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

SAFETY EVALUATION REPORT
Docket No. 71-3057
Model No. MST-30
Japanese Certificate of Competent Authority J/159/AF-96
Revision No. 3

SUMMARY

By letter dated June 3, 2020 (Agencywide Documents Access and Management System [ADAMS] Accession No. ML20156A074), the U.S. Department of Transportation (DOT) requested that the U.S. Nuclear Regulatory Commission (NRC) staff perform a review of the Japanese Certificate of Competent Authority J/159/AF-96, Rev. No. 3, for the Model No. MST-30 transport package and make a recommendation concerning the revalidation of the package for import and export use. The NRC reviewed the safety analysis report against the requirements in International Atomic Energy Agency (IAEA) Specific Safety Requirements, No. SSR-6, "Regulations for the Safe Transport of Radioactive Material," 2012 Edition (SSR-6).

In support of this request, the DOT provided the following documents with its letter dated November 6, 2019:

1. Safety Analysis Report for the Model MST-30 Protective Shipping Package For 30-Inch UF6 Cylinders, Revision No. 6;
2. Tables showing differences in the safety analysis report (SAR) from Revision 1, which NRC reviewed in June 2002;
3. List of Pages with Proprietary information; and
4. Japanese Certificate of Competent Authority - J/159/ AF-96 (Rev. 3).

The NRC previously reviewed and recommended revalidation of Japanese Certificate of Competent Authority J/159/AF-85 for this package on June 2, 2002 (ADAMS Accession No. ML021620003). Based upon our review, the statements and representations contained in the application, and for the reasons stated below, we recommend revalidation of Japanese Certificate of Competent Authority J/159/AF-96, Rev. No. 3 for the MST-30 transport package. This recommendation includes the condition that air transport is not authorized.

1.0 GENERAL INFORMATION

The MST-30 is Type A fissile package consisting of a protective overpack and 30-inch cylinders (30B cylinders) for shipment of uranium hexafluoride (UF_6) enriched up to 5 weight percent (wt. percent) uranium-235.

1.1 Package Description

1.1.1 Packaging

The overpack is a right circular cylinder which is composed of top (upper) and bottom (lower) halves and is constructed of two stainless steel shells with an annulus. The thickness of the outer and inner shells is 3 millimeters (mm) (0.12 inches [in.]) and the thickness of the outer and inner shell endplates is 6 mm (0.24 in.). The packaging is approximately 1.2 meters (m) (47 in.) in diameter and 2.4 m (95 in.) in length. The maximum weight of the overpack is

1,228 kilograms (kg) (2,707 pounds [lbs]) and the maximum gross weight of the package is 4,170 kg (9,193 lbs).

The annulus between the shells is filled with two kinds of shock absorbing and fire resistant foam. Closed-cell polyurethane foam is used in the ends of the package for extra impact resistance and has densities of 0.37 grams per cubic centimeter (g/cm^3) and 0.48 g/cm^3. The annulus of the package is filled with low-chloride phenolic foam.

The 30B UF_6 cylinder is constructed and maintained in accordance with American National Standards Institute N14.1, "Uranium Hexafluoride - Packaging for Transport" or International Standard Organization (ISO) 7195, "Nuclear energy — Packagings for the Transport of Uranium Hexafluoride (UF_6)."

1.1.2 Drawings

The package is constructed in accordance with the drawings provided in Appendix 1.3.2, "Drawing of Model MST-30 Protective Shipping Package," and Appendix 1.3.3, "Drawing of 30B Cylinder."

1.2 Contents

The MST-30 contents include cylinders with UF_6 with a maximum enrichment of 5.0 wt. percent of uranium-235 and a total radionuclide content not to exceed a Type A quantity. A maximum of 2,277 kilograms (kg) (5,020 lb) of UF_6 is allowed per package. The specification of the maximum quantity of radionuclides in the UF_6 is as follows:

- 0.0001 microgram uranium-232 per gram uranium,
- 11.0×10^3 microgram uranium-234 per gram uranium-235,
- 5.0 wt. percent uranium-235,
- 5000 microgram uranium-236 per gram uranium-235,
- Uranium-238 is the balance of total uranium content, and
- 0.01 microgram Technetium-99 per gram uranium.

The applicant stated that the values for uranium-232, uranium-234 and technetium-99 are taken from the radionuclide specification for enriched commercial grade UF_6 in the ASTM International (ASTM) Standard No. C996-2010, "Standard Specification for Uranium Hexafluoride Enriched to Less Than 5 % ^{235}U." The value of uranium-236 complies with the definition of unirradiated uranium in SSR-6.

1.3 Criticality Safety Index

The criticality safety index (CSI) is 0.

2.0 STRUCTURAL EVALUATION

The purpose of the structural evaluation is to verify that the structural performance of the package meets the requirements of IAEA SSR-6. A summary of the staff's structural evaluation is provided below.

2.1 Description of Structural Design

The MST-30 protective shipping package is a Type A fissile material package used for the shipment of 30-inch cylinders containing solid UF_6 enriched to 5 wt. percent or less. It is designed to provide water leak-tightness of the UF_6 cylinder during normal and accident conditions of transport, as required by IAEA SSR-6.

Section 1.1 of this SER includes a general description of the package. Structural design features of the package are described below.

a. The overpack is a right circular container composed of a top and bottom half constructed of stainless-steel shells (outer and inner),

b. The annulus between the inner and outer shell is filled with two kinds of shock-absorbing and/or fire-resistant materials (closed-cell polyurethane foam and phenolic foam), and

c. A ring plate constructed of stainless steel is inserted in the gap on the plug side between the overpack and the cylinder to prevent excessive deformation of the inner shell of the overpack.

The applicant provided figures and diagrams of the MST-30 package in Appendices 1.3.2 and 1.3.3 of the SAR. The staff reviewed the figures and diagrams for completeness and accuracy and finds that the applicant adequately described the relevant details of the major components of the MST-30 package.

2.2 Materials Evaluation

The purpose of the materials evaluation is to verify that the material performance of the MST-30 package meets the regulatory requirements of IAEA SSR-6. The review focused on the materials changes associated with a new ring plate that was added to the design since the NRC's previous recommendation to revalidate the package.

2.2.1 Package Description

SAR Section 1.2 and Figure 1-1 describe the MST-30 package as an overpack, which includes a ring plate used to protect a 30B cylinder containing unirradiated UF_6, with a maximum enrichment of 5.0 wt. percent uranium-235, during transport. Since the NRC's previous recommendation to revalidate the MST-30 package, a stainless steel ring plate was added, seated on a ring plate pad, which is inserted in the gap between the overpack and the 30B cylinder. The ring prevents excessive deformation of the inner shell of the overpack to protect the end of the cylinder where the valve and plug are located. The carbon steel 30B cylinder, valve and plug are defined to be the containment system for the packaging, as defined in Paragraph 635 of SSR-6.

2.2.2 Drawings

The staff reviewed the SAR, Appendix 1.3.2, "Drawing of Model MST-30 Protective Shipping Package," and Appendix 1.3.3, "Drawing of 30B Cylinder," and verified that the applicant provided an adequate description of the component safety functions, materials of construction, dimensions and tolerances, and fabrication specifications. The staff finds that the applicant provided acceptable information in the SAR and associated drawings to describe the package materials. Therefore, the staff finds the package design drawings acceptable and meets the requirements in Paragraph 640 of IAEA SSR-6.

2.2.3 Design Criteria

2.2.3.1 Codes and Standards

SAR Section 2.1.2 described design criteria and Appendix 2.10.1, “Compliance Test Report for the MST-30 Protective Shipping Package,” stated that the package is designed to conform to the technical and regulatory requirements of a Type A fissile material package as specified in the current Japanese Safe Transport Regulations pursuant to IAEA SSR-6. In addition, an analysis was conducted to evaluate the structure of a Type A fissile package under normal conditions of transport and accident conditions of transport. The applicant referenced the Japan Society of Mechanical Engineers (JSME) S NC1-2005/2007 “Codes for Nuclear Power Generation Facilities – Rules on Design and Construction for Nuclear Power Plants.” The staff notes that the American Society of Mechanical Engineer (ASME) Boiler and Pressure Vessel (BP&V) Code Section III, Division 1 is the counterpart to JSME S NC1.

