeled the package under routine conditions of transport and normal conditions of transport. The only difference between the normal conditions of transport and hypothetical accident conditions models is that the spacing provided by the impact limiters is reduced under hypothetical accident conditions due to the free drop. The configuration of the applicant's package model is shown in figures II-D.1 and II-D.2 of the SAR for routine conditions of transport, and figures II-D.3 and II-D.4 of the application for NCT.

5.4 Shielding evaluation

The applicant used the DORT two-dimensional discrete ordinates transport code to estimate package external surface and 1-meter gamma fluxes as a function of energy under routine conditions of transport and NCT. For these calculations, the applicant used the SCALE

47-group ENDF/B-VII gamma cross section library. The applicant converted the calculated external gamma fluxes to estimated dose rates using flux-to-dose conversion factors from International Commission on Radiation Protection (ICRP) Publication 74, “Conversion Coefficients for use in Radiological Protection against External Radiation.” Although this deviates from NRC recommendations to use flux-to-dose conversion factors from American National Standards Institute/American National Standard (ANSI/ANS) 6.1.1-1977, “Neutron and Gamma-Ray Flux-to-Dose-Rate Factors,” the staff considers the ICRP factors acceptable, since the calculated dose rates are significantly less than the regulatory limits, and the difference in calculated dose rates between the two flux-to-dose conversion factors is significantly exceeded by the margin to the regulatory limits.

The applicant reported the resulting calculated external dose rates in table II-D.5 of the SAR. These reported dose rates are much lower than the package surface dose rate limit in paragraph 527 of SSR-6 of 2 millisieverts per hour (mSv/hr) (200 mrem/hr) and the transport index limit in paragraph 526 of SSR-6 of 10, which corresponds to a dose rate of 0.1 mSv/hr (10 mrem/hr) at 1 meter from the package surface.

The staff reviewed the certificate of compliance for the Model No. MX-6P package, as well as the applicant’s initial assumptions, model configurations, analyses, and results in the application. The staff finds that the applicant has conservatively evaluated the shielding performance of the Model No. MX-6P package with the requested contents and demonstrated that the package external dose rates meet the limits under routine and normal conditions of transport. Therefore, the staff finds with reasonable assurance that the packaging, with the requested contents, will meet the package external dose rate requirements of IAEA SSR-6.

6.0 CRITICALITY EVALUATION

The applicant has requested a revalidation of the Japanese Certificate of Compliance for the Model No. MX-6P transportation package for shipping unirradiated PWR fuel assemblies that contain uranium dioxide (UO_2) enriched up to 5 wt.% ^{235}U under the requirements of the IAEA SSR-6.

6.1 Description of Criticality Design and Contents

The MX-6P is designed to hold up to 8 PWR 14×14 fuel assemblies. There are two types of 14×14 assemblies, which are shown in Table II-A.1 of the application, with the major fuel specifications listed in Table II-E.2. Fuel assemblies may contain gadolinium rods, but the gadolinium is conservatively neglected in the analysis. All fuel is considered to be enriched to 5.0 wt% ^{235}U for all evaluated cases. The MX-6P uses borated stainless steel in the basket structure as a neutron poison.

6.2 General Considerations for Criticality Safety

The applicant modeled the important parameters for evaluating the subcriticality of the MX-6P package, including the fuel specifications, fuel cladding, neutron absorbers in the basket, basket structure, spacers, and the inner stainless steel shell of the package. These parameters are shown in Table II-E.2 and illustrated in Figures II-E.1, II-E.2, and II-E.3 of the application. To account for routine, NCT and ACT, the models assume an infinite length of fuel assemblies, and ignore the external plates, stiffeners, shell part resin, lid bottom, and shock absorbing covers. All of the control rod guide thimbles and the in-core instrument guide thimbles are conservatively ignored in the analysis. The borated stainless steel is assumed to be at the minimum allowed and is acceptable for use since the ASTM standard has a range that would ensure that the boron credited in the analysis is acceptable. Full density water is assumed within the package and the package is evaluated using mirror reflection on the periphery of the package. Deformation of the fuel assemblies is conservatively modeled by expanding the pitch of the fuel rods within each assembly to fill each basket location.

