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

SAFETY EVALUATION REPORT

Docket No. 71-9338
Model No. 3977A
Certificate of Compliance No. 9338
Revision No. 4

SUMMARY

By letter dated March 31, 2018, as supplemented on July 31, 2018 and October 2 and December 9, 2019 (Agencywide Documents Access and Management System (ADAMS) Accession Nos. ML18136A483, ML19218A004, ML19275D608 and ML19343A003 respectively), Croft Associates Limited submitted an amendment request to revise the certificate of compliance (CoC) for the Model No. 3977A package. The applicant submitted a shielding analysis, a gas leak rate analysis and drawings seeking authorization to transport proton irradiated thorium. The U.S. Nuclear Regulatory Commission (NRC) staff reviewed the application using the guidance in NUREG-1609, “Standard Review Plan for Transportation Packages for Radioactive Material.” Based on the statements and representations in the application, as supplemented, the staff agrees that these changes do not affect the ability of the package to meet the requirements of Title 10 of the *Code of Federal Regulations* (10 CFR) Part 71.

1.0 GENERAL INFORMATION

1.1 Packaging Description

The applicant initially wanted to modify the package design by adding a fluoroelastomer O-ring seal to the shielding plug associated with the split lid configuration which staff authorized in Revision 2 of CoC 9338. The applicant incorporated this design change to retain radioactive material inside the containment vessel (CV) cavity. The applicant also initially proposed two transportation configurations which deviated from all previously approved transportation configurations. The first configuration consisted of the thorium as bare metal in pieces within a plastic product container. The second configuration consisted of the thorium encased in Inconel. For both configurations, the applicant planned to add stainless steel (SS) spacers to locate the radioactive material in the approximate center of the CV cavity. However, testing performed by the applicant demonstrated that the seal made it difficult to fit the plug into the CV cavity. Therefore, the applicant modified their design. The applicant chose to only ship the thorium in pieces. After placing the thorium pieces into a container made of either plastic or metal, the applicant used packing to position the thorium pieces in the bottom of the container. Using SS spacers, the applicant located the container approximately in the axial center of a SS insert which was subsequently loaded into the CV cavity. Staff reviewed the package description in chapter 1 of the safety analysis report (SAR) and found it acceptable.

1.2 Drawings

For the shipment of proton irradiated thorium, the applicant constructed and assembled the packaging in accordance with Croft Associates Limited Drawing Nos:

1C-7940, Rev. C	Cover Sheet for Safkeg HS Design No. 3977A – #4109 Insert
0C-7941, Rev. C	Safkeg HS Design No. 3977A – 4109 Insert
0C-7942, Rev. B	Keg Design No. 3977 – 4109 Insert
0C-7943, Rev. B	Cork Set for Safkeg HS – 4109 Insert
1C-7944, Rev. C	Containment Vessel Design No. 3978 – 4109 Insert
1C-7945, Rev. B	Containment Vessel Lid – 4109 Insert
1C-7946, Rev. C	Containment Vessel Body – 4109 Insert
1C-7947, Rev. B	Containment Vessel Plug – 4109 Insert
1C-7975, Rev. D	Packing for Thorium Target in Design No. 3978 - #4109 Insert
2C-6920, Rev. A	Silicone Sponge Rubber Disc (Licensing Drawing)
2C-8094, Rev. B	HS-55x113-SS Insert Design No. 4109

Staff reviewed these drawings for conformance to NUREG/CR-5502, “Engineering Drawings for 10 CFR Part 71 Package Approvals,” and found them acceptable.

1.3 Content Description

The applicant identified the contents as normal form metallic proton irradiated thorium. Originally, the applicant planned to define the proposed contents using the radionuclides produced from proton irradiation of the thorium as well as their maximum specific activity, mass and decay heat and did not request this information be withheld as proprietary information. After working to address NRC staff information requests, the applicant wanted this information withheld as proprietary information. However, after discussions with NRC staff, the applicant chose to specify the contents using the source strength (i.e., photons per second) and photon energy spectra emitted by the thorium after 24 hours decay time following the proton irradiation of the thorium target using a proton current (i.e., protons per second) of a given proton energy (ADAMS Accession No. ML19269D033). The applicant revised the SAR to provide the maximum source strength for the energy spectra emitted by the proton irradiated thorium content in SAR Table 1-4-6. The staff incorporated this information within the CoC eliminating the need for specifying individual nuclides, proton irradiation characteristics or cooling time.

1.4 Findings

Based on a review of the statements and representations in the application, the staff concludes that the package has been adequately described to meet the requirements of 10 CFR Part 71.

2.0 STRUCTURAL

2.1 Materials Evaluation

2.1.1 General

The applicant requested an irradiated thorium target, housed within a SS insert, be approved as a new content. The applicant provided details of the new design in the drawings specified in SER Section 1.2. The staff finds the drawings acceptable based on their conformance to NUREG/CR-5502, “Engineering Drawings for 10 CFR Part 71 Package Approvals.”