SAR Table 2-2 described metal properties of the MST-30 packaging conforming, typically, to Japanese Industrial Standard (JIS) G 4303 “Stainless Steel Bars,” JIS G 4304, “Hot-Rolled Stainless Steel Plate, Sheet and Strip,” or JIS G 4305, “Cold-Rolled Stainless Steel Plate, Sheet and Strip,” and that several potential stainless steel types, (e.g., equivalent to ASTM Types 304 and 316) are used within those standards. SAR Table 2.10.6-1 described the material properties used in analysis models of the MST-30 package, including the new JIS SUS304 stainless steel ring plate. The staff finds that the applicant adequately referenced the MST-30 package materials codes and standards, which provide materials chemistry, mechanical properties, and fabrication requirements. Therefore, the staff finds the package material codes and standards to be acceptable, as required by Paragraph 640 of IAEA SSR-6.

2.2.3.1 Weld Design and Inspection

The staff notes that no welding and related inspection are required for the fabrication and installation of the new ring plate.

2.2.4 Material Properties

2.2.4.1 Mechanical Properties

SAR Section 2.3 and Table 2-2 described mechanical properties of stainless steel materials used for the MST-30 overpack, including the JIS SUS 304 used to construct the new ring plate. The staff reviewed the temperature-dependent mechanical properties of stainless steels used in the applicant’s mechanical calculations and confirmed that the properties are consistent with those in the technical literature (e.g., ASME B&PV Code Section II, data sheets, handbooks, etc.). The staff finds the applicant adequately identified the properties of the stainless steel used in the design and fabrication of the MST-30 ring plate. Therefore, the staff finds the ring plate mechanical properties to be acceptable as required by Paragraph 639 of IAEA SSR-6.

2.2.4.2 Thermal Properties

SAR Section 3.2 and Table 3-3 described the thermal properties of the MST-30 package materials used in the thermal evaluation of the package. The staff evaluated the applicant's thermal properties of the materials credited in the thermal analysis (e.g., thermal conductivity, specific heat, density, etc.) and determined that the thermal properties are consistent with those in the technical literature. The staff finds the applicant adequately identified the thermal properties of the materials (i.e., ring plate) used in the Model MST-30 package. Therefore, the staff finds the ring plate thermal properties to be acceptable as required by Paragraph 639 of IAEA SSR-6.

2.2.4.3 Fracture Toughness

SAR Section 2.6.2 described the minimum design temperature of the MST-30 package is limited to -20°C (-4°F) for cold conditions of transport as specified in the design certificate of Model MST-30. The applicant stated that JIS SUS304 stainless steel used in fabrication of the Model MST-30 overpack has no possibility of the ductile to brittle transition since these are austenitic. The staff finds that the applicant has adequately considered fracture toughness behavior in the Model MST-30 package design because the austenitic stainless steel used in the ring plate construction provides excellent fracture toughness at low service temperatures. Therefore, the staff finds the ring plate fracture toughness to be acceptable as required by Paragraph 639 of IAEA SSR-6.

2.2.5 Corrosion, Chemical Reaction and Radiation Effects

2.2.5.1 Corrosion Resistance/Content Reactions

SAR Section 2.4.4 described chemical and galvanic reactions. The applicant stated that the MST-30 materials of construction are such that no significant chemical or galvanic reactions occur between the package components and/or the package contents. The staff notes that the new stainless steel ring plate is housed within the outer overpack, which is sealed with a 13 mm (½-inch) thick silicone rubber gasket to prevent water ingress that could lead to corrosion of the internal package materials during normal conditions of transport. The staff notes that stainless steel is highly resistant to corrosion in this environment. The staff also notes that periodic visual inspections of the ring plate can identify corrosion, should it arise. The staff finds that the applicant appropriately accounted for chemical and galvanic reactions and that no credible corrosion, galvanic or other adverse reactions of the MST-30 unirradiated UF_6 package will exist during normal conditions of transport. Therefore, the staff finds the corrosion resistance and content reactions to be acceptable as required by Paragraph 614 of IAEA SSR-6.

2.3 Mechanical Analysis

The following sections include discussions of the information provided by the applicant related to the mechanical analysis of the MST-30.

2.3.1 Stacking Test

The IAEA SSR-6 requires subjecting packages to compressive loads as defined in Paragraph 723. Since the shape of the MST-30 prevents stacking, this test is not applicable to this package.

2.3.2 Lifting Test

In Section 2.5.1 of the SAR, the applicant described the analysis of the lifting devices. The MST-30 may be lifted using either a fork-truck or a crane. For crane lifting, the package is lifted using slings or shackles. The package is fitted with four shackle fixtures that are welded to the outer shell of the bottom half of the overpack. The material of the shackle fixtures is stainless steel and each shackle has a minimum proof load of 15,872 pounds force (lbf). The applicant evaluated the load and stresses that will develop in the lifting shackles from lifting operations. The margin of safety between the calculated lifting load and the minimum proof load using an angle of 60 degrees is 4.9 and the margin of safety against yielding is 7.2.

The staff reviewed the analysis submitted by the applicant for the lifting devices. The staff finds that the applicant appropriately evaluated all lifting attachments to ensure the package meets the requirements prescribed in IAEA SSR-6.

2.3.3 Penetration Test

In Section 2.6.10 of the SAR, the applicant stated that dropping a 6 kg (13 lb) rod has a negligible effect on the 3 mm stainless steel shell of the MST-30. Based on the thickness of the package shell, the applicant concluded that the penetration test will cause no significant damage to the package. Therefore, a penetration test was not performed. The staff finds that the licensee's conclusion is acceptable.

2.3.4 Tie-Down Test

The MST-30 package is tied down to the conveyance at eight bolted locations in the foot plate using M18 bolts. The applicant used the criteria in 10 CFR 71.45(b) and evaluated a vertical component of 2 times the total weight of the package, a horizontal component along the direction in which the vehicle travels of 10 times the total weight of the package, and a horizontal component in the transverse direction of 5 times the total weight of the package. The applicant calculated a margin of safety against shearing of 1.39 and a margin of safety against yielding of 1.16.

The staff reviewed the analysis submitted by the applicant for the tie-down bolts. The staff finds that the applicant appropriately evaluated the tied-down attachments to ensure the package meets the requirements prescribed in IAEA SSR-6.

2.4 Structural Evaluation under Normal and Accident Conditions of Transport

The following sections include a summary of the information provided by the applicant related to the structural analysis during normal and accident conditions of transport for the MST-30.

2.4.1 Drop Tests

The applicant performed a series of drop tests with various impact configurations as described in the SAR Sections 2.6.7, 2.6.8 and 2.7. The applicant used three prototype packages having the same structural features of an actual MST-30 package for the tests. The applicant performed tests using a series of full-scale progressive drops to account for conditions during normal and accident conditions of transport, including the following:

(1) free drop from 0.98 ft (0.3 m),
(2) free drop from 4 ft (1.2 m),
(3) free drop from 30 ft (9m), and
(4) drop tests from 3.28 ft (1 m) onto a punch bar.

The drop test orientations were chosen to cause maximum damage to the package including vertical, corner and horizontal drops, with configurations including a side drop on the valve and a side drop on the plug. After the drop testing campaign, the applicant concluded that the overpack was not breached during the series of drops, that the overpack remained closed at all times, and that no water ingress occurred. The results and deformations identified during the drop testing campaign are summarized in Table 2-4 of the SAR.

In addition to the physical drop tests, and because the prototype tests were conducted without the ring plate, the applicant developed a finite element model of the package using the LS-DYNA code for the vertical end drop and corner drop configurations. The analyses were performed in order to confirm that the cylinder valve and plug did not make contact with the overpack. Based on the results of the analyses, the applicant demonstrated that the valve and plug do not make contact with the overpack.

The staff reviewed the analysis and test results submitted by the applicant and finds that these tests and analysis, in aggregate, meet the requirements of IAEA SSR-6 for drop tests under normal and accident conditions of transport.