6.3 Demonstration of Maximum Reactivity

The applicant used conservative assumptions throughout their analysis of both NCT and ACT, as mentioned in the general considerations for criticality safety, as well as assuming that the MX-6P contains a maximal load of 8 fuel assemblies fully flooded with water. The applicant evaluated routine conditions of transport, a package in isolation, individual package in isolation under NCT and ACT, and package arrays under both NCT and ACT, with the bounding effective multiplication factor plus three times the standard deviation ($k_{eff} + 3\sigma$) is less than 0.92.

6.4 Criticality Safety Evaluation

The applicant used the SCALE system of codes to perform their calculations of the effective multiplication factor for the MX-6P design using the KENO-VI Monte Carlo code package and the ENDF/B-VII 238 group cross-section data library. The applicant's evaluation was reported in the appendices to Chapter II-E of the application and summarized into tables for the evaluated parameters of the package. Chapter II-E, appendix-1 examined the effects of drop, thermal and immersion tests, and the resultant bounding k_{eff} values based on fuel configurations were used in the subsequent evaluations. Chapter II-E, appendix-2 evaluated the effects of water density for both single packages and arrays and found that the most reactive condition was with full density moderator inside the package, with low water density surrounding the package. Chapter II-E, appendix-3, evaluated the effects of inner shell expansion based on the results of the structural analysis in section A.9.2 of the SAR and found the effect on the multiplication factor to be negligible. Chapter II-E, appendix-4 looked at the effects of varying the fuel rod pitch and determined the maximum k_{eff} as the fuel rod pitch varies. Chapter II-E, appendix-5 evaluated the effects of the drop tests and the resultant deformation of the inner shell and aluminum spacers and found the effect on the multiplication factor to be negligible similar to the analysis in appendix-4. Finally, Chapter II-E, appendix-6 looked at the effects of packaging material within the MX-6P, including cardboard, cotton bags, and PTFE resin, and found to have minimal effect on the package k_{eff}.

Section II-E..4 provides the results of the applicant's benchmarking analysis. The applicant evaluated experiments from the International Criticality Safety Benchmark Evaluation Project, which include a range of enrichments and moderation levels. Since the applicant used the SCALE code package (which has proven to be a robust method of modeling), since all the benchmark calculations were within a half percent of critical benchmark results and given the margin to the maximum k_{eff} of 0.95, the staff finds the benchmarking analysis to be sufficient for use with the MX-6P package.

The staff reviewed the Japanese certificate of compliance for the Model No. MX-6P package, as well as the assumptions used by the applicant, model configurations, analysis, and the results presented in the application. The staff finds that the applicant has conservatively evaluated the criticality safety performance of the Model No. MX-6P package with requested contents of up to eight PWR 14×14 fuel assemblies and has demonstrated that the MX-6P package will remain subcritical for all routine, NCT, and ACT. The staff based its finding on its verification of adequate system modeling performed by the applicant. The acceptance standard of a maximum

k_{eff} of 0.95 was maintained for all analyzed scenarios and meets the requirement that the package maintain subcriticality under all conditions of routine, normal and accident conditions as required by the IAEA SSR-6, 2012 Edition, Paragraphs 637(a) and 682.

7.0 MATERIALS EVALUATION

General Considerations
The purpose of the staff's materials evaluation for the revalidation of the MX-6P package is to assess whether the applicant adequately described and evaluated the materials used in the MX-6P package for ensuring that the package meets the requirements of the IAEA regulations in SSR-6. The staff performed its materials evaluation for the revalidation of the MX-6P package by following the technical guidance in NUREG-2216.

The applicant provided information concerning the MX-6P package materials in chapter I, "Description of Nuclear Fuel Package" and chapter II, "Safety Analysis of Nuclear Fuel Package," sections II-A, "Structural Analysis," II-B, "Thermal Analysis," II-C, "Containment Analysis," and II-E, "Criticality Analysis" of the MX-6P SAR. The staff identified that these sections contain material information and data for packaging components and package contents that are applicable to each of the of respective package functionality analyses for normal conditions of transport and accident conditions of transport.