2.1.2 Material Properties

Materials not mentioned in section 2.1.2 are identical to those already used in this package in earlier revisions. The applicant specified that a container (i.e., a jar or a tin) made from either plastic or metal, shall be used to carry the thorium. The applicant also specified that knit wire flexible packing held the thorium in place at the bottom of the jar. See SAR Figure 1-7.

2.1.3 Chemical and Galvanic Reactions

Pyrophoric Reaction
At the staff's request, the applicant provided information demonstrating that the proposed contents will not spontaneously combust. The applicant clarified that the thorium is in the form of a metal disk (i.e., not in powder form), the only moisture present is from the humidity in the air, and there is no source of ignition within the CV. Los Alamos National Laboratory also reported that they have not observed any evidence of combustion in their handling of many thorium targets. The staff finds that the information provided by the applicant is acceptable based on the staff's independent studies on pyrophoricity (ADAMS Accession No. ML18136A487).

Radiation Effects
The SAR Table 1-4-6 presented the irradiated thorium target source strength. At the staff's request, the applicant assessed the potential impact of radiation on the following: (i) moisture radiolysis and hydrogen generation; (ii) integrity of seal and plastic components; and (iii) SS insert integrity.

(i) Moisture Radiolysis and Hydrogen Generation

The applicant identified the maximum pressure that could arise from gas production due to radiolysis of moisture in the CV in SAR section 3.3.2 and added calculation CS 2019/02 to SAR section 3.5.2. The proprietary calculation assumed the moisture was fully dissociated which is a conservative assumption since full dissociation cannot occur. The calculation showed that, even with this conservative assumption, the pressure only increased by 0.02 bar. Staff finds this pressure increase negligible. Calculation CS 2019/02 also showed that the maximum hydrogen produced would be approximately 0.2% which is below the level of concern for either detonation or deflagration. The staff finds the results acceptable because the calculation conservatively assumes full dissociation of all water molecules.

(ii) Seal and Plastic Components Integrity

The applicant calculated the dose absorbed in the Viton containment seal and the 4109 insert seal for a one year period to be 0.0047 Mrad and 2.5 Mrad respectively. Staff reviewed industry data for elastomeric materials, including Viton, and determined that these values are well below the limiting dose of 10 Mrad. The applicant also evaluated the dose to the container which will hold the thorium pieces assuming the container is a plastic jar. The applicant calculated an absorbed dose below 2.5 Mrad for the plastic jar. Staff reviewed the available data on the dose to cause damage to polymer materials and determined the calculated values are below the exposure needed to damage the plastic container. The staff finds these assessments acceptable because the applicant's dose estimates conservatively used plastic (i.e., the material most susceptible to damage) in the evaluation, assumed a constant radioactive strength for one year even though the radiation strength will reduce by approximately 88% after 4 days and because the values calculated by the applicant are below the values at which the plastic container will degrade.

(iii) Stainless Steel Insert Integrity

The applicant assumed that SS would maintain its structural integrity under radiation. The staff confirmed this assumption based on the literature data on the effects of radiation on SS mechanical properties (Chopra and Rao, 2011); therefore, staff finds this acceptable.

Thermal Effects
The applicant stated that the decay heat for the package with the thorium content is bounded by the decay heat for the package with previously approved contents. Staff reviewed the Parker O-Ring Handbook and determined that the Viton containment O-ring will not be affected in the operating temperature range with the bounding heat loading. Therefore, the staff finds that the O-ring will be stable in the operating temperature range.

2.2 Evaluation Findings

Based on review of the statements and representations in the application, the NRC concludes that the materials used in the transportation package design have been adequately described and evaluated and that the package meets the requirements of 10 CFR Part 71.

2.3 References

1. O. Chopra and A. Rao, A Review of Irradiation Effects on LWR Core Internal Materials – Neutron Embrittlement, J. of Nuclear Materials, 412 (1) (2011), pp. 195-208.
2. U.S. Department of Energy (DOE), DOE Handbook, Primer on Spontaneous Heating and Pyrophoricity, FSC-6910, DOE.
3. The NRC, Engineering Drawings for 10 CFR Part 71 Package Approvals.
4. The NRC, Standard Review Plan for Transportation Packages for Radioactive Material, NUREG-1609, 1999.
5. Parker (Parker Hannifin Corporation, O-Ring Division), Parker O-Ring Handbook, ORD 5700.

3.0 THERMAL EVALUATION

Staff reviewed the Safkeg–HS Model No. 3977A transportation package application to verify that the thermal performance of the package had been adequately evaluated for the tests specified for normal conditions of transport (NCT), hypothetical accident conditions (HAC) and that the package design satisfies the thermal requirements of 10 CFR Part 71. Staff also reviewed the application to determine if the package is consistent with the acceptance criteria listed in Section 3 of NUREG-1609, "Standard Review Plan for Transportation Packages for Radioactive Material," as well as associated Interim Staff Guidance documents.