In addition to the test drop configurations performed by the applicant for accident conditions of transport, the staff postulated a scenario of a 9 m (30 ft) drop in which the protruding fasteners of the overpack hit the non-yielding surface. Although not specifically prescribed by IAEA SSR-6, this postulated scenario was considered due to the importance of the overpack to remain in place for the criticality evaluations. The staff considered the following factors in assessing this scenario: 1) the structural capacity of the materials and dimensions used for the fasteners; 2) the results of the applicant's testing campaign for which, under consecutive and cumulative drops, the applicant did not identify damage to the fasteners or overpack that would impair the safety function of the overpack; and 3) previous experience with reviews of similar packages in which the drop configuration with the fasteners hitting the non-yielding surface did not result in failure of the fasteners. Based on these factors, the staff concluded that the overpack fasteners will not fail under the postulated drop scenario. Therefore, the staff concludes that the overpack will continue to perform its safety function under the 9m drop scenario.

2.4.2 Water Immersion Test

In Section 2.7.4 and 2.7.5 of the SAR, the applicant stated that the criticality analysis assumes that water does not enter the 30B cylinder. The applicant concluded that, based on the results of the drop test campaign and subsequent tests of the cylinder boundary, no water enters the cylinder under the accident conditions of transport. The applicant performed helium leak testing of the 30B cylinders, which are further discussed in Chapter 4, in order to calculate maximum leak rates. Based on the results of the leak test, the applicant concluded that the cylinders will not leak and will maintain containment.

2.5 Evaluation Findings

Based on a review of the description of the design, mechanical and materials evaluations, and a structural evaluation during normal and accident conditions of transport, the staff finds that the structural and materials performance of the MST-30 meets the requirements of IAEA SSR-6.

3.0 THERMAL EVALUATION

The objective of the thermal evaluation is to demonstrate that the package meets the thermal performance requirements of the IAEA SSR-6, when evaluated for normal and accident conditions of transport as defined in the IAEA regulations. The MST-30 was issued a US DOT certificate, with the requisite review and approval by NRC, on July 18, 2002. In the previous application (ADAMS Accession No. ML010370156), the applicant evaluated the thermal response of the package through prototype testing and analytical evaluation. The MST-30 is provided with insulation to assure that the UF_6 temperatures and the internal pressure of the 30B cylinder are maintained below the specified design limits. Changes made to the package to meet the requirements for the 2012 version of IAEA SSR-6 do not have any impacts on the current thermal performance of the package.

3.1 Normal Conditions of Transport

The thermal performance of the MST-30 package with the newly defined contents, which were only slight changed from those originally approved by the staff will have no effect on the thermal performance and continues to be bounded under normal conditions of transport. Therefore, the package meets the requirements of IAEA SSR-6.

3.2 Accident Conditions of Transport

The thermal performance of the MST-30 package with the newly defined contents, which were only slight changed from those originally approved by the staff ,will have no change on the thermal performance, continues to be bounded under accident conditions of transport. Therefore, the package meets the requirements of IAEA SSR-6.

3.3 Evaluation Findings

Based on the staff's review of the thermal and related sections of the application, the staff agrees with the applicants' conclusion that the MST-30 package meets the thermal standards of IAEA SSR-6 for normal and accident conditions of transport.

4.0 CONTAINMENT EVALUATION

The objective of the containment evaluation is to demonstrate that the package meets the containment performance requirements of the IAEA transport regulations found in IAEA SSR-6, when evaluated for normal and accident conditions of transport as defined in the IAEA regulations.

4.1 Containment Boundary

In the previous application, the applicant evaluated the containment performance of the package through review of the containment boundary for the package, which is the 30B cylinder. The applicant states that the package is designed to maintain a leakage rate that excludes water from entering the cylinder and prevents UF_6 from leaking out of the cylinder, for both normal and accident conditions of transport.

The primary change to the 30B cylinder described in the current application, specifically in Sections 4.1 and 4.1.3 of the SAR, is to specify that only a socket head plug may be used on the 30B cylinder, and not a hex head plug, or, alternatively, a cylinder without a plug and plug coupling. These changes do not affect the containment boundary and therefore do not impact the staff's previous findings.

4.2 Leak Testing

In their 2001 application, the applicant proposed to conduct several leak tests on the package to ensure that it excludes water from entering the cylinder and prevents UF_6 from leaking out of the cylinder, for both normal and accident conditions of transport.

Detailed descriptions of the helium leak test proposed by the applicant may be found in Appendix 2.10.5 of the SAR and the tests proposed generally comply with the standards in American National Standard Institute (ANSI) N14.5-1997, "For Radioactive Materials — Leakage Tests on Packages for Shipment," and ISO 12807 1996, "Safe Transport of Radioactive Materials — Leakage Testing on Packages."

The staff's review of the applicant's 2001 evaluation agreed with the applicant's conclusion that the containment boundary excludes water from entering the cylinder and prevents UF_6 from leaking out of the cylinder, for both normal and accident conditions of transport. The staff's original finding remains valid for this application.

4.3 Evaluation Findings

Based on the staff's review of the containment and related sections of the application, the staff agrees with the applicants' conclusion that the MST-30 package meets the containment standards of IAEA SSR-6 for normal and accident conditions of transport.

5.0 SHIELDING EVALUATION

The purpose of the shielding review is to confirm that the package together with its contents meet the external radiation requirements in IAEA SSR-6. These requirements include the radiation level limits for routine transport and the limits on the changes in the package radiation levels resulting from normal conditions tests (test conditions in Paragraphs 719-724). Since the package is a Type AF package, the radiation level limits for packages experiencing accident conditions (test conditions in IAEA SSR-6, Paragraphs 726-729) do not apply.

The purpose of the package is to ship commercial-grade, low-enriched, solid uranium hexafluoride (UF_6). The material is unirradiated and is not enriched from recycled uranium. The maximum enrichment is limited to not more than 5 wt. percent. Per Table 2 of IAEA SSR-6, unirradiated uranium of this enrichment is a Type A quantity.

5.1 Description of Shielding Design and Summary of Radiation Levels

The packaging is composed of a 30B cylinder fabricated to the specifications of ANSI N14.1 and ISO 7195; an overpack with steel inner and outer shells, the cavity of which is filled with foam materials; and a stainless steel ring plate that fits in the cavity of the overpack on the plug side of the 30B cylinder. The packaging does not have any components with a primary function of shielding, though the steel components do provide gamma shielding.

The applicant's summary table of radiation levels (Table 5-1 in the application) shows the package radiation levels are below the limits for non-exclusive use with significant margins (see IAEA SSR-6 Paragraphs 526 and 527). It also shows that the changes in radiation levels as a result of the normal conditions tests do not exceed the limit of 20 percent (IAEA SSR-6 Paragraph 648).

5.2 Source Term and Shielding Models

The applicant developed source terms using the ASTM C996 standard's specification for commercial grade low enriched uranium at the maximum enrichment of 5 wt. percent. The applicant decayed the uranium and allowed impurities for 10 years to allow accumulation of uranium-232 progeny using the ORIGEN-2.2 computer code. The staff notes that ORIGEN-2.2 is an old code that has not been supported by the code developer for many years. Thus, the staff has concerns with the use of this code; however, given the significant margins to the limits and the staff's confirmatory calculations described below, the staff finds use of this code is adequate for this application. While there are some neutrons produced in the contents, the applicant determined they contribute negligibly to the package radiation levels. Thus, the neutron source is ignored for the analysis. Based on experience with other similar packages, the staff identified that the neutron source may contribute a few percent to package radiation levels. With the significant margins to the limits, the staff finds that neglecting the neutron source is acceptable.

Since only the gamma source is used, the applicant used a point-kernel code, QAD-CGGP2R, to calculate package radiation levels. QAD-CGGP2R is a revised version of the QAD-CGGP code available through the Radiation Safety Information Computational Center at Oak Ridge National Laboratory. The applicant also used the dose conversion coefficients in International Commission on Radiological Protection (ICRP) Publication 74, "Conversion Coefficients for use in Radiological Protection against External Radiation." Given the simplicity of the model and the package and the margins to the limits, staff finds the use of this code is acceptable. Also, while the staff does not agree that the ICRP Publication 74 conversion factors are the appropriate factors for calculations of package radiation levels[1], given the significant margins to the limits, the staff finds their use in this case to be acceptable.