7.1 Drawings and Description of Package

Chapter I of the application provides the MX-6P package design drawings and a general description of the package. The general description includes information concerning the package contents (new PWR nuclear fuel assemblies), packaging components, component assemblies, component design functions, materials of construction, and fabrication methods. The four major packaging components include the following:(1) the packaging body, (2) the lid assembly, (3) the internal fuel basket, and (4) shock absorbing covers located on the top and rear ends of the package. Section I-C.2 of the application provides general information on the design and construction of the four major packaging components. The staff noted that the four major packaging components incorporate the following subcomponents and materials:

1. The packaging body consists of a cylindrical stainless steel inner shell, stainless steel external plates, stainless steel radial stiffeners that join the inner shell to the external plates, a stainless steel top flange, and the bottom components. Metallic components of the packaging body are joined by welding. The volume enclosed by the inner shell, external plates, and radial stiffeners is filled with a specified type of resin for radiation shielding. The bottom components include a stainless steel bottom plate, bottom resin, and a stainless steel bottom resin cover.

2. The packaging lid assembly consists of the main closure lid made of titanium alloy, low alloy steel closure lid tightening bolts for securing the lid onto the top flange, lid resin, and a stainless steel lid resin cover. The closure lid sealing function is provided by EPDM rubber gaskets that are installed between the contact surfaces of the lid and the top flange. The lid assembly also includes a stainless steel quick connection cover and EPDM rubber sealing gaskets for the quick connection cover.

3. The fuel basket consists of an assembly of stainless steel and aluminum alloy discs for structural support, borated stainless steel lodgments that contain and support the fuel assemblies, aluminum alloy spacers, connecting components, mechanical fasteners,

and other support, alignment, and interfacing components that are described in detail in the application. The lodgments containing the fuel assemblies are welded assemblies of borated stainless steel plates that function as neutron absorbers for the PWR fuel.

4. The top and rear shock absorbing covers consist of welded assemblies of stainless steel plates that enclose a volume. The enclosed volume is filled with a specified type of wood that functions as the shock absorbing material. The top and rear shock absorbing covers are secured to the top flange and to the bottom plate of the packaging body with tightening bolts as specified in the application.

The NRC staff reviewed the MX-6P package design drawings and the general description of the package contents, packaging components, component assemblies, component design functions, materials of construction, and fabrication methods. The staff verified that the application includes drawings that adequately depict the mechanical configuration, geometry, and dimensions of the packaging components. The staff also verified that the application provided an adequate general description of the packaging components, component assemblies, component safety functions, materials of construction, and fabrication methods.

Based on the foregoing evaluation, the staff finds that the design drawings and the general description of the packaging components in the application are acceptable. Therefore, the staff finds that the package meets the requirements in paragraph 640 of IAEA SSR-6.

7.2 Material Specifications and Standards

Section I-C.3 of the application provides information concerning the material specifications and the applicable material consensus standards for the packaging components. For the metallic components of the packaging body, the lid assembly, the fuel basket, and the top and rear shock absorbing covers, the staff noted that the application identifies standard material specifications that are established in internationally recognized consensus standard documents that are managed by internationally recognized standards organizations. Based on its confirmation of the material composition and properties for the metallic packaging components, the staff determined that the material standards specified in the application are suitable for use in the construction of the packaging components.

The nonmetallic components of the packaging include the wood for the shock absorbers, the resin for the packaging body and closure lid assembly, and EPDM rubber gaskets for the closure lid. The staff noted that a national or international material consensus standard is not specified for the nonmetallic items. However, the staff verified that the application specifies sufficient information concerning the composition and properties of these materials to enable staff review of the performance of these materials in the package safety analyses.

Based on the foregoing evaluation, the staff finds that the material specifications and standards included in the application are acceptable. Accordingly, the staff finds that the package meets the requirements in paragraph 640 of IAEA SSR-6.

7.3 Weld Design and Inspection

The application documents the use of welded metallic items for several packaging components, including the packaging body, the fuel basket lodgments, and the top and rear shock absorbing covers. The staff noted that the initial application did not include sufficient technical information concerning the codes, standards, and/or other specifications that are followed for design and fabrication of welds that are used to join the metallic subcomponents for the packaging body, the fuel basket lodgments, and the top and rear shock absorbing covers.