The applicant sought approval to transport solid metallic thorium (content Type CT-6). The addition of this content had the potential to change the maximum normal operating pressure and maximum predicted temperatures because of new materials and a new package geometry discussed in SER Section 1.1. However, as explained in SER Section 1.1, the applicant modified their approach and utilized a similar package geometry to that used for previously approved contents. The applicant stated that, because of the low decay heat emitted by the contents (i.e., 0.036 W) (ADAMS Accession No. ML19218A007), the package temperatures would be bounded by those calculated for the higher heat output of 30 watts for previously approved contents, and that a new thermal evaluation is not required. The applicant provided a calculation for the pressure increase from gas production due to radiolysis of moisture in the CV. In the calculation, the applicant showed that the pressure rise due to radiolysis would be very small. Therefore, the applicant concluded that previous pressure analyses remain bounding for the new contents.

The staff reviewed the application, assumptions, and analysis results to determine consistency with NUREG-1609. The staff finds that the low decay heat emitted by the new contents will have a minor impact on predicted temperatures and are bounded by the higher heat load of the contents that are currently authorized by the package certificate. The staff reviewed the pressure calculations and verified that the pressure increase is minor and will not challenge the design pressure of the CV. Based on its review of the application, staff concludes that the Safkeg-HS Model No. 3977A transportation package thermal design has been adequately described and evaluated for the new metallic thorium contents, and that the thermal performance of the package meets the thermal requirements of 10 CFR Part 71.

4.0 CONTAINMENT EVALUATION

4.1 Review Objective

The objective of the containment review of the Safkeg-HS 3977A package is to verify that the package design satisfies the containment requirements of 10 CFR Part 71 under NCT and HAC. The objective includes review of changes to the containment design characteristics and containment analyses for the Safkeg-HS 3977A. The applicant requested several changes to the Safkeg-HS 3977A package design and only those changes that affect the containment system are discussed in this section. Staff reviewed the Safkeg-HS 3977A package containment analyses to ensure that the package continues to meet the regulatory requirements of 10 CFR 71 under NCT and HAC.

4.2 Description of Containment System

The applicant proposed to allow metallic thorium content (i.e., content type CT-6) to be carried in the package within insert design number 4109. The form of CT-6 (i.e., thorium metal in a metal insert) also provided containment of the radioactive material within the CV. The applicant stated in SAR Section 4.1 that the dose rate at the CV containment seal at the time of loading (24 hours from end of beam) was calculated as 5.4×10^{-7} Mrad/hour (5.4×10^{-3} Gy/h), as shown in Table 8-13 of Atkins document 5183326 (ADAMS Accession No. ML19289A805). The applicant determined that, at this dose rate, the containment seals would receive 0.0047 Mrad for a full year which is below the limit of 10 Mrad identified in the Parker O-Ring Handbook.

Staff reviewed the SAR section 4.1 description and the dose rate calculation of $5.4\ \times10^{-7}$ Mrad/hour and 0.0047 Mrad/year for the CV containment seal at time of loading. Staff finds both the description and the calculation acceptable. Staff finds the containment system acceptable because the dose rate of 0.0047 Mrad for a full year is much less than the limit of 10 Mrad for the Viton containment seal.

4.3 General Considerations for Type B Packages

In addition to stating in SAR Chapter 4 that the Safkeg-HS 3977A package is leaktight as defined in ANSI N14.5 (1997), the applicant provided Calculation Sheet CS 2018/01 to show the maximum amount of radioactive gases that may be carried in the package carrying metallic thorium. In Calculation Sheet CS 2018/01, the applicant used the method provided in ANSI N14.5 to determine the maximum permissible volume leakage rates for both NCT and HAC based on the allowed regulatory release rates. Staff reviewed Calculation Sheet CS 2018/01 and confirmed that the assumptions used in the calculation are applicable to the Safkeg-HS 3977A package. Staff finds that the calculated leakage rates are acceptable because they are below the limits of 10^{-6} A_2/hr and A_2/week, specified by 10 CFR 71.51(a)(1) for NCT and 71.51(a)(2) for HAC respectively.

4.4 Containment under Normal Conditions of Transport

The applicant stated in SAR section 4.2 that the Safkeg-HS 3977A package is designed to be leaktight during NCT, where leaktight is defined as demonstration of a leakage rate of less than or equal to $1\text{x}10^{-7}$ ref-cm^3/s as specified by ANSI N14.5 (1997). The applicant also stated in SAR Section 4.2 that the content types CT-6 is carried within an insert that confines the solid radioactive material within the CV shielding. In addition, the applicant stated in SAR Section 4.3.2 that, for gaseous radioactive material in content type CT-6, it is assumed that the gas leaks through the containment seal at a leakage rate of 1x 10^{-7} ref-cm^3/s and the gas contents are limited to ensure that the leakage rate would not exceed the limit of $10^{-6}A_2$/hour as specified in 10 CFR 71.51(a)(1). Staff finds that the NCT containment evaluations, described in SAR Section 4.2, demonstrate that the seals, bolts, and containment system materials maintain their containment functions under NCT. Therefore, staff concludes that the containment system meets the requirements for providing containment of solid and gaseous radioactive contents within the package under NCT.