The applicant modeled the 30B cylinder as a right circular cylinder with flat axial ends at the maximum outer dimensions and nominal wall thickness specified in ANSI N14.1 for a 30B cylinder. The applicant modeled the 30B cavity filled with the maximum allowed mass of UF_6. The applicant neglected the ring plate in the model. The applicant ignored the materials of the overpack but credited the spacing provided by the overpack. The applicant slightly reduced the spacing for the routine conditions model and further reduced it uniformly by 6 cm (2.4 in.) around the cylinder for the normal conditions model. Based on the impacts of the normal conditions tests (including no impacts on the 30B cylinder), the staff finds that the normal conditions model bounds the deformation from the tests, with the exception of one instance

[1] Package radiation level limits are in terms of dose equivalent and confirmation at the time of shipment is by measurement, whereas conversion factors such as those used in ICRP Publication 74 are in terms of effective dose equivalent, which is a different dose quantity and one that is not measured, but requires calculation to derive from measurements.

having a slightly larger deformation in one dimension. However, given the significant margins, staff finds this acceptable.

The material properties in the model are given in Table 5-4 in the application. The material specifications for the contents are consistent with the maximum mass allowed in the package. The applicant modeled the carbon steel of the 30B cylinder as iron with a slightly lower density than is typical for carbon steel. A lower density is conservative and therefore acceptable.

5.3 Summary of Radiation Levels

The applicant calculated radiation levels at the package surface, at the center of one axial end and the midpoint of the radial side, and at 1 meter (40 in.) from package surface at these same points for the routine conditions model. For the normal conditions model, the applicant calculated the radiation levels at the new package surface position at the center of one axial end and at the midpoint of the radial side. As discussed in Section 5.1, above, the radiation levels in Table 5-1 of the application show the regulatory limits are met with significant margins and that the radiation levels increase by less than 20 percent when normal conditions impacts are considered.

The staff performed simple confirmatory calculations. The staff used the Radiological Toolbox Version 3.0.0 computer code to determine the progeny after 10 years of decay for each uranium isotope at the amount allowed in the certificate for the allowed maximum enrichment level, using the ASTM C996 uranium specifications. Comparison of the calculated quantities of radionuclides with the values in Table 5-2 of the application showed acceptable agreement with the staff's results. The staff used the MicroShield Version 12.00X computer code to calculate gamma radiation levels and modeled the contents as uranium at a density equivalent to the maximum UF_6 mass for the same dimensions as the applicant used. The staff input the source as the quantities of the uranium isotopes, their progeny, and the technetium-99 allowed by the certificate specifications. The staff placed measurement points at the same radial positions used by the applicant for the radial side of the package (the staff only calculated radiation levels for the radial side locations). The results of the staff's calculation are bounded by the applicant's results and confirm the applicant's conclusions.

The staff notes that ANSI N14.1 allows the 30B cylinder walls to become as thin as 0.794 cm (0.313 in.). Evaluations with this wall thickness showed a 15% to 20% increase in radiation levels, but this is still significantly below the limits. The staff also notes that residual hydrates are allowed in the 30B cylinder as well at amounts up to 11.3 kg (24.9 lb) per ANSI N14.1. The applicant did not evaluate the impact of these hydrates. Based on staff experience, consideration of these hydrates could increase radiation levels by about 25 times at the package surface and about 15 times at 1 meter from the package, depending on the configuration in the package. Even accounting for these increases, the radiation levels for the MST-30 will still remain well below the regulatory limits.

5.4 Evaluation Findings

Based on a review of the information and representations provided in the application and the staff's confirmatory calculations, the staff has reasonable assurance that the MST-30 package with its contents will satisfy the shielding requirements and radiation level limits in IAEA SSR-6.

6.0 CRITICALITY EVALUATION

The purpose of the criticality review is to confirm that the packaging together with its contents meet the criticality safety requirements in IAEA SSR-6. These requirements include being subcritical under routine transport, normal conditions (test conditions specified in Paragraph 684(b)) and accident conditions (test conditions specified in Paragraph 685(b)). They also include defining an appropriate CSI, which limits the number of packages that can be shipped together to ensure subcriticality (Paragraph 686). The applicant requested a reduction of the CSI from 5.0 to 0.0 and performed a completely new criticality analysis to support the requested CSI reduction.

6.1 Description of Criticality Design

The package is designed for the transport of commercial-grade low-enriched UF_6 up to a mass of 2,277 kg (5,020 lb) and a maximum enrichment of 5 wt. percent uranium-235. The packaging components include a carbon steel 30B cylinder, with its valve and plug, that are designed and constructed in accordance with the ANSI N14.1 or ISO 7195 standards, consistent with the requirements in IAEA SSR-6, Paragraphs 631–634. The packaging also includes a stainless steel ring plate and an overpack. The ring plate is placed in the overpack cavity with the 30B cylinder, on plug end of the 30B cylinder. Its purpose is to prevent excessive deformation of the internal end plate of the overpack on the plug side of the 30B cylinder. The overpack is comprised of an inner and an outer stainless steel shell of nominal 6 mm (0.24 in.) thickness each. The steel is the equivalent to ASTM SS-304. The spacing between the shells is filled with polyurethane and phenolic foams for impact resistance. There are no neutron absorbers in the package.

The 30B cylinder is the containment system for the package. The overpack and ring plate function to protect the 30B cylinder from the effects of normal and accident conditions, evaluated per the requirements in IAEA SSR-6, Paragraphs 684(b) and 685(b), respectively. Given the nature of the contents and to ensure criticality safety, a design criterion of the package is that it withstand these tests without leakage, consistent with the requirements in IAEA SSR-6 Paragraphs 631–634. The impacts of the specified tests and the performance of the package's containment are described, above, in the structural, thermal, and containment sections of this SER. As described in those SER sections, the containment function is maintained sufficiently to prevent leakage of water into the package. Even so, the applicant evaluated the amount of water that could leak into the 30B cylinder as moist air over a period of 1 year using the highest measured leak rate; the amount was negligible.

As described, above, in the structural and thermal sections of this SER, the other impacts to the package from the required normal and accident conditions tests are confined to the overpack. In other words, there are no impacts to the 30B cylinder with one exception. For the Drop II test specified in IAEA SSR-6 Paragraph 727(b), with the point of impact on the package top (radial side), the applicant noted that there is slight deformation of the 30B cylinder, though it does not affect the cylinder's containment function.

Additionally, the overpack top half is held in place by fasteners that attach it to the bottom half of the overpack. These fasteners protrude out from the overpack body (i.e., are not recessed in the overpack shells). Thus, the staff considered that dropping the package such that the fasteners impact the target surface first might result in the fasteners failing, allowing the overpack top half to come off of the package and expose the 30B cylinder. However, based on the evaluation described, above, in the structural section of this SER, even though the package was not dropped in this orientation, the staff determined that such a drop would not result in greater damage to the package nor would it result in the top half of the overpack being able to separate from the bottom half. This is important for evaluating any credit given for the overpack in the criticality analyses, since taking any credit for the spacing and materials of the overpack would result in decreases in k-effective (k_{eff}) in analyses of package arrays. It is also important because the staff's evaluation and recommendation to revalidate the package certificate relies upon the applicant's analyses with the applicant's model that gives the most credit for the overpack, as described in the rest of this criticality evaluation section of the SER.

As identified below, various aspects of the applicant's analysis proved to be non-conservative for the 30B cylinder or otherwise do not represent the most reactive system. Based on the staff's confirmatory calculations, analyses with the bare 30B cylinder and analyses with one of the two models crediting the overpack would yield k_{eff} values in excess of the applicant's upper subcritical limit (USL), if these non-conservative aspects in the applicant's analysis were to be addressed. However, if the applicant addressed the same non-conservative aspects in the analyses with the model that takes the most credit for the overpack (this model is conservative and bounding versus the results of the normal transport and accident conditions tests), the applicant's results would still be subcritical (i.e., still below the USL). Thus, credit taken for the damaged overpack becomes necessary to demonstrate the package will be subcritical.