Section II-C.2 of the initial application included some general information on structural strength testing, leakage testing, and nondestructive examination (NDE) activities that are performed for packaging body shell welds that form the containment boundary. However, the staff noted that this section did not include any information on codes, standards, or quality assurance criteria that are applied for weld qualification tests (e.g., mechanical tests of weld samples to ensure the required structural strength) and NDE criteria for inspections of safety-related production welds in packaging components that are placed into service. Further, the staff noted that the general information in Section II-C.2 concerning qualification testing and NDE activities for the packaging body shell welds did not address other safety-related welds such as the other packaging body welds that are not shell welds, the fuel basket lodgment welds, and the welds that join the metallic plates of the shock absorbing covers.

Considering the above findings, the staff issued a request for additional information (RAI) No. 2-1, requesting that the applicant describe the applicable consensus codes, standards, and/or other controls that are followed for design, fabrication, qualification testing, and acceptance inspections of packaging body welds, fuel basket lodgment welds, and top and rear shock absorbing cover welds to ensure that the welds will be capable of maintaining their structural integrity.

In its response to RAI 2-1 dated July 27, 2022 (ML22298A201), the applicant provided a description of the manufacturing processes and inspection methods for the packaging components. The applicant’s description of manufacturing processes includes information on weld joint design and weld fabrication methods for packaging components; quality assurance controls that are applied to welding processes; the identification of consensus standards used for qualification tests of welding personnel; and identification of consensus standards for qualification of welding procedures. The applicant’s description of inspection methods includes identification of NDE methods for inspection of weld joints in packaging components, acceptance criteria for the each of the weld NDE methods, and associated consensus standards.

The staff noted that the RAI response documents the following general requirements for fabrication of packaging body welds and shock absorbing cover welds:

- Welding procedure specifications must be approved before use.
- Welding must be performed in accordance with the approved welding procedure and by welders qualified by an approval laboratory in accordance with the specified standards.
- The welding procedure qualification record shall substantiate full compliance with the mechanical property requirements for component welds.
- Weld seams shall receive the specified NDE according to the specified standards. Weld NDE acceptance criteria are defined in the specified standards.
- Weld NDE must be performed in accordance with approved procedures.

The RAI response describes similar requirements for fabrication of fuel basket lodgment welds:

- The supplier must establish welding documents that must be approved before use.
- Procedures for welding of lodgments and qualification of welding operators must be in accordance with the specified standards.
- Lodgment welds shall receive the specified NDE according to the specified standards. NDE acceptance criteria are defined in the specified standards.
- Lodgment weld NDE must be performed in accordance with approved procedures.

The staff reviewed the applicant's RAI response and confirmed that the applicant provided an adequate description of the weld joint design characteristics and weld fabrication methods for packaging components. The staff also determined that the applicant provided an adequate description of the qualification requirements for welding procedures and welding personnel (including mechanical property tests) and weld NDE methods and acceptance criteria to provide assurance that the packaging welds placed into service will maintain their structural integrity as needed to support the requisite safety functions of packaging components. The staff also determined that the applicant's RAI response included citations of suitable consensus standards for qualification of welding processes and NDE methods for inspection of production welds. Therefore, based on its review of the applicant's response to RAI 2-1, the staff determined that the design, fabrication, qualification, and inspection of the packaging welds is acceptable.

Based on the foregoing evaluation, the staff determined that the welds used in the construction of the packaging components are acceptable since they are designed, fabricated, tested, and inspected to meet the requirements of the applicable construction code and associated welding standards. Accordingly, the staff finds that the package meets the requirements in paragraphs 640 and 648 of IAEA SSR-6.

7.4 Mechanical Properties of Materials

Mechanical Properties

Chapter II-A of the SAR includes information concerning the mechanical properties of the packaging materials. Section II-A.3 includes a listing of the mechanical properties of the packaging materials used in the package structural analyses. Section II-A.4 includes an evaluation of the lowest service temperature performance characteristics of the packaging materials.

Section II-A.3 lists mechanical properties of the metals used in the package structural analyses. Metallic items for which specific mechanical properties are relied upon in the package component structural analyses include stainless steels, low alloy steels, titanium alloy, and aluminum alloy, as specified in the application. This section specifies design yield stress, design tensile stress, percentage elongation, Poisson's ratio, density, Young's modulus, and the coefficient of linear thermal expansion. The staff noted that, where applicable, the properties are specified at temperatures that correspond to the temperatures specified for the applicable structural analysis conditions. The staff reviewed the material properties specified for these items and verified that they are consistent with those specified in the applicable standards and technical literature for these types of materials. Therefore, the staff determined that the mechanical properties of the metallic items for the packaging components are acceptable.

