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

SAFETY EVALUATION REPORT
Docket No. 71-3091
Model No. F-522
Canadian Certificate of Approval CDN/2094/B(U)-96,
Revision No. 2

SUMMARY

By letter dated November 6, 2019, (Agencywide Documents Access and Management System [ADAMS] Accession No. ML19344A012), the U.S. Department of Transportation (DOT) requested that the U.S. Nuclear Regulatory Commission (NRC) staff perform a review of the Canadian Certificate of Approval CDN/2094/B(U)-96, Rev. No. 2, for the Model No. F-522 transport package and make a recommendation concerning the revalidation of the package for import and export use. Specifically, DOT requested that the NRC review the content revision to add zircaloy encapsulated molybdenum target contents 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, 2012 Edition).

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

1. Canadian Certificate of Approval No. CDN/2094/B(U)-96, Revision No. 2, dated November 4, 2019, and

2. BWX Technologies, Inc., Document No. IS/TR 2650 F522[5], "Engineering Assessment of the Ability of the F-522/UK-201 Type B Package to Meet IAEA SSR-6, 2012 Edition,"

The NRC previously reviewed and recommended revalidation of Canadian Certificate of approval No. CDN/2094/B(U)-96, Revision 1, for this package to the DOT on July 26, 2018 (ADAMS Accession No. ML18208A260). Based upon our review, the statements and representations contained in the application, and for the reasons stated below, we recommend revalidation of Canadian Certificate of Approval CDN/2094/B(U)-96, Revision No. 2 for the F-522 transport package.

1.0 GENERAL INFORMATION

The F-522 package consists of an F-522 overpack, a UK-201 shielding vessel, and a containment system for this approval consists of a welded zirconium capsule and the contents. The source capsule meets the tests requirements for special form material. Neither the F-522 overpack nor the UK-201 shielded vessel was modified for this approval.

Enclosure

1.1 Package Description

1.1.1 Packaging

The F-522 overpack is a stainless steel vessel with an inner and outer shell outfitted with fittings for lifting and tie-down. The stainless steel shells enclose closed-cell polyurethane foam used for impact and thermal protection. The overpack lid is secured by screws and incorporates a tamper evident wire seal. The overpack, which provides thermal and impact protection to the shielding vessel and the containment system, includes an optional heat screen that is used when the decay heat load exceeds 26.2 W.

The UK-201 shielding vessel is contained within the F-522 overpack. Shielding is provided by depleted uranium encased within stainless steel. Secondary containment is provided by O-ring seal around the top plug.

1.2 Contents

The source capsule consists of a Source Model Number G615-01 or similar welded Zircaloy encapsulations that have been shown to pass a helium leak test in accordance with the International Organization for Standardization (ISO) Standard No. 9978, “Radiation Protection - Sealed Radioactive Sources - Leakage Test Methods,” following completion of the impact, percussion and heat tests specified in Paragraphs 705, 706, and 708 of IAEA SSR-6, 2012 Edition. These targets contain up to 185 TBq (5000 Ci) of Molybdenum-99 (^{99}Mo) and associated activation products associated with neutron activation of the targets and 7.4 TBq (200 Ci) of activation products associated with the neutron activation of Zircaloy cladding.

2.0 STRUCTURAL EVALUATION

The staff reviewed the proposed change to allow the shipment of irradiated Molybdenum metal disks within welded zircaloy capsules in the F-522 transportation package to verify that the applicant has adequately evaluated the structural performance of the package and demonstrated that the system meets the regulations of IAEA SSR-6, 2012 Edition.

The zircaloy capsules are placed within the UK-201 shielding vessel which is contained in the F-522 overpack. There were no changes made to the UK-201 shielding vessel or the F-522 overpack. The previously approved structural safety bases of the shielding vessel and overpack, discussed in the July 26, 2018 safety evaluation report, are unaffected by the new contents. The previously approved package contained the F-248X leak proof insert within the UK-201 shielding vessel and F-522 overpack. The capsules in a source holder would replace the F-248X leak proof inserts.

2.1 Materials Evaluation

In the previous application of this package the staff focused the materials review on the following: (1) packaging materials and fabrication/welding; (2) radiolysis (for liquid); (3) pyrophoricity; (4) thermal properties and effects on materials and found them to be acceptable. Therefore, for the current review the staff only evaluated the material change, an addition to the contents with neutron irradiated molybdenum targets within a welded zircaloy cladding.