Chapter 6 of the application summarizes the criticality analysis for the package, while Appendix 6.7.1 provides more details about the analysis including different sensitivity studies that the applicant conducted to determine the most reactive conditions of the package and its contents. The results the applicant used to show subcriticality are for a bare 30B cylinder with a small external layer of full density water and the contents, including impurities as described in Figures 6-1(a) and 6-1(b) and Table 6-1 of the application. Table 6-2 in the application provides the result of that calculation, showing that k_{eff} plus 3 times the standard deviation (i.e., $k_{eff} + 3\sigma$) equals 0.949. Which is less than the applicant's USL. Though not explicitly stated, the staff expects the applicant's USL to be 0.95, which includes an administrative margin of 0.05. This maximum is for an infinite array of packages in a triangular pitch array. Thus, the CSI is specified as 0.0.

The applicant only performed analysis for the infinite array of packages under accident conditions, stating that this would bound the results for the evaluations of individual packages (i.e., package in isolation) specified in IAEA SSR-6 Paragraph 682 since the array accounts for neutron interactions between packages, which increase k_{eff}. Also, since the accident array accounts for the cumulative effects of the normal conditions and accident conditions tests and the array is infinite, the applicant determined that the accident array would bound an infinite normal conditions array. Since, with a CSI of 0.0, both arrays would be infinite, and the accident array includes damage from the normal as well as the accident conditions tests, which enhances neutron interaction between packages, the staff agrees that the accident array would bound the normal conditions array in terms of maximum k_{eff}. Also, given the package design, the staff expects a significant amount of neutron interaction between packages in an array and thus agrees that the array results will be bounding for packages in isolation. Therefore, the staff finds it acceptable to only perform analyses of the accident array.

6.2 Package contents

The package contents are unirradiated, commercial-grade, low-enriched UF_6. The maximum mass of the UF_6 is limited consistent with ANSI N14.1 and ISO 7195 to 2,277 kg (5,020 lb). The maximum enrichment is 5 wt. percent uranium-235, also consistent with the standards. UF_6

enriched from recycled uranium is not allowed or analyzed for. The specifications of the uranium follow those given in ASTM C996 for commercial-grade uranium, including the impurities of several uranium isotopes and technetium-99. For purposes of the criticality analysis, the impurities are neglected, and the uranium is assumed to be 5 wt. percent uranium-235 with the remaining being uranium-238. The contents purity level is specified as at least 0.995 percent UF_6, which is consistent with the standards and forms the basis for the standards' maximum enrichment specification. This means that a maximum of 11.385 kg (25 lb) of impurities may be present in the contents. For the criticality analysis, these impurities are assumed to be entirely anhydrous hydrogen fluoride (HF), to maximize moderation within the package, which maximizes reactivity.

Additionally, due to reuse of the 30B cylinder, residual hydrates may also be present. The applicant briefly mentions, without details, a determination of the amount or these residual hydrates. In the analysis, the applicant assumed an amount of hydrates equivalent to 300 grams (0.66 lb) of uranium. The hydrates may take various forms, typically a combination of uranyl fluoride (UO_2F_2) with some amount of water (H_2O) and possibly HF. For the criticality analysis, the applicant selected a hydrate form that maximizes the ratio of hydrogen to uranium to increase moderation within the package, which maximizes reactivity. The staff finds that the packages are an under-moderated system; thus, assumptions which maximize moderator in the packages will, for the amounts of moderator being added, result in increased reactivity. Therefore, the staff finds that modeling the impurities as all HF and selecting a hydrate form that maximizes the ratio of hydrogen to uranium in the hydrates is acceptable. Staff review of the amount of the residual hydrates is discussed below.

6.3 General Considerations for Criticality Evaluations

6.3.1 Model Configuration

As stated above, the applicant's model is shown in Figures 6-1(a) and 6-1(b) of the application. The applicant designed the model to be bounding for the combined impacts of the normal conditions and accident conditions tests specified in IAEA SSR-6, Paragraphs 684(b) and 685(b). The design basis model is a bare 30B cylinder with a thin layer of full density water. The water layer thickness is set to maximize k_{eff}. The applicant modeled the 30B at the maximum outer dimensions, including tolerances, specified in standards ANSI N14.1 and ISO 7195. The applicant modeled the cylinder walls as 1.1 cm (0.43 in.) thick. The applicant also modeled the cylinder with the axial ends flat, versus being round as is the actual 30B design. The model neglects the valve, plug and skirts of the cylinder. Neglecting these other items reduces the amount of materials that could absorb neutrons as well as allows for closer spacing between adjacent packages in the array model, which results in higher k_{eff}. The applicant placed the package model in a hexagonal prism that, outside of the thin water layer is void. With this geometry, the array has a triangular pitch which places the packages in a more compact array than a square pitch array, increasing the neutron interaction between packages and the array's k_{eff}. A reflective boundary condition on each surface of the hexagonal prism creates the infinite array.

With respect to the package contents, the applicant's most reactive model is a heterogeneous model of the UF_6, the impurities and the residual hydrates, with the 30B cylinder completely filled. As seen in the application figures, the hydrates are concentrated into a small sphere, which is surrounded by a shell of UF_6. This UF_6 shell is then surrounded by a shell composed of the HF impurities. The applicant positioned this multi-layer sphere so that it is touching the center of the wall at one axial end of the 30B cylinder. The rest of the cylinder is filled with UF_6

with a density to keep the quantity at the maximum mass allowed in the 30B cylinder. The selection of this configuration for the contents, including the dimensions of the heterogeneous configuration are based on a sensitivity study described in the proprietary Appendix 6.7.1 of the application. That same appendix also includes a conservative evaluation of the impacts of moisture ingress as well as an evaluation of the effects of different levels of credit for the overpack.

As part of the review, the staff evaluated the sensitivity study in Appendix 6.7.1. The staff identified that some aspects of the model configuration also depend upon the densities of the materials. This aspect is discussed below in the section about material properties. As part of the review, the staff also considered UF_6 packages certified by the NRC for domestic transport. Identification of similarities and differences in package models and sensitivity trends helped to inform the staff's review. The staff determined that neglect of items such as the 30B valve, skirts, and plug is acceptable because this results in a more compact array and removes material that absorb neutrons, leading to increased array k_{eff}. The staff also finds that minimum wall thickness for the 30B cylinder is acceptable because this also minimizes neutron absorption in the 30B cylinder wall, which increases the k_{eff}. The staff noticed that the minimum wall thickness used in the MST-30 analysis is larger than the minimum that is allowed by ANSI N14.1. This is acceptable because the Japanese certificate for the package and the 5-year periodic inspection criterion in paragraph 8.2.2.2(c) of the application require that the 30B wall be at least 11.3 mm (0.444 in.) thick to remain in service. Thus, the thickness used in the criticality analysis is bounding for the allowed minimum thickness for this package.

Based on experience with other packages, the staff would typically accept that using the maximum outer dimensions for the 30B cylinder would be bounding. However, there are differences between the analysis for those packages and the MST-30 that make use of the minimum outer dimensions, including tolerances, specified in ANSI N14.1 and ISO 7195 the more reactive configuration. Also, based on the staff's confirmatory analysis, the staff determined that a configuration with minimum 30B outer dimensions is more reactive. The difference in reactivity is enough that the k_{eff} of the applicant's design basis model would exceed the applicant's USL of 0.95. The staff also investigated the impact of changing the shape of the axial ends of the 30B in the model to be rounded like they are in the actual 30B design. Staff experience has been that a model with flat ends is more reactive; however, staff confirmatory calculations showed that a model with round ends is more reactive for the MST-30. Differences in analysis approaches lead to this deviation from staff experience. The difference in reactivity for this model change also is enough that the k_{eff} of the applicant's design basis model would exceed the applicant's USL.

The staff finds that modeling a bare 30B cylinder with just a thin layer of water is bounding since the normal conditions and accident conditions tests show the overpack remains in place around the cylinder, though with various levels of damage. The use of a water layer around the 30B cylinder accounts for any water that can leak into the overpack and get around the cylinder. The staff does note that the 30B cylinder is described as being slightly deformed due to the Drop II tests performed in accordance with IAEA SSR-6, Paragraph 727(b). The staff used the description of that damage in the application to estimate a potential amount of deformation the 30B cylinder experienced and conservatively applied that uniformly to the radial surface of the 30B cylinder in the staff's confirmatory calculations. The result was an increase in reactivity, again enough to exceed the applicant's USL, though the effect would likely be negligible for a more realistic evaluation that confined the deformation to the area of the 30B cylinder impacted in that test.