The only nonmetallic item that is credited in the package structural analyses is the wood used in the top and rear shock absorbing covers. Although there are no specific mechanical design properties listed for the wood, the staff verified that section A.10.2, appendix 2 of the application includes an adequate demonstration that the shock absorbing covers are capable of performing their energy absorption function during the analyzed impact events under NCT and ACT. Further, the staff noted that the application documents that the wood is fully encased in welded metal plates. The staff determined that the encasement of the wood in welded metal plates provides assurance that the wood is adequately protected from water intrusion that could degrade its mechanical properties.

Lowest Service Temperature Evaluation

Section II-A.4 includes an evaluation of the lowest service temperature performance characteristics of the packaging materials. This section states that the metallic items used in the packaging will not be susceptible to brittle fracture at the lowest service temperature of -40 °C for the package. The staff reviewed the information in the application regarding the low temperature fracture resistance of the stainless steels, titanium alloy, and aluminum alloy used in the respective shell parts of the packaging body, the lid assembly, the internal fuel basket, and the shock absorbing covers. Based on its review, the staff verified that these materials would not be susceptible to brittle fracture at the lowest service temperature. For the low alloy steel used for the lid tightening bolts and other safety-related connecting bolts, and the stainless steel type used in the top flange and bottom plate of the packaging body, the staff verified that the application documents that these materials are impact tested at -40 °C to ensure that the materials used for these components have the required fracture toughness. The application indicates that the EPDM rubber gaskets used for the closure lid seals and the wood used in the shock absorbing covers will not show a loss of functionality at -40 °C. The staff reviewed these materials and confirmed that they would remain capable of performing their requisite safety functions at -40 °C. Based on its review of the information in section II-A.4 of the application, the staff determined that the lowest service temperature performance characteristics of the packaging materials are acceptable.

Based on the foregoing evaluation, the staff finds that the mechanical properties of the packaging materials used in the package structural analyses and the lowest service temperature performance characteristics of the packaging materials are acceptable. Accordingly, the staff finds that the package meets the requirements in paragraphs 616, 639, 640, and 648 of IAEA SSR-6.

7.5 Thermal Properties of Materials

Section II-B.2 of the application provides thermal properties of the packaging materials used in the package thermal analyses. Section II-B.3 provides service temperature ranges for non-metallic materials. The thermal properties reported in the application include density, thermal conductivity, specific heat capacity, emissivity, and solar absorption. The staff noted that the thermal properties of the packaging materials are specified for the temperature ranges corresponding to those calculated based the thermal analyses of the packaging components. The staff reviewed the thermal properties of the packaging materials and verified that they are consistent with the values available in the technical literature.

For NCT and the simulated fire accident for ACT, the staff confirmed that all packaging materials demonstrate adequate performance considering the maximum component temperatures calculated based on the thermal analyses. For those cases where certain packaging materials show deformation or damage due to the high temperatures associated with the simulated fire accident, the staff verified that the application included adequate evaluations of the impacts of these effects on the other package safety analyses, including the structural and criticality analyses.

Based on the foregoing evaluation, the staff finds that the thermal properties of the packaging materials used in the package thermal analyses are acceptable, and the package meets the requirements in paragraphs 616, 639, and 640 of IAEA SSR-6.

7.6 Criticality Control Materials

Chapter II-E of the application describes the criticality safety analysis for the MX-6P package. The neutron absorber credited in the criticality safety analysis is borated stainless steel. This material constitutes the lodgments (located inside the fuel basket) that directly contain the unirradiated fuel assemblies. The staff noted that that section I-C.3 of the application specifies an established material consensus standard for the borated the stainless steel plates that form the lodgments. The staff reviewed the borated stainless steel material specified in section I-C.3 and verified that it is suitable for use as a neutron absorber because the minimum required boron concentration for the material, as specified in the standard, is used for the criticality analysis and the standard requires chemical analysis to ensure the material contains the minimum boron concentration. Further, the staff confirmed that the package structural and thermal analyses demonstrate that the borated stainless steel plate is unlikely to fail in service, considering the required mechanical properties for the material and evaluations of its performance for NCT and the ACT. Based on its review of the applicant’s response to RAI 2-1 dated July 27, 2022, documented above in Section 7.3 of this SER, the staff determined that there is sufficient information concerning the design, fabrication, qualification, and inspection of the welds for the borated stainless steel lodgments to provide assurance of weld structural integrity to support criticality safety.