4.5 Containment under Hypothetical Accident Conditions

The applicant stated in SAR Section 4.3 that the Safkeg-HS 3977A package is designed to be leaktight during HAC, where leaktight is defined as demonstration of a leakage rate of less than or equal to $1\text{x}10^{-7}$ ref-cm^3/s as specified in ANSI N14.5 (1997). The applicant stated in SAR Section 4.3 that content type CT-6 is carried within an insert material that confines the solid radioactive material within the CV shielding. For gaseous radioactive material in content type CT-6, the applicant assumed the gas leaks through the containment seal at a leakage rate of $1\text{x}10^{-7}$ ref-cm^3/s and the gas contents are limited to ensure that the leakage rate would not exceed the regulatory limit of A_2/week for HAC, specified in 10 CFR 71.51(a)(2).

In SAR Section 4.5.2, the applicant provided supporting document CS 2018/01 for CT-6 which identifies the maximum amounts of radioactive gases that may be carried and no escape of other radioactive material exceeding a total amount of A_2 in a week, as given in 10 CFR 71.51 (a)(2). Staff reviewed the gas content limit calculations for leaktight conditions shown in documents CS 2018/01. Staff determined the calculated leakage rates meet the HAC limits of no escape of Kr-85 exceeding 10 A_2, and no escape of other radioactive material exceeding a total amount of A_2 in a week as required by 10 CFR 71.51(a)(2).

4.6 Evaluation Findings

Based on review of the statements and representations in the application, the staff concludes that the containment design has been adequately described and evaluated and that the package design meets the containment requirements of 10 CFR Part 71.

5.0 SHIELDING EVALUATION

The purpose of the staff's review is to verify that the package design, including the proposed contents, meets the external radiation limit requirements of 10 CFR Part 71 for NCT and HAC. The NRC staff reviewed the application to ensure it meets the external radiation limit requirements in 10 CFR Part 71. The staff performed its shielding review using the guidance in Chapter 5, "Shielding Evaluation" of NUREG-1609, "Standard Review Plan for Transportation Packages for Radioactive Material." This portion of the SER documents the staff's review pertaining to the adequacy of the shielding design of the package.

5.1 Shielding Design Description

5.1.1 Design Features

The applicant designed the Safkeg-HS 3977A package as an outer SS keg enclosing insulating cork packing and an inner CV. Originally, the applicant planned to load the proposed contents (i.e., metallic thorium) directly into the CV. However, due to technical difficulties associated with the original design, the applicant modified their approach to utilize a cylindrical SS insert as shown in proprietary Drawing 2C-8094, "HS-55x113-SS– Design No. 4109". As a result, the Safkeg-HS 3977A shielding design featured three major components: the insert, the CV, and the outer packaging that is referred to as the keg. However, the applicant took no credit in the shielding evaluation for the ability of the insert material to reduce dose rates.

The CV consisted of a body, a lid and a CV plug as shown in Drawing 1C-7944, "Containment Vessel Design No. - #4109 Insert." The CV body, which is shown in Drawing 1C-7946, "Containment Vessel Body - #4109 Insert," utilized approximately 46 millimeters (mm) depleted uranium (DU) shielding at the base of the CV and 47.6 mm DU shielding along the side of the CV except at the top where the lid seats. The activated thorium content required the use of a split CV lid configuration. For the split CV lid configuration, the applicant employed a SS CV lid, which is shown in Drawing 1C-7945, "Containment Vessel Lid - #4109 Insert," and a CV plug, which is shown in Drawing 1C-7947, "Containment Vessel Plug - #4109 Insert." The CV plug utilized DU within a SS body and a layer of steel situated below the DU. The CV plug resided inside the CV cavity. Table 1-3-6 of the application discussed the required configuration for shipping the thorium target content.

The staff reviewed the figures, certificate drawings, and discussion describing the shielding features of the package. The applicant included the shielding features, materials, and dimensions with tolerances. The staff found that they are sufficiently detailed to support staff evaluation.

5.1.2 Summary Table of Maximum Radiation Levels

The applicant summarized the maximum calculated package dose rates under NCT and HAC in SAR Table 5-1 at the locations prescribed by the regulations. The SAR Table 5-1 provided the calculated dose rates for a package under NCT loaded with the activated thorium content at the bottom package surface, the outer surface of the conveyance, two meters from the edge of the conveyance, one meter from the package surface and one meter from the edge of the conveyance. The limiting dose rates proved to be at the bottom of the package.