The staff has reviewed the package structural design description and concludes that the contents of the application, codes and standards used in package design are acceptable and continued to meet the requirements of IAEA SSR-6, 2012 Edition.

The staff finds, to the maximum credible extent, there are no significant chemical, galvanic or other reactions for each packaging component, among the packaging components, among package contents, or between the packaging components and the contents in dry or wet environment conditions based on the review of the package licensing drawings and bill of material. In addition, the effects of radiation on materials were evaluated and found to be negligible based on lower dose imposed compared to the previous Application.

2.2 Evaluation of Zirconium Capsules

The applicant performed impact, percussion, and heat tests on individual zircaloy capsules. These tests are described in Appendix 17 of the Document No. IS/TR 2650 F522[5], and were conducted according to the Tests for Special Form Radioactive Material in IAEA SSR-6, 2012 Edition, paragraphs 704–711, as appropriate. Following these tests, the capsules were shown to pass a helium leak test and a leach test. In addition to IAEA SSR-6, 2012 Edition requirements, the capsules retained in a source holder were subjected to vibration testing as described in Appendix 18 to Document No. IS/TR 2650 F522[5].

Based on previously approved safety basis of the overpack and shielding vessel and the results of the tests performed on the capsules, the NRC staff concludes that the effects on structural safety from the shipment of solid ^{99}Mo within welded zircaloy capsules in the F-522 transportation package have been adequately described and evaluated and the package has adequate structural integrity to meet the requirements of IAEA SSR-6, 2012 Edition.

3.0 THERMAL EVALUATION

Purpose of the thermal review is to verify that the package design satisfies the thermal safety requirements of the IAEA SSR-6, 2012 Edition. Staff reviewed the thermal material properties, the descriptions of the thermal modeling, the assumptions used in the thermal analyses, and the calculations provided by the thermal models for normal transport and accidental transport under the revalidation request for F-522 transport package.

The applicant stated in Appendix 16 to Document No. IS/TR 2650 F522[5] that the total heat load of the ^{99}Mo sources loaded within the F-522 package is less than the 26.2--watt limit that requires use of the heat screen and less than the certified 40-watt capacity of the package.

Staff reviewed Appendix 16 to Document No. IS/TR 2650 F522[5] and determined that the thermal features of the F-522 package, loaded with ^{99}Mo targets, are well described and its heat generation for special-form zircalloy capsule is appropriate for thermal evaluation.

3.1 Thermal Evaluations for Normal Conditions of Transport and Hypothetical Accident Conditions

As stated in Addendum 16.1 to Appendix 16 to Document No. IS/TR 2650 F522[5], the applicant performed thermal analysis with the entire shielding vessel raised up and in direct contact with the top of the internal cavity to analyze shielding vessel O-ring thermal performance in the hypothetical accident conditions fire. The applicant presented both normal conditions of transport and hypothetical accident conditions thermal evaluations in Addendum 16.1. Thermal modeling approach is identical to the one described in Appendix 6 to Document No. IS/TR 2650 F522[5] that was reviewed and recommended for approval by the NRC (NRC July 26, 2018 approval). Both normal conditions of transport and hypothetical accident conditions thermal evaluations are conservative given that the 40-watt heat load was used in the thermal analysis for the F-522 package loaded with the ^{99}Mo targets is greater than the total heat load of the ^{99}Mo target. The applicant provided the package component temperatures of normal conditions of transport, hypothetical accident conditions 30-minute fire, and hypothetical accident conditions post-fire cooldown, respectively, in Figures A16.8, A16.9, and A16.10/11 of Addendum 16.1 to Appendix 16 to Document No. IS/TR 2650 F522[5]. The applicant also presented the temperature history of the O-rings in Addendum 16.1 to Appendix 16 to Document No. IS/TR 2650 F522[5] for the hypothetical accident conditions fire.

Staff reviewed the thermal assessment and Figures A16.8–A16.11 for package component temperatures presented in Addendum 16.1 to Appendix 16 to Document No. IS/TR 2650 F522[5] and agrees that the applicant's thermal justification for the addition of ^{99}Mo targets transported by F-522 package shows that all package component temperatures are below their temperature limits for both normal conditions of transport and hypothetical accident conditions. This is because (1) thermal model approach is consistent with the approach reviewed and approved by the NRC in the previous application and (2) temperatures of the package components, including the O-rings, are below the corresponding service limits for normal conditions of transport and hypothetical accident conditions.