Based on the foregoing evaluation, the staff finds that the properties of the neutron absorbing material used in the package criticality analysis are acceptable, and the package meets the requirements in paragraphs 673 and 728 of IAEA SSR-6.

7.7 Chemical and Galvanic Reactions

Section II-A.4 of the application includes an evaluation of the potential for chemical and galvanic reactions of the packaging components and the package contents. This section lists all of the dissimilar materials that may come into contact with each other due to contact between packaging components or contact between packaging components and the package contents. Based on the evaluation of the dissimilar material contacts, the applicant determined that no chemical or galvanic reactions will occur between dissimilar materials when they come into contact with each other since the materials are not chemically reactive and the package is transported in a dry condition. Section II-A.5.2 of the application includes an evaluation of the effects water spray on the external surfaces of the package, which confirms that the stainless steel external surfaces will not deteriorate due to water spray. The application also identifies that non-metallic packaging materials composed of organic compounds, including the packaging body resin and the wood used for the shock absorbers, are encased in unreactive metal and protected from water intrusion.

The staff reviewed this information and confirmed that the MX-6P packaging body is designed to be a leaktight containment boundary for NCT, which will preclude the intrusion of water and dissolved compounds from weather and debris into the package interior. The staff confirmed that all dissimilar materials that may come into contact with each other would not exhibit any significant chemical, galvanic, or corrosive reactions since the materials are not reactive in the dry package environment and they are chemically stable over the temperature range specified for normal operating conditions. For ACT, the staff noted that metallic components would remain chemically unreactive, and organic compounds, while showing some damage (as accounted for in the package thermal analysis) would not show unacceptable performance with respect to their chemical stability and chemical reactivity. Therefore, the staff determined that the application includes an adequate demonstration that packaging components and package contents are suitably protected from adverse chemical and galvanic reactions.

Based on the foregoing evaluation, the staff finds that the design and construction of MX-6P package adequately protects against adverse chemical and galvanic reactions that may affect the ability of the package to perform its safety functions, and the package meets the requirements in paragraph 614 of IAEA SSR-6.

7.8 Content Integrity – Unirradiated Fuel Cladding

Section I-D of the application states that the MX-6P package contains fresh (unirradiated) PWR fuel assembles. This section specifies three types of zirconium alloy cladding for the unirradiated fuel rods, zircalloy-4, MDA, or ZIRLO.

The package structural analyses in section II-A of the application include evaluations of the structural performance of the fuel cladding for NCT and ACT. The application includes fuel cladding integrity evaluations for the following conditions:

- Section II-A.5.3 evaluated the structural performance of the fuel cladding for the 0.3 meter free drop normal operating condition

- Section II-A.9.2 evaluated the structural performance of the fuel cladding for the 9 meter drop test accident condition

- Section II-A.9.2 evaluated the pressure-retaining performance of the fuel cladding at elevated temperature for the fire test accident condition

The evaluations demonstrate that fuel cladding integrity is maintained for these three conditions based on the mechanical properties of fuel cladding listed in table II-A.15, the assumed stress-strain relationship for fuel cladding addressed at the top of page II-A-83 in section II-A.5.3 and depicted in figure II-A.31, and the elevated temperature tensile strength of the fuel cladding identified on page II-A-141 in section II-A.9.2 of the SAR.

The staff noted that the fuel cladding integrity evaluations in sections IIA.5.3 and IIA.9.2 of the SAR do not distinguish between the three types of zirconium alloy cladding that may be used for the unirradiated fuel assemblies contained in the package. Since different types of zirconium alloy cladding materials can show different mechanical properties and stress-strain relationships, the staff did not have sufficient basis for ascertaining that the results of the structural performance evaluations are representative for all three cladding types, considering the potential for significant differences in the mechanical properties and stress-strain relationships for the three zirconium alloy cladding materials.