Under NCT, the applicant calculated the following maximum dose rates: 818 mrem/hr at the package surface, 24 mrem/hr at the conveyance surface, and 3 mrem/hr two meters from the conveyance surface. Because the applicant stated in SAR Section 5.2.1 that the Safkeg-HS 3977A will be transported within a closed-sided truck, the staff finds that these values meet the regulatory dose rate requirements in 10 CFR 71.47(b), which limits the package dose rates for exclusive use, to 1000 mrem/hr at the package surface, to 200 mrem/hr at the conveyance surface if transported within a closed vehicle, and to 10 mrem/hr two meters from the conveyance surface.

For the package under HAC, the calculated dose rate included the highest dose rate at 1 meter from the side, top and bottom locations of the package surface. The SAR Table 5-1 identified this dose rate as 17 mrem/hr. The staff finds that this value meets the regulatory dose rate requirement for HAC in 10 CFR 71.51(a)(2) which limits the dose rate to 1000 mrem/hr at one meter from the package surface.

5.2 Radiation Source

The applicant proposed to add proton irradiated thorium as a new content within the Safkeg-HS 3977A. The applicant stated that the thorium target is nominally 60mm in diameter, 0.37mm thick and cut into five pieces. The applicant wanted to transport up to 7.46 GBq (0.2 Ci) of Ac-225 along with other radionuclides arising from proton irradiation of thorium. The applicant determined that 498 isotopes result from proton activation of the thorium target using the FLUKA code. The source included nuclides emitting primary gamma radiation as well as nuclides emitting beta radiation which generated bremsstrahlung gamma radiation. Because of the excessive number of isotopes which would be listed within the certificate, and because the applicant did not want to make the isotopes from the irradiation publicly available, the applicant defined the source in terms of the maximum number of gammas per second per energy bin by combining the primary gamma radiation and the bremsstrahlung gamma radiation. Being unfamiliar with the FLUKA code, the staff did not make a finding regarding how accurately the applicant determined the nuclides generated by proton irradiation of thorium. However, not knowing the exact nuclides present in the activated thorium is not necessary because the resultant gammas/second and energy spectra is a condition within the CoC that the package user must meet.

Based upon the gamma energies emitted by the primary gamma emitting nuclides, the applicant developed a group structure of fifteen energy groups ranging from less than 30 keV up to a maximum of 6 MeV. The applicant provided these groups in Appendix B of the proprietary Brookhaven National Laboratory report, C-A/BLIP/001, “Activation of Th-232 target using FLUKA simulation code,” January 2019. The combined gammas per second for all nuclides for each energy group make up the source term for the primary gamma emitters and is referenced in the CoC as the allowable source for the thorium content. Although defining the source in this manner requires extra user calculations to determine if a given activated thorium target is allowable for transport, the grouped source simplifies the CoC, provides loading flexibility, and protects the proprietary nature of the nuclides generated in the irradiation process.

In addition to evaluating the primary gamma radiation source, the applicant assessed the dose rate contribution from Bremsstrahlung radiation (i.e., photons generated by electrons interacting with the material through which it travels) because, although the electrons emitted by the thorium target will not penetrate the package shield materials, the photons generated by the electron travelling through the high Z shield materials (i.e., DU gamma shield and SS) could produce a significant radiation source and must be considered. The applicant assessed the bremsstrahlung contribution by inputting the individual nuclides into the ORIGEN code from the SCALE code system to determine a bremsstrahlung only source term. The ORIGEN bremsstrahlung calculations are based on pre-calculated estimates from electron interactions in UO_2. Since the ORIGEN code does not have libraries for all nuclides, the applicant generated a beta spectrum for each nuclide that did not have an ORIGEN library and combined the separate energy spectrums into a single beta source term. The applicant assumed that every beta particle in the source term was converted to gamma photon of the same energy. The staff found that this is a reasonable way to estimate the bremsstrahlung contribution to the external dose for this package and content.

The applicant modeled this bremsstrahlung source within Monte Carlo N–Particle Transport Code System Version 6.2 (MCNP) and found that the dose rate contribution of bremsstrahlung radiation is less than one percent of the primary gamma source as shown in Table 8-9 of the Atkins report. Since the bremsstrahlung contribution to the dose rate is very low, it is likely that it will be accounted for by other modeling conservatisms (e.g., modeling gammas at the highest energy of an energy bin as mentioned above). Therefore, the staff found that it is unnecessary to provide additional CoC conditions on beta emitting nuclides within the proton irradiated thorium content.

The applicant evaluated the dose rate contribution from each nuclide individually and summed them all up for each location specified within the limits. The applicant binned the various gamma energies into energy groups and represented these energy groups using the maximum energy of the group. The staff found this approach to be conservative because most gammas grouped within an energy bin are at an energy below the maximum. Consequently, representing them as the maximum energy will cause the predicted dose rate to be higher than the as loaded condition; therefore, the staff found it acceptable. The applicant provided the results in Appendix A-1 of the Atkins report.