3.2 Evaluation Findings

Based on review of the statements and representations in the F-522 package amendment application, staff concludes that (a) the thermal design, thermal model, and heat removal capability of the package, loaded with ^{99}Mo targets contained within special-form zircalloy capsules, have been adequately described and evaluated, and (b) the new content of ^{99}Mo targets is not significantly different from the existing contents per thermal review and the heat load generated by ^{99}Mo targets is less than the already-authorized maximum of 40 watts for the F-522 package. Therefore, staff confirmed that F-522 package, loaded with the ^{99}Mo targets contained within the zircalloy capsules, continues to meet the thermal requirements of IAEA SSR-6, 2012 Edition.

4.0 CONTAINMENT EVALUATION

The primary containment of the ^{99}Mo target is provided by the zircalloy capsule which meets the criteria for special form material and the capsule is contained within the UK-201 cavity of the F-522 package. The applicant has shown that the zirconium capsule is contained within the UK-201 cavity, and the O-ring maintains its ability to contain any possible contamination.

Staff reviewed Appendix 16 and Appendix 17 to Document No. IS/TR 2650 F522[5] and confirmed that the containment of the special-form zircalloy capsule and the containment boundary of the F-522 package are well described for containment evaluation.

4.1 Heat Test on Zircalloy Capsules

The applicant stated in Appendix 17 to Document No. IS/TR 2650 F522[5] that a single zircalloy capsule was subjected to the heat test as described in paragraph 708 of the IAEA SSR-6, 2012

Edition and the heat test results are presented in Addendum 17.1 to Appendix 17 to Document No. IS/TR 2650 F522[5].

Staff reviewed results of containment testing of capsule prototypes provided in Appendix 17 to Document No. IS/TR 2650 F522[5] and verified the Testing Certificate attached in Addendum 17.1 to Appendix 17 to Document No. IS/TR 2650 F522[5] for special-form heat test results. Staff confirmed that the special-form zircalloy capsule passed the heat test in compliance with paragraph 708 of the IAEA SSR-6, 2012 Edition.

4.2 Helium Leak Test on Zircalloy Capsules

The applicant stated in Appendix 16 to Document No. IS/TR 2650 F522[5] that the zircalloy capsules are subjected to a helium leak test in accordance with ISO 9978 during manufacture and remain leaktight with acceptance criterion of 10^{-7} ref-cm^3/sec and with no gross release of ^{99}Mo targets. The applicant performed the incremental analysis, as presented in Addendum 16.1, that demonstrates that the service temperatures of package containment O-ring seals are not exceeded at a heat load of 40 watts. Heat load limit of the F-522 package loaded with the ^{99}Mo targets contained within the zircalloy capsules is less than the authorized 40.0 watts for the F-522 package.

Staff reviewed Addendum 16.1 and Appendix 16 to Document No. IS/TR 2650 F522[5] and ensured that the special-form zircalloy capsules containing ^{99}Mo targets passed the helium leak test with a leakage rate less than 10^{-7} ref-cm^3/sec.

Based on the results from the heat test presented in Addendum 17.1 and the helium leak test discussed in Appendix 17 to Document No. IS/TR 2650 F522[5], staff confirmed that zircalloy capsules containing ^{99}Mo targets meet special-form requirements for containment.

4.3 Secondary Containment of F-522 Package

The applicant performed the incremental thermal analysis as presented in Addendum 16.1 and stated that the maximum temperatures of the package O-ring seals are below the corresponding service limits for normal conditions of transport and hypothetical accident conditions. The applicant stated that the F-522 package, loaded with the ^{99}Mo targets within the zircalloy capsules, still meets the containment requirements for the package.

Staff reviewed Addendum 16.1 and referred to the previous application for the package O-ring seal service temperature limits for normal conditions of transport and hypothetical accident conditions. Staff confirmed that the maximum O-ring seal temperatures of the F-522 package, loaded with the ^{99}Mo targets contained within the zircalloy capsules, do not exceed the service limits for normal conditions of transport and hypothetical accident conditions and therefore the O-rings will maintain their effectiveness.