The staff issued RAI 2-2, requesting that the applicant provide information to demonstrate that the mechanical properties and stress-strain relationship for the fuel cladding, as specified in sections II-A.5.3 and II-A.9.2 of the application (detailed above), are sufficiently representative for all three cladding types identified section I-D of the application to ensure that the three cladding types will maintain their integrity for the 0.3 meter free drop condition, the 9 meter drop test accident condition, and the fire test accident condition, as demonstrated in sections II-A.5.3 and II-A.9.2 of the application.

In its response to RAI 2-2 dated July 27, 2022, the applicant identified that the mechanical properties of the fuel cladding that are reported in the application for the structural analyses are taken from a supplier technical report. The applicant stated that mechanical and physical property data for zircalloy fuel cladding are compiled in this report based on various sources from research institutes, industry sources, and standards organizations. The applicant provided data sheets from the supplier technical report that show tensile strength, percent elongation, Young’s modulus, and Poisson’s ratio as a function of temperature for zircalloy-4. The applicant identified that zircalloy-4 is the material chosen for selecting the values used in the application. Considering the three types of zirconium alloy cladding (zircalloy-4, MDA, or ZIRLO) specified in the application for the unirradiated PWR fuel assembly contents, the applicant stated that zircalloy-4 has the lowest strength of the three cladding types. On this basis, the applicant concluded that the mechanical properties of zircalloy-4 are representative of the three types of zirconium alloy cladding.

The staff reviewed the applicant’s RAI response and confirmed that the values of cladding tensile strength, percent elongation, Young’s modulus, and Poisson’s ratio reported in the application for the evaluation of the 0.3 meter free drop normal operating condition and the 9 meter drop test accident condition are consistent with those reported in the RAI response data sheets at the applicable test temperature. The staff also confirmed that the value of cladding tensile strength reported in the application for the elevated cladding temperature corresponding to the evaluation of the fire test accident condition is consistent with the corresponding value reported in the RAI response data sheet. With respect to the applicant’s assumption that these values are representative of the properties of all three of the cladding types (zircalloy-4, MDA, and ZIRLO) for the evaluations of cladding performance for the drop tests and the elevated temperature test, the staff noted that a lower strength for zircalloy-4 relative to the other cladding types (MDA and ZIRLO) does not correspond to greater protection against cladding failure for drop test conditions if nonductile fracture of the other cladding types were to occur. However, the staff also considered the following criteria in assessing the applicant’s RAI response:

- No plastic deformation was reported for the lower strength zircalloy-4 cladding for either of the drop test conditions;
- There is no significant likelihood of cladding failure based on the large margin between calculated pressure-induced stresses and elevated temperature tensile strength for the fire test condition; and
- Tensile tests for a variety of different zirconium alloy claddings show an acceptable percent elongation at ambient temperature indicating that nonductile fracture is unlikely to occur in the zirconium alloy claddings at ambient temperature.

In considering these factors, the staff ascertained that the applicant’s statement that the zircalloy-4 has the lowest strength of the three cladding types provides reasonable assurance that the other two cladding types would also show acceptable performance for the drop test and fire test conditions since the other two zirconium alloy claddings would likely have greater resistance to ductile failure, and nonductile fracture of the other two zirconium claddings is unlikely to occur at the drop test and fire test temperatures. Therefore, the staff determined that there is adequate basis for ascertaining that the results of the structural performance evaluations are sufficiently representative for all three cladding types. On this basis, the staff determined that the applicant's response to RAI 2-2 is acceptable.

Based on the foregoing evaluation, the staff finds that the fuel cladding is capable of maintaining the fuel in its analyzed configuration during normal and accident conditions of transport, and the package meets the requirements in paragraphs 673, 682, and 726 of IAEA SSR-6.

7.9 Materials Evaluation Findings

Based on the review of the statements and representation in the application, the NRC staff concluded that the applicant adequately described and evaluated the materials used in the MX-6P package and that the package meets the requirements of IAEA SSR-6.

8.0 OPERATING PROCEDURES

The staff reviewed the description of the operating procedures for the Model No. MX-6P package against the standards in the IAEA SSR-6. The package handling procedures in the safety analysis report include sections on package acceptance, loading, unloading, and pre- and post-shipment requirements. The operating procedures have specific measures to be taken prior to each shipment, including ensuring packaging is unimpaired physical condition, loading contents, installing the package closures and confirming that the lid bolts are properly torqued, and measurements of radiation and contamination levels.