In reviewing the configuration of the contents, including the residual hydrates and the impurities, the staff identified that various features were consistent with staff experience, while others were not. The staff used that experience and the information provided in the application to identify potentially more reactive configurations than what the applicant considered. These included differences in the size of the UF_6 shell in the multi-layer sphere of hydrates, UF_6 and impurities and the position of the sphere relative to the 30B cylinder wall. Staff calculations confirmed some aspects of the applicant's configuration to be the most reactive. However, the staff's calculations indicated that a UF_6 shell with an outer radius of 10 or 11 cm (3.94 in. or 4.33 in.) was more reactive as was the multi-layer sphere being positioned a small distance from the cylinder's end wall. The difference in reactivity for each of these model changes also is enough that the k_{eff} of the applicant's design basis model would exceed the applicant's USL.

The staff notes that crediting the overpack, as the applicant has considered in Appendix 6.7.1, Section 6.7.1.7, of the application, results in decreased array k_{eff}, which is expected. The staff reviewed this part of the applicant's analysis also. As can be seen from both the instances described above and those described below, credit for the overpack becomes necessary to demonstrate the package will remain subcritical under accident conditions and for an infinite array of such packages. In fact, the applicant's model that gives the most credit for the overpack (among the overpack analyses the applicant performed) is necessary to demonstrate subcriticality since the analysis that gives less credit for the overpack would still not demonstrate subcriticality.

The staff performed confirmatory calculations by which the staff identified more reactive configurations for the overpack models. The staff's calculations credited the overpack in the same way as the applicant but also used staff experience to identify configuration differences that were likely to increase k_{eff}. In other aspects, namely the amount of credit given for the overpack, the staff finds that the applicant's models for determining the effect of the overpack are conservative and bounding based on the results of the normal conditions and accident conditions tests (i.e., the credit given for the overpack is conservative and bounding versus the results of the normal transport and accident conditions tests). The staff performed further calculations that used the staff-identified higher reactivity configuration for the model giving the most credit for the overpack and applied the other changes identified above and below that resulted in increased package reactivity. These calculations resulted in k_{eff} increasing by 3 to 4 percent. The staff did not perform further analyses to determine whether or not the staff's model maximizes k_{eff} or if further changes (e.g., changing water layer thickness around the 30B cylinder or the density of the water layer) would increase k_{eff} further. However, based on staff experience, it is the staff's judgement that even if further increases in k_{eff} are possible through model optimization, the increases would not be more than 1 or 2 percent in k_{eff}. The result would still be below the applicant's USL and below a USL that is based on a more comprehensive benchmark analysis (see Section 6.6 below).

With respect to the requirements in IAEA SSR-6, Paragraph 673, the staff determined that, except as affected by the items described above and below that affect the package analysis, the applicant has adequately addressed those items related to criticality safety for this package. Given the performance of the package under the tests specified in Paragraph 685(b) as evaluated in the other sections of this SER, the package meets the conditions of Paragraph 680(b) for not needing to consider water leakage into the containment system (the 30B cylinder). However, the applicant did evaluate the amount that could leak in as moist air at the measured leak rates of the post-accident drop test prototype packages. The applicant evaluated water in a layer around the 30B cylinder that maximizes k_{eff} and the models that include the overpack also account for water. Thus, the staff finds that the requirement in

Paragraph 673(a)(i), with consideration of meeting Paragraph 680(b), is met. Paragraph 673(a)(ii) is not applicable since there are no built-in absorbers or moderators in the package. Any moderation ability of the packaging's foams would be bounded by the water layer assumed in the criticality analysis. Regarding Paragraph 673(a)(iii), as described above, there are some arrangements of the contents which the staff found would increase reactivity beyond what the applicant analyzed. However, given the staff's evaluation above that accounts for the overpack, the applicant has adequately met this requirement. This also is true with regard to Paragraph 676. The consideration of the water layer around the 30B and neglect of the overpack also comply with Paragraph 673(a)(iv)-(v); the overpack models in the sensitivity analysis for crediting the overpack also comply with these same two requirements. The applicant's evaluations support compliance with Paragraph 673(b)(iv) as well.

6.3.2 Material Properties

Section 6.3.2 and Table 6-1 of the application describe the material properties that the applicant used in its analysis. The densities specified for the materials in the table correspond to the applicant's maximum k_{eff} model. According to the staff's references, the density of the UF_6 in the multi-layer sphere of hydrates and HF is equivalent to the UF_6 density at about 20°C. The density for the remaining UF_6 is set to ensure the total mass of UF_6 in the cylinder is maintained at the maximum allowed amount of 2,277 kg (5,020 lb). The density of the HF appears to be the density of anhydrous HF at about the same or somewhat lower temperatures. The applicant did not describe the basis for the densities of the UF_6 and HF shells. The staff's review of Figure 2 in NUREG/CR-4360, Vol. 1, and the density figure in Vol. 1.1 of Honeywell's "Specialty Chemicals, Hydrofluoric Acid Properties", indicates that the densities of these materials could be higher at lower temperatures that are within the range allowed for package transport in the package's certificate. The staff notes that the requirements in IAEA SSR-6 (see Paragraphs 639 and 679) require the package be designed for an ambient temperature as low as -40°C unless otherwise specified in the package certificate. The MST-30 package's Japanese certificate limits the minimum temperature for this package to only -20°C (see certificate condition 9); thus, the staff only considered material properties at temperatures at and above -20°C. Staff calculations indicate that higher densities for materials in these shells result in increased k_{eff}. In these calculations, the staff modified the HF shell's outer radius to maintain constant HF mass. The staff also adjusted the density of the UF_6 filling the remainder of the cylinder to keep the total UF_6 mass in the cylinder constant, while the UF_6 mass in the UF_6 shell varied with density. The difference in reactivity for this model change also is enough that the k_{eff} of the applicant's design basis model would exceed the applicant's USL. The staff notes that the evaluation of the densities of the contents also supports compliance with IAEA SSR-6 Paragraphs 673(a)(vi) and 679.

The applicant set the carbon steel composition for the 30B cylinder to 0.3 wt. percent carbon as a maximum in the model, with the remaining material all being iron, since carbon has a moderating effect. The staff notes that the standard Standardized Computer Analyses for Licensing Evaluation (SCALE) code specification is for 1 wt. percent carbon with the rest of the steel being iron. The staff's calculations confirmed that the use of the standard SCALE code material specification resulted in higher k_{eff} even though the applicant used a slightly lower density than the standard SCALE code density for carbon steel. However, the staff notes that the certificate (Table 1 of the certificate) specifies the carbon steel to be ASTM A516 for the 30B cylinder shell and heads. Table 2.10.6-1 of the application further clarifies the steel to be Grades 55, 60, 65, or 70. The ASTM standard for this material (ASTM A516/A516M) limits the maximum carbon content in carbon steel of the thicknesses relevant to the 30B cylinder design to less than 0.3 wt. percent. Thus, the staff finds the carbon steel composition used in the model to be acceptable.

As previously described, the applicant assumed the amount of residual hydrates in the 30B is the amount equivalent to 300 g (0.66 lb) uranium. The composition, per Table 6-1 of the application, is UO_2F_2-5.5H_2O, which maximizes the ratio of hydrogen to uranium for the hydrate composition. The applicant briefly mentioned a determination of the amounts of hydrates that may remain in a 30B cylinder. However, no information is provided about this determination, nor did the applicant provide any justification as to how the determination represents cases that are typical or standard for usage and cleaning of the 30B cylinders across the international community. The staff has identified other evaluations that are stated to be based on 30B usage practices in which the amount of residual hydrates is taken to be approximately 3.9 kg (8.6 lb) (e.g., "Criticality Analyses of Enriched Uranium-Hexafluoride Containing Impurities" by Rezgui and Hilbert from the 17th International Symposium on the Packaging and Transportation of Radioactive Materials (PATRAM) August 2013). This difference in amount of residual hydrates can have a significant effect on k_{eff} and can result in the applicant's design basis case exceeding the applicant's USL, including for cases where some aspects of the overpack are credited. However, as described in Section 6.3.1 above, the staff finds that there is sufficient margin to ensure subcriticality for the package based on the analysis that gives the most credit to the overpack (this credit is conservative and bounding versus the results of the normal transport and accident conditions tests) while accounting for the impacts of items including the mass of hydrates that can be in the package.