4.4 Evaluation Findings

Based on review of the statements and representations in the F-522 package amendment application, staff concludes that the special-form zircalloy capsule and the secondary containment system of the package, loaded with the ^{99}Mo targets contained within the zircalloy capsules (which have been shown to meet the criteria for special form material), have been adequately described and evaluated, and that the F-522 package continues to meet the containment requirements of IAEA SSR-6, 2012 Edition.

5.0 SHIELDING EVALUATION

The staff reviewed the application to ensure that the shielding is adequate to meet the radiation level requirement within the IAEA SSR-6, 2012 Edition for protecting people and the environment, for this type of package. Specifically, staff reviewed for compliance with the requirements of paragraphs 523, 526, 527, 648(b), and 659(b)(i).

5.1 Description of the Shielding Design

The F-522 package consists of the following components: a containment vessel, which for this amendment is a source that meets the requirements for special form, a UK-201 shielding vessel; and a F-522 overpack.

5.2 Evaluation Method

NRC staff previously reviewed the applicant's evaluation for ^{60}Co, liquid ^{99}Mo with ^{132}I, solid, fission product ^{99}Mo, and activated Rb, and staff found the applicant's analysis acceptable. The applicant has requested a new contents type, solid, zircaloy-clad Mo irradiation targets. These targets contain up to 185 TBq (5000 Ci) of ^{99}Mo and associated activation products associated with neutron activation of the targets and 7.4 TBq (200 Ci) of activation products associated with the neutron activation of Zircaloy cladding. The applicant showed the target cladding meets the helium leak test per ISO 9978 following the completion of the test required by IAEA SSR-6, 2012 Edition, paragraphs 705, 706, and 708.

The applicant evaluated the shielding capability for the F-522 package by calculating the radiation level using the isotopes present in the target post irradiation. The applicant presented the most significant isotopes at end of irradiation with 1 and 2 hours of decay in Table 1 of Appendix 16 to Document No. IS/TR 2650 F522[5]. The applicant determined the isotopes that contribute 0.05% or more of the total activity and presented those in Table 2 of Appendix 16 to Document No. IS/TR 2650 F522[5]. The applicant further determined the isotopes that most contribute to surface dose with MicroShield and presented post-irradiation dose rates after 1 and 2 hours in Table 3 of Appendix 16 to Document No. IS/TR 2650 F522[5]. Prior staff review found the applicant's use of MicroShield acceptable for this package (NRC July 26, 2018 approval).

5.2.1 Package Modeling

In prior analysis, the applicant determined that the external radiation level through the radial side of the package is most limiting for the F-522. Prior staff review confirmed this determination. The applicant's model consists of an idealized system of nested cylinders, with the innermost cylinder consisting of the target material. The applicant used dimensions that correspond to the radial thickness of each component important to shielding. Prior NRC review found the applicant's MicroShield model dimensions acceptable (NRC July 26, 2018 approval). The applicant omitted the iron, leak-proof container from its model, which staff finds acceptable since this will reduce shielding and increase predicted dose rates.

5.2.2 Source Modeling

The applicant modeled the source as a cylinder consisting of zircaloy, which has a lower density than molybdenum. Staff finds this acceptable as the lower material density will reduce source self-shielding and result in higher calculated external dose rates. The applicant also assumed the maximum permissible impurities were present in the target before irradiation. The composition of the target material and cladding are shown in Tables 1 and 2, respectively, of Appendix 16.2 to Document No. IS/TR 2650 F522[5]. Staff finds this acceptable since the activation of these impurities contributes more to the external dose rates than the desired target material, on a per-weight basis. In addition, the applicant used conservative neutron fluxes to maximize the predicted target activation. Staff finds this acceptable since it increases the calculated source strength and dose rates.

5.2.3 Flux-to-Dose Rate Conversion Factors

The applicant used default flux-to-dose rate conversion factors in MicroShield. These conversion factors are based on International Commission on Radiological Protection (ICRP) Publication 51, “Data for Use in Protection against External Radiation” and are non-conservative compared to the flux-to-dose rate conversion factors from American National Standards Institute (ANSI/ANS) 6.1.1-1977, “Neutron and Gamma-Ray Flux-to-Dose Factors,” (ANSI/ANS 1977). Prior staff review found the calculated dose rate increased by about 20% when the ANSI/ANS 1977 conversion factors are used (NRC July 26, 2018 approval).