5.3 Shielding Model

The following subsections discuss how the applicant modeled the package under NCT and HAC for its shielding evaluation. The staff reviewed the structural and thermal sections of the SAR to identify the impacts, if any, these disciplines might have on the shielding evaluation. The staff found the shielding model acceptable based on the following discussions and margin to regulatory dose rate limit under HAC in 71.51(a)(2).

5.3.1 Packaging Model

The staff verified that shielding model dimensions are consistent with those in the Safkeg-HS 3977A cask drawings. The staff compared the dimensions shown in Tables 8-1 and 8-2 of the Atkins report to those in drawings 0C-7942, 0C-7943, 1C-7945, 1C-7946, and 1C-7947. The staff verified that the applicant used minimum dimensions.

The applicant determined that the conditions and tests required by 10 CFR 71.71(c) produced an approximately 8 mm dent in the package outer keg. Since this would bring the package surface approximately 8 mm closer to the source, the applicant accounted for this by reducing the package outer steel shell dimensions by approximately 8 mm under NCT. The staff found this to be conservative and acceptable since it applies a localized effect to the entire package which results in higher calculated dose rates.

As discussed in the staff's SER for the initial issuance of CoC 71-9338 (ADAMS Accession No. ML14092A086), a rubber disc is utilized to prevent movement of the insert and loosening of the insert lid due to phenomena such as vibration. See SAR section 7.1.4, "Loading of Contents with a Split CV Lid with Insert Design No. 4109," does not state that the rubber disc is needed for this configuration. The staff found this acceptable with respect to the shielding evaluation because the shielding material within the insert is not credited within the shielding evaluation. However, the presence of the insert has been credited for its function in positioning of the source and needs to be present for the source to remain in the approximate center of the CV cavity during NCT.

To prevent the source from escaping from its analyzed position within the insert due to vibration under NCT (10 CFR 71.71(c)(5)), the applicant placed the thorium source within a container (e.g., a polymer or metal jar or tin) which is held in the approximate axial center of the insert using two spacers as shown in Drawing 1C-7975. The required physical dimensions of the spacers, the container and the container lid ensured that, even if the lid becomes loose during transport, it would remain in contact and the source would remain inside the container. Staff added CoC condition 7 that states the container lid must be greater than 6.1 mm in depth which is the maximum amount of space available after accounting for the internal dimensions of the insert cavity, spacers and container body. Having a lid greater than 6.1 mm ensures that the source would remain inside if the lid becomes loose during transport. The staff discussed this condition with the applicant and the applicant found it acceptable (ADAMS Accession No. ML20066F970).

The applicant stated in SAR section 5.2.2 that the HAC drop tests produce an 11 mm dent in the package and that this damage results in a 5% increase in dose rate. However, the SAR contained no qualifying information supporting this assumption. The applicant also stated that the only other damage that would affect the shielding is the loss of the cork material during a fire. Although the analysis supporting authorization of the proton irradiated thorium credited the presence of the cork, the applicant did not evaluate the possibility that the source relocated closer to the detector due to the steel shell around the cork failing to hold the weight of the package if the cork ablated during a fire. In addition, the applicant did not assume that the spacers and the container holding the source in the center of the insert fail and the source relocates. Despite these possible events that would cause dose rates to increase under HAC, the staff found that the dose-rate margin is large enough to provide reasonable assurance the package will not exceed the regulatory limits in 10 CFR 71.51(a)(2). As a result, staff finds the applicant's HAC modeling for this package and content sufficient. The staff also performed independent calculations which are discussed in Section 5.5 of this SER.

5.3.2 Source Model

Table 8.1 of the Atkins report 5183326-HS-REP-001-01 (ADAMS Accession No. ML19289A805) identified that the source is modeled as a thorium disc approximately 57 mm in diameter and 0.37 mm in height. Because these dimensions are slightly smaller than those cited in Drawing 1C-7975, staff finds them conservative because modeling smaller dimensions would credit less self-shielding than is actually present.

The applicant modeled the source as five wedge shaped pieces inside a container. The SS spacers centered the source container within the CV cavity. Drawing 1C-7975, “Packing for Thorium Target in Design No. 3978,” showed the packing for the source container and spacers. The evaluation took no credit for either the spacer material or the container material. However, the evaluation took credit for the spacers and container maintaining the positioning of the source.

Since the five wedge-shaped segments within the container can rearrange to any possible configuration, the applicant modeled two extreme scenarios to bound all possible configurations. The first configuration stacked all five segments directly on top of each other, and the second configuration modeled the five wedge pieces as a disc at the bottom of the container. The stack minimized the distance to the side of the package while the disc minimized the distance to the bottom of the package. The applicant’s analysis showed that the dose rate is the highest on the bottom of the package for both configurations.

5.3.3 Material Properties

The applicant specified the material densities used in the MCNP model in Table 8-4 of the Atkins report. For the steel, uranium, and thorium, the staff found the material composition and densities acceptable as they are consistent with the material densities found within available literature (Reference: PNNL-15870 Rev. 1, “Compendium of Material Composition Data for Radiation Transport Modeling,” Rev. 1, March 2011).