6.3.3 Analysis Methods and Nuclear Data

The applicant performed the analysis using the SCALE code system, Version 6.0. In particular, the applicant used the CSAS6 sequence, which uses the Keno-VI module. The applicant used the ENDF/B-VII 238-energy-group cross section library. The applicant used the BONAMI, CENTRM, and PMC modules for cross section processing. This code system with the CSAS6 sequence was developed specifically for the purposes of performing criticality analyses, including for fissile material packages. The CSAS6 sequence and Keno-VI module enable modeling of a variety of geometries as well as triangular pitch arrays, like as were evaluated for the MST-30 package. The code has undergone verification and validation to demonstrate its suitability for use. The cross-section library is also acceptable as it contains some of the latest cross section data for the materials of interest in the analysis and its structure is general enough to be used for a variety of fissile material compositions in different scenarios. Based on these considerations, the staff finds the use of the selected code and code version and cross section library to be acceptable.

6.3.4 Demonstration of Maximum Reactivity

The applicant's approach is to demonstrate subcriticality for a bare 30B cylinder in an infinite array. This represents an infinite array of packages under accident conditions. As described previously, this approach is bounding for packages in isolation under routine, normal, and accident conditions and for arrays of packages under normal conditions. Table 6-2 shows the applicant's maximum $k_{eff} + 3\sigma$ is 0.949, which the applicant stated has sufficient safety margin for subcriticality. While, not explicitly stated, the staff expects that the applicant has applied an administrative margin of 5% in k_{eff}, or 0.05, for a USL of 0.95.

As described previously and in the confirmatory calculation section below, the staff identified various features of the applicant's analysis which were not conservative or where differences in materials properties and configurations would increase k_{eff}. Any one of these on their own, results in a k_{eff} + 3σ that exceeds the applicant's USL. In combination, the result is a k_{eff} + 3σ that significantly exceeds that USL. The staff recognizes that the applicant's proprietary sensitivity studies included the effects of crediting the overpack to varying degrees. Applying the staff's identified properties and configurations to these models resulted in k_{eff} + 3σ for one of these cases also exceeding the USL. However, applying these properties and configurations to the case that gives the most credit (this credit is conservative and bounding versus the results of the normal transport and accident conditions tests) for the overpack would still be below the USL with margin. This would still be true even with a USL that is based on a more comprehensive benchmark analysis (see Section 6.6. below), though the margin would be reduced somewhat. Thus, on the basis of this latter case, which is conservative in its representation of the overpack post normal and accident conditions testing, the staff finds the package and an infinite array of packages would be subcritical and that a CSI of 0.0 would be appropriate.

6.3.5 Confirmatory Calculations

As already stated, the staff performed calculations to confirm the applicant had identified the most reactive package materials specifications and configuration parameters and to confirm the package and an infinite array of damaged packages would be subcritical. The staff also used the SCALE code; however, the staff used Version 6.2.3. The staff also used the ENDF/B-VII 238-energy-group cross section library. The staff used previous staff experience to inform its review of the MST-30 criticality analysis and identify aspects of the analysis worth potential investigation with confirmatory calculations. The staff did calculations for each identified item (described in the preceding sections) individually, making only those adjustments that were needed to maintain constant UF_6 mass in the package or stay within other appropriate constraints. The staff also calculated various combinations of the identified items, including a combination of all those items that increased k_{eff}. The combination of all the identified items, or differences, resulted in k_{eff} + 3σ for the bare 30B that significantly exceeds the applicant's USL. The staff's calculations resulted in one variation of crediting the overpack also exceeding the USL while a variation that gives the most credit for the overpack still remained below the USL with margin.

6.3.6 Air Transport of Fissile Material

In its review of the safety analysis, the staff determined that the applicant did not evaluate the package for air transport conditions, as described in IAEA SSR-6 Paragraph 683. Therefore, the model configurations do not consider impacts from Type C package tests. Thus, the staff recommends that the package revalidation be conditioned to preclude transport by air.

6.4 Single Package Evaluations

As previously described, the applicant did not do analyses of the package in isolation. These analyses are bounded by the infinite array analysis. Thus, the requirement in Paragraph 681 regarding optimum package reflection is not directly applicable to the MST-30 criticality analysis. In the array, a water layer with a thickness that maximizes k_{eff} is modeled around each 30B cylinder for inter-package moderation while the overpack materials and spacing are neglected. Also, the requirements in Paragraph 682 are satisfied by the bounding analysis with this array of packages in lieu of performing analyses of packages in isolation.

6.5 Package Array Evaluations

As previously described, the applicant did analyses for an infinite array of packages. The configuration of the packages in the array is set to bound the combined effects of the normal conditions (Paragraph 684(b)) and accident conditions tests (Paragraph 685(b)). This array is bounding for an infinite array of packages that have experienced only the tests for normal conditions of transport. Thus, the applicant satisfied the requirements in Paragraph 684 with the bounding array analysis that is done for Paragraph 685. Since the array is infinite, following the requirements in Paragraph 686, the CSI is 0.0. Based on the staff's review, as described throughout the criticality section of this SER, the staff finds this approach to the criticality analysis and this CSI to be acceptable. No fissile material escapes the package following the tests specified in Paragraph 685(b); therefore, no analysis with fissile material outside the package is needed. Also, since the array is infinite, reflection around the array is not possible and was not done. As described previously in this section of the SER, the applicant considered moderation between packages in a way that maximizes k_{eff}, with the water layer around each 30B cylinder. The applicant included sensitivity analyses to determine the impact of various levels of credit for the overpack for this array of packages. With the configuration that gives the most credit for the overpack, the staff determined, based on the evaluations described above, that an infinite array of packages would be subcritical and a CSI of 0.0 was appropriate. The amount of credit for the overpack in this model is necessary because of properties and configurations the staff identified that, based on the staff's calculations, would result in the array with the bare 30B cylinder and arrays crediting less of the overpack exceeding the USL.

6.6 Benchmark Evaluation

The applicant performed a benchmark analysis for the criticality analysis using the same code and cross section library. Based on this benchmark analysis, the applicant determined that the calculation method performs adequately. Though not explicitly stated, the staff expects that the applicant has applied an administrative margin of 0.05 (i.e., a USL of 0.95) and determined based on the benchmark analysis that such a margin is appropriate. Thus, the applicant's criterion for subcriticality, the USL, is $k_{eff} + 3\sigma \leq 0.95$.

In reviewing the applicant's benchmark analysis, the staff identified various concerns with the analysis. These include the limited number of experiments the applicant used in the analysis. The concerns also included the characteristics of the experiments selected as compared to the characteristics of the package and the contents. The description of the benchmark analysis was very limited and did not describe evaluations of trends with respect to key physical and neutronic parameters. Nor did the applicant justify the applicability of the experiments to the package analysis. Also, the number of analyzed benchmark experiments is so few that it is not clear that evaluations based on parametric statistical techniques (i.e., techniques that assume the data are normally distributed) are appropriate since the data are too few to be able to determine the normality of the data and their distribution.

Thus, based on the applicant's benchmark analysis alone, it was not clear to the staff that the benchmark analysis demonstrates the calculation method's performance for analyzing the MST-30 package with its contents. Nor was it clear to the staff that the application of a 0.05 administrative margin alone to determine the USL is adequate. The staff considered that a larger margin may be necessary to cover the additional uncertainties due to a lack of critical experiments that are sufficiently similar to the package and its contents and any non-conservative bias and bias uncertainty in the calculation method.

With the results of the design basis calculation being a k_{eff} + 3σ of 0.949, this is an important issue. However, as described above, the staff found that consideration of non-conservatisms and other aspects of the applicant's analysis would result in the applicant's design basis case exceeding a USL of 0.95 by a significant amount. This is also true of one of the models that gives some credit for the overpack. The staff found, however, that the model that gives the most credit for the overpack would still be below the applicant's USL with margin. Thus, the staff evaluated whether a more comprehensive benchmark analysis, one that used a sufficient number of experiments that were justified to be applicable to the package analysis, would result in a USL that could indicate that this third model may also not be subcritical.