The applicant also used a volumetric source which relies on self-shielding. In prior revisions, the applicant modeled the source as a single point, which contributed to the conservative margin in the analysis. Staff confirmatory analysis showed the applicant’s conservative use of reduced-density target material provides about 15-18% extra margin. The staff finds the applicant’s use of the ICRP-51 flux-to-dose rate conversion factors acceptable considering the following: the applicant used conservative irradiation and impurity activation assumptions, which will maximize the source term; the applicant reduced self-shielding by modeling the target as zircaloy rather than molybdenum, which counters most of the added dose-rate change had the applicant used the ANSI/ANS 1977 flux-to-dose rate conversion factors; and after 2 hours of decay, the applicant’s calculations show significant margin to the regulatory radiation limits.

5.2.4 Maximum Dose Rates

The applicant presented the most important isotopes contributing to external dose in Table 3 of Appendix 16 to Document No. IS/TR 2650 F522[5]. Since the applicant’s modeling assumptions increase predicted source strength, minimize shielding, and yield increased calculated dose rates, the applicant’s results show it is possible the surface dose rates might exceed the regulatory limits in IAEA SSR-6, 2012 Edition, paragraph 527 at short decay times. However, the isotope responsible for about 75% of the calculated external dose rate 1 hour post-irradiation has a half-life less than 15 minutes. The applicant’s evaluation showed significant reduction of dose rates after an additional hour of decay, which staff analysis confirmed. Since the package shall be surveyed before it is shipped, any packages that temporarily exceed the IAEA SSR-6, 2012 Edition dose-rate limits can be brought into compliance with a relatively short waiting period. As a result, staff finds reasonable assurance the F-522 package can meet the does-rate requirements within the processing time frame stated by the applicant.

5.3 Hypothetical Accident Conditions

Staff previously evaluated the effects of accident conditions on the package and found reasonable assurance the package meets the requirements of IAEA SSR-6, 2012 Edition. Since the packaging remains essentially unchanged, that finding remains applicable. The applicant showed the target material meets the requirements to be determined special source under IAEA SSR-6, 2012 Edition. As a result, staff finds reasonable assurance that any effects on the targets would not result in significant changes from the configuration evaluated by the applicant.

5.4 Confirmatory Evaluations

Staff conducted a confirmatory analysis with the MONACO/MAVRIC code in SCALE 6.2. Staff used a 19-group gamma cross-section library based on the ENDF/B-VII nuclear data. Staff modeled a simplified, three-dimensional version of the F-522 package using the idealized dimensions provided by the applicant. The staff's analysis was comparative to estimate the conservative margin of some of the applicant's modeling assumptions. Staff evaluated how much the external dose rates can be expected to change if the target is modeled as molybdenum instead of zircaloy. Staff determined the reduced target density conservatively adds about 15-18% margin to the calculated dose rates. Staff also changed the spectrum and intensity of the source to evaluate the effect of an additional hour of decay on the external dose rates. Staff results confirmed the applicant's calculated reduction in external dose rates from 1 to 2 hours of decay after irradiation.

5.5 Evaluation Findings

Based on review of the statements and representations in the F-522 package application and as discussed above, the staff has reasonable assurance that the F-522 package meets the requirements in paragraphs 523, 526, 527, 648(b), and 659(b)(i) in IAEA SSR-6, 2012 Edition. The staff recommends revalidation of Canadian Certificate of Approval No. CDN/2094/B(U)-96, Rev. No. 2, for the F-522 package.

6.0 CRITICALITY EVALUATION

There is no fissile material in the package, therefore a criticality evaluation is not required.

7.0 OPERATING PROCEDURES EVALUATION

The applicant did not propose any changes to the operating procedures.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM EVALUATION

The applicant did not propose any changes to the acceptance tests or maintenance program.

CONCLUSION

Based on the statements and representations contained in the documents referenced above (see SUMMARY), the staff concludes that the Model No. F-522 package meets the requirements of International Atomic Energy Agency Regulations for the Safe Transport of Radioactive Material, IAEA Safety Standards Series, No. SSR-6, 2012 edition.

Issued with letter to R. Boyle, Department of Transportation,
dated February 6, 2020.