9.0 MAINTENANCE PROGRAM

The staff reviewed the description of the maintenance program for the Model No. MX-6P package against the standards in the IAEA SSR-6. The maintenance program includes requirements for each shipment, after 1 year or, if a package is used more than 10 times a year, every 10 package uses, and prior to a use if the package has been stored without use for long period after the last inspection. The maintenance tests include visual inspections, and inspections on basket for criticality safety. The gaskets are replaced prior to each shipment.

10.0 Quality Management System

The purpose of the quality assurance (QA) [i.e., management system in IAEA SSR-6] review is to verify that the package design meets the requirements of the IAEA SSR-6. The staff reviewed the description of the QA program for the Model No. MX-6P package against the standards in the IAEA SSR-6.

10.1 Evaluation of the Quality Assurance Program

The applicant developed and described a QA program for activities associated with transportation packagings for nuclear fuel materials. Those activities include design, procurement, fabrication, assembly, testing, modification, maintenance, repair, and use. The applicant described the QA organization's independence from other branches in the organization, which includes those responsible for product cost and schedule. The applicant's description of the QA program meets the applicable requirements of IAEA SSR-6 and is based on International Organization for Standardization, Standard No. 9001, "Quality management systems — Requirements," 2015 Edition, and other applicable standards. The staff finds the QA program description acceptable, since it allows implementation of the associated QA program for the design, procurement, fabrication, assembly, testing, modification, maintenance, repair, and use of the Model No. MX-6P transportation package.

The staff finds, with reasonable assurance, that the QA program for the MX-6P transportation packaging:

a. meets the requirements in IAEA SSR-6, and
b. encompasses design controls, materials and services procurement controls, records and document controls, fabrication and maintenance controls, nonconformance and corrective actions controls, an audit program, and operations or programs controls, as appropriate, adequate to ensure that the package will allow safe transport of the radioactive material authorized in this approval.

10.2 Evaluation Findings

Based on review of the statements and representations in the Model No. MX-6P package application and as discussed in this SER section, the staff has reasonable assurance that the MX-6P package meets the requirements in IAEA SSR-6. The staff recommends revalidation of Japanese Competent Authority Certificate of Approval J/2037/AF-96, Revision 0.

CONCLUSION

Based on the statements and representations contained in the documents referenced in this evaluation, the staff concludes that the Model No. MX-6P package meets the requirements of the IAEA SSR-6, 2012 Edition.

Issued with letter to Richard W. Boyle, U.S. Department of Transportation, dated December 27, 2022

CERTIFICATE OF APPROVAL NO. J/2037/B(U)F FOR THE MODEL NO. MX 6P PACKAGE – REVALIDATION RECOMMENDATION DATE December 27, 2022

DISTRIBUTION: Docket: 71-3100
KJamerson, NMSS/MSST/MSEB
HLindsay, NMSS/DFM/IOB

ADAMS Accession No.: ML22333A877; ML22333A879 *** via email**

OFFICE	NMSS/DFM/STLB	NMSS/DFM/STLB	NMSS/DFM/IOB	NMSS/DFM/NARAB
NAME	BWhite *BW*	SFigueroa *SF*	AThomlinson ARivera-Varona for *AR*	ABarto *AB*
DATE	Dec 9, 2022	Dec 12, 2022	Dec 15, 2022	Dec 12, 2022
OFFICE	NMSS/DFM/CTCFB	NMSS/DFM/MSB	NRR/DNRL/NVIB	NMSS/DFM/NARAB
NAME	JSolis *JS*	PKoch *PK*	CSydnor *CS*	JSmith *JS*
DATE	Dec 12, 2022	Dec 12, 2022	Dec 15, 2022	Dec 12, 2022
OFFICE	NMSS/DFM/MSB	NMSS/DFM/IOB	NMSS/DFM/CTCFB	NMSS/DFM/CTCFB
NAME	TBoyce SSamaddar for *SS*	ARivera-Varona *AR*	JPiotter *JP*	DMarcano *DM*
DATE	Dec 22, 2022	Dec 15, 2022	Dec 22, 2022	Dec 19, 2022
OFFICE	NMSS/DFM/STLB*****			
NAME	YDiaz-Sanabria NGarcia for *NG*			
DATE	Dec 27, 2022			

OFFICIAL RECORD COPY