The cork density used in the MCNP model is below that used for the acceptance criteria in SAR Chapter 8.1.5.4 and within Drawing 0C-7943. Staff finds this conservative. Although the staff was unable to verify the elemental composition of the cork, the staff found that the elements assumed are reasonable for this material for the following reasons. First, gamma shielding capability is mostly dominated by the material density which is conservative for this application. Second, although different materials of the same density can show differences in gamma shielding capability, the cork is not the predominant gamma shield for this package.

As discussed in Section 4.1.1 of the Atkins report, the applicant modelled the SS components as carbon steel. The staff determined that, because the composition of carbon steel and SS are similar, the material differences between SS and carbon steel would have a negligible effect on dose rates. Staff also determined that carbon steel is slightly less dense. Therefore, staff determined that any change in dose rates due to a different steel would likely be conservative. As a result, staff finds the applicant’s material assumptions acceptable.

5.4 Shielding Evaluation

5.4.1 Methods

The applicant performed the shielding calculations using the ENDF/B-VII.1 data library with the general-purpose, continuous-energy, generalized-geometry, time-dependent, coupled neutron/photon/electron code MCNP6, Version 6.2. Given the code’s capabilities and its extensive application in industry (ensuring the code is well-vetted), the staff found the code acceptable for this application.

5.4.2 Input and Output Data

The staff reviewed the applicant's representative MCNP input and output files submitted on October 2, 2019. Due to the complexity of the model, the staff did not verify that the geometry of the package model was correctly represented within the code; however, the staff performed its own calculations, which are discussed in SER Section 5.5, to provide further assurance that the Safkeg packaging was modeled correctly. The staff verified that the source input was properly represented and that the output file shows that proper convergence was achieved. Since the applicant performed a separate calculation for each energy group to determine a dose rate contribution per gamma and calculated the dose rate contribution from each nuclide, the staff could not confirm that the dose rates in the applicant's representative output file agreed with those in the application because the applicant did not provide every input file. However, the staff performed independent calculations which modeled the entire source together, and staff found with reasonable assurance, that the proposed source within the Safkeg packaging meets regulatory dose rate limits.

5.4.3 Flux-to-Dose-Rate Conversion

As stated in SAR section 5.5.3 and Section 4.1 of Atkins report 5183326-HS-REP-001-01 (ADAMS Accession No. ML19289A805), the applicant derived flux-to-dose-rate conversion factors from a polynomial fit using coefficients in Figure 9-3 of ANSI/ANS 6.1.1-1977 for gamma dose rates consistent with the recommendations in NUREG-1609. The applicant showed the factors in Table 8-5 of the Atkins report. The staff verified that these factors are consistent with the published values from the standard and were properly input into the representative MCNP input file.

5.4.4 Locations for Evaluating the Dose Rate

The applicant performed scoping calculations and determined that the most limiting dose rate location is at the bottom of the package as shown in Table 8-6 of the Atkins report. The staff finds that the results of the study align with the expectation that this location should produce the highest dose rates due to the decreased thicknesses of the DU shielding and dimensions of the cork (effectively decreasing the distance to the detector).

The applicant provided additional information on the size and location of the tallies in Table 2 of Section 6 in "SARP Update Matrix for Thorium Target," December 2019 (ADAMS Accession No. ML19343A006) that shows that the volume is sufficiently small to calculate a maximum dose rate and not an average dose rate. In this table, the applicant also stated the locations at which the dose rates are calculated and these account for the annular hole at the base of the Safkeg. The staff determined that the distances meet the requirements in 10 CFR 71.47(b) and 10 CFR 71.51(a)(2).

5.4.5 External Radiation Levels

The applicant calculated both the NCT and the HAC external dose rates to ensure they meet the requirements in 10 CFR 71.47(b) and 10 CFR 71.51(a)(2) as discussed in SER Section 5.1.2. At the package surface, the applicant calculated 818 mrem/hr which meets the limit of 1000 mrem/hr for this location in 10 CFR 71.47(b)(1). As a result, the package is subject to the following requirements: the package must be shipped within a closed transport; the package must be secured to the vehicle so that its position remains fixed during transportation; and no loading or unloading operations occur between the beginning and end of the transportation. The applicant calculated the dose rate at the outer surface of the conveyance to be 24 mrem/hr. This meets the limit of 200 mrem/hr in 10 CFR 71.47(b)(2) for this location. The applicant calculated the dose rate at 2 meters from the conveyance to be 3 mrem/hr. This meets the limit of 10 mrem/hr in 10 CFR 71.47(b)(3) for this location. Under HAC, the applicant calculated the dose rate at one meter from the package surface to be 17 mrem/hr. As discussed in SER Section 5.3.1, the staff did not find the HAC modeling to be conservative; however, because the applicant's calculated HAC dose rate meets the limit of 1000 mrem/hr in 10 CFR 71.51(a)(2) with significant margin, the staff has reasonable assurance that the package will meet the regulatory limit despite the non-conservativism discussed in SER Section 5.3.1.