The staff referenced the benchmark analysis for another UF_6 package which has received domestic approval under the NRC's regulations. The criticality analysis for that package, the DN-30, also used the same code and code version and cross section library that were used for the MST-30 analysis. The DN-30 analysis actually used two versions of the code; however, the differences in the versions do not affect the criticality calculation. Thus, based on this similarity between the packages' analyses, the staff determined that the benchmark analysis for the DN-30 package would provide a good indication of the type of bias and bias uncertainty that may be expected for the MST-30 package and thus the appropriateness of the applicant's USL. The staff noticed similar behavior in the calculation results for the experiments versus the experiment's reported k_{eff} for both packages as well. This further helped to support the usefulness of considering the DN-30 benchmark analysis as an indicator for what could be expected for an appropriately comprehensive benchmark analysis for the MST-30 package. According to the staff's safety evaluation report for Revision 0 of the DN-30 certificate of compliance (see Accession No. ML19203A265 in the NRC's electronic documents system ADAMS), the bias for the DN-30 was 0.0129. Using that bias together with a 0.05 administrative margin would result in a USL of 0.9371. Thus, the staff would anticipate that an appropriate USL for the MST-30 would be close to this value.

As part of the confirmatory calculations, the staff also calculated k_{eff} for a couple of cases with the same model specifications that the applicant used. In both cases, the staff's results were less than the applicant's results, with the difference being approximately the same, small amount in both instances. Thus, the staff has confidence in the applicant's analysis technique and that it will result in higher k_{eff} predictions.

The staff's calculations for the model that gives the most credit for the package's overpack resulted in an increase of k_{eff} of between 3 and 4 percent versus the applicant's most reactive case for that model. The staff did not do calculations to identify the maximum k_{eff} with the changes the staff made to the model. Thus, the staff considers it is possible that k_{eff} could be yet higher. However, based on experience, the staff considers that the potential further increase in k_{eff} would not be more than 1 or 2 percent. Even with the application of a bias and USL similar to that for the DN-30 and modifications to the applicant's analysis to address staff-identified concerns which maximize k_{eff} , the staff finds reasonable assurance that the applicant's model that includes the most credit for the overpack would still be subcritical with a margin of 2 to 3 percent. Therefore, the staff finds the benchmark analysis to be acceptable in this instance. However, changes to the analysis that change the basis for this finding in future requests will necessitate a review to determine whether that finding is still appropriate for that request.

6.7 Evaluation Findings

Based on a review of the information in the application, including the design drawings and design descriptions and the criticality analyses, and the staff's confirmatory calculations, the staff finds, with reasonable assurance, that the package with its contents satisfy the criticality safety requirements (e.g., Paragraphs 682, 684 through 686) in IAEA SSR-6, the 2012 Edition.

As described previously in this section of the SER, the applicant did not evaluate the package for air transport. Therefore, the staff recommends that the revalidation of the package's certificate be conditioned to preclude air transport.

7.0 OPERATING PROCEDURES EVALUATION

The NRC staff reviewed the operating procedures, which include procedures for cylinder inspection and filling; overpack inspection; loading and unloading the MST-30 overpack, and shipment of empty packages. The package is inspected to determine whether it is free from damage and in good working order. The inspections also include ensuring the 30B cylinder is filled, inspected, tested, and handled in accordance with ANSI N14.1 and ensuring the package is operated to protect the 30B cylinder's valve. The package loading procedures include loading the cylinder into the overpack, inserting the ring plate, closing the overpack and installing tamperproof seals. Post-loading operating procedures also include performing needed radiation surveys, determining the package transport index, and verifying compliance with the appropriate radiation level limits. Based on this review, the staff determined that the package will be operated in a manner consistent with its approval and the applicable regulations.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM EVALUATION

The staff reviewed the acceptance tests and maintenance programs described in Section 8 of the application to ensure the package is fabricated and maintained in a condition that is consistent with its approval.

8.1 Acceptance Tests

The acceptance tests on the MST-30 overpack are provided in Chapter 8 of the application and include fit-up of the removable components, visual inspection of welds, measuring the weight of the top and bottom halves and visual verification that the package does not contain cracks or defects.

Acceptance tests on the 30B cylinder will be performed in accordance with the latest version of ANSI N14.1 or ISO 7195, in effect at the time of cylinder fabrication. As a minimum, as described in Section 8.1.2, "Acceptance Tests for the Cylinder," the following tests, which are described in Section 8.1.2, are performed on new cylinders:

- Hydrostatic Pressure Test of Cylinder Body and Plug,
- Air Leak-Tightness Test of Cylinder Valve,
- Air Leak-Tightness Test of Cylinder installed with Valve and Plug, and
- X-ray Examination for Cylinder.

With respect to criticality safety, there are various features that are important, such as the minimum wall thickness of the 30B cylinder. Based on the criticality analysis, the minimum wall thickness of the 30B cylinder cannot be less than 11 mm (0.433 in.). Fabrication in accordance with ANSI N14.1 ensures the nominal thickness is 12.7 mm (0.5 in.). As for the tolerance, that is assured by the certificate specification that the shell, including the heads, material is ASTM A516 carbon steel (see the Japanese certificate Table 1). Per Table 2.10.6-1 of the application, this is further clarified to be Grades 55, 60, 65, or 70. The ASTM standard for this material (ASTM A516/A516M) refers to ASTM A20/A20M for specifications regarding dimension tolerances. Based on the information in that standard, the allowed under-tolerance is 0.3 mm (0.118 in.). This assures that, at fabrication, the minimum 30B wall thickness is not less than 12.4 mm (0.488 in.).

The NRC staff reviewed the acceptance tests and determined that they are sufficient to ensure that the package fabrication is consistent with its approval.

8.2 Maintenance Program

In Section 8.2, “Maintenance Program,” the applicant provided inspection and maintenance for the overpack and 30B cylinder. In particular Section 8.2.1, “Maintenance Program for the MST-30 Overpack,” provides the items inspected and maintained for the overpack and ring plate, which includes annual inspections (or after every 10 shipments of an overpack, if more than 10 shipments are conducted in a year), and weighing the overpack halves to evaluate their water retention at least every 5 years (or whenever the overpack is shipped from the manufacturer).

Section 8.2.2, “Maintenance Program for the 30B Cylinder,” provides items for annual inspection (or after every 10 shipments, if a cylinder is transported more than 10 times a year), and tests performed on the cylinder every 5 years. The following inspections, which are described in Section 8.2.2.2, are performed every 5 years on cylinders in use:

- Hydrostatic Pressure Test of Cylinder Body,
- Air Leak-Tightness Test of 30B Cylinder, and
- Cylinder Shell Thickness Inspection.

For periodic inspections of the 30B cylinder thickness, while ANSI N14.1 allows the wall thickness to be as thin as 7.94 mm and still allow use of the 30B cylinder, the test in Section 8.2.2.2, paragraph (c) of the application and Condition 10 of the certificate specify that the 30B cylinder’s minimum allowed wall thickness for continued use is 11.3 mm (0.445 in.). The staff finds that this criterion and the check to ensure it is met in the 5-year periodic inspection will ensure the package performs its criticality safety function as designed and analyzed. The staff reviewed the other acceptance test and maintenance program descriptions and determined they are also adequate to ensure the package is fabricated and maintained in a manner to ensure it performs as designed with respect to its criticality safety function, including to ensure water cannot leak into the package.

The NRC staff reviewed the maintenance program and determined that it is sufficient to ensure that the package is maintained in a manner consistent with its approval.

CONCLUSION

Based on the statements and representations contained in the documents referenced above (see SUMMARY, above), the staff concludes that the Model No. MST-30 package meets the requirements of International Atomic Energy Agency Regulations for the Safe Transport of Radioactive Material, IAEA Safety Standards Series, No. IAEA SSR-6, 2012 edition.

Issued with letter to R. Boyle, Department of Transportation,
Dated January 29, 2021.