5.5 Staff Calculations

The staff independently calculated the dose rates on and around the Safkeg package with the requested thorium source using the MAVRIC (Monaco with Automated Variance Reduction using Importance Calculations) sequence within the SCALE 6.2.3 code package. The MAVRIC sequence employs the Monte Carlo code Monaco which is a fixed-source shielding code that uses the SCALE General Geometry Package (SGGP, the same as used by the criticality code KENO-VI) and the standard SCALE material information processor. Monaco can use either multi-group or continuous-energy cross section libraries. MAVRIC is based on the Consistent Adjoint Driven Importance Sampling methodology for variance reduction which uses an importance map and biased source that are derived to work together.

The staff used the ENDF/B-VII.1 continuous-energy neutron and gamma library in its evaluation. The staff simulated the source simultaneously within the package versus the method used by the applicant that simulated the dose rate contribution per energy group of the source. The staff's model used nominal dimensions for the packaging and only calculated dose rates at the bottom of the package based on the discussion in SER section 5.4.4. Although the staff's calculated dose rates were higher than the applicant's calculated values by 20-50%, they remained below the regulatory limits for all prescribed locations within 10 CFR 71.47(b) and 10 CFR 71.51(a)(2). This gave the staff additional assurance that the package will meet regulatory dose rate limits.

Based on the discussion in SER section 5.3.1, the staff performed sensitivity studies removing the cork as well as assuming the spacers fail and the source relocates to the bottom of the cavity. The staff also assumed that if the cork was absent, the steel shell surrounding the cork would fail and bring the detector location closer to the source. The staff found that the change in dose rate due to these effects is not enough to exceed the regulatory limit in 10 CFR 71.51(a)(2). This further supports the staff's finding that the HAC modeling, as discussed in SER section 5.3.1, is adequate for the proton irradiated thorium content.

5.6 Evaluation Findings

Based on its review of the statements and representations in the application and independent confirmatory calculations, the staff finds that the shielding design of the package has been adequately described and evaluated and there is a reasonable assurance that the package meets the external radiation requirements of 10 CFR Part 71. The staff performed its review following the guidance provided in NUREG-1609, "Standard Review Plan for Transportation Packages for Radioactive Material."

6.0 CRITICALITY EVALUATION

Section 6 of the SAR states that the contents of this package are non-fissile and therefore no evaluation for the safety of fissile contents is required. Since the contents associated with this revision are not fissile material, staff did not perform a criticality review.

7.0 PACKAGE OPERATIONS

The applicant added SAR section 7.1.4 to address loading the thorium contents into the Model No. 3977A package, and SAR section 7.2.4 to address unloading the thorium contents from the Model No. 3977A package. The applicant originally intended to use an O-ring in the CV plug and load the contents directly into the CV using spacers to locate the contents in the approximate axial center of the CV. However, because the O-ring seal made it difficult to install the CV plug, the applicant modified their design to use insert Design No. 4109 in conjunction with a container and knit wire packing as shown in SAR Figure 1.7. The applicant subsequently provided instructions in SAR section 7.2.4 for removing the insert from the CV and the container from the insert. The applicant specified that the contents should be removed from the container using site specific procedures. Based on a review of the statements and representations in the application, the staff concludes that the operating procedures meet the requirements of 10 CFR Part 71 and that these procedures are adequate to assure the package will be operated in a manner consistent with its evaluation for approval.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM REVIEW

The applicant originally revised several SAR Chapter 8 to add references to the sealed split CV lid package configuration and to specify leak test procedures for the sealed split CV lid package configuration. When the applicant modified their design, they removed the leak testing procedures. They also replaced references to the sealed split CV lid package configuration with references to insert 4109. Based on review of the statements and representations in the application, the staff concludes that the acceptance tests for the packaging meet the requirements of 10 CFR Part 71, and that the maintenance program is adequate to assure packaging performance during its service life.

CONDITIONS

The CoC includes the following condition(s) of approval:

Condition 5(a)(2) was revised to describe insert 4109.

Condition 5(a)(3) was revised to list the licensing drawings for the insert 4109 package configuration.

Condition 5(b)(1)(vi) was added to list the type and form of the thorium authorized for transport.

Condition 5(b)(2) was revised to identify the maximum amount of radioactive material authorized for transport.

New Condition 7 was added to specify a container lid limitation for transport of the radioactive material and subsequent CoC conditions were re-numbered as necessary.

The references section has been updated to include this request.

Minor editorial corrections were made.

CONCLUSIONS

Based on the statements and representations contained in the application, as supplemented, and the conditions listed above, the staff concludes that the design has been adequately described and evaluated, and the Model No. 3977A package meets the requirements of 10 CFR Part 71.

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on April 14, 2020.