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

SAFETY EVALUATION REPORT

Docket No. 71-9320
Model No. MIDUS Package
Certificate of Compliance No. 9320
Revision No. 3

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SUMMARY

By letter dated March 30, 2016, (ADAMS Package Accession No. ML16096A074) and supplemented on July 14, 2016 (ADAMS Package Accession No. ML16202A424) and October 20, 2016 (ADAMS Package Accession No. ML16299A083), Energy*Solutions* (the applicant), requested a revision to the Certificate of Compliance (CoC) for the Model No. MIDUS packaging. Also, by letter dated October 20, 2016, the applicant requested to renew the CoC of the MIDUS packaging with the changes corresponding to the revision request submitted in March 2016. The applicant submitted a consolidated application by letter dated October 20, 2016. Therefore, the CoC for the Model No. MIDUS references the application submitted by letter dated October 20, 2016.

The applicant proposed the following changes to the Model No. MIDUS CoC:

1) adding solid molybdenum-99 (^{99}Mo) as authorized content;

2) reducing the previously approved fracture toughness for the depleted uranium shielding material; and

3) changes to licensing drawings.

The NRC staff (the staff) evaluated the changes to the package and the addition of the proposed contents against the regulatory standards in 10 CFR Part 71, “Packaging and transportation of radioactive material,” including the general standards for all packages and performance standards for Type B packages under normal conditions of transport (NCT) and hypothetical accident conditions (HAC). The staff used NUREG-1609, "Standard Review Plan for Transportation Packages for Radioactive Material," as guidance to perform this review. Based on the statements and representations provided by the applicant, the staff concludes that the package meets the requirements of 10 CFR Part 71. The CoC has also been renewed for five years.

The following sections include the staff’s evaluation and findings in the areas related to the review.

1.0 GENERAL INFORMATION

1.1 Package Description

1.1.1 Packaging

The main materials of construction of the packaging are stainless steel, elastomers (e.g., ethylene propylene), polyurethane foam, steel, and depleted uranium alloys. The packaging consists of two primary components:

(1) an inner package assembly that provides containment of the radioactive material and radiation shielding, and

(2) an overpack that provides impact and thermal protection.

The package assembly includes a machined stainless steel containment vessel, surrounded by depleted uranium for radiation shielding. The containment system closure lid is a stainless steel plate attached to the package body by eight socket head cap screws. The closure lid has a leak test port. Two concentric ethylene propylene O-rings serve to seal the containment system and, at the top end of the package, a lid installed over the closure lid and a stainless steel clad depleted uranium shield plug in the package cavity provide shielding. The applicant proposed changing the minimum Charpy V-notch impact energy for the of depleted uranium (used as shielding material) from 10 feet-pound (ft-lb) at 70 Fahrenheit (°F) to 6ft-lb at 70°F due to availability of material meeting the 10ft-lb at 70°F specification. The overpack is constructed of thin stainless steel shells filled with rigid polyurethane foam. The overpack lid is attached to the base by eight recessed alloy steel bolts.

The overall dimensions of the package are approximately 520 millimeters (mm) (20.5 inches) [1] in diameter and 551 mm (21.7 inches) [2] in height. The maximum weight of the package is 330 kilograms (kg). The dimensions and maximum weight of the package remained unchanged.

1.1.2 Contents

1.1.2.1 Type and form of material

The Model No. MIDUS package is a Type B(U) package currently approved for transporting ^{99}Mo with its daughter products as natrium molybdate in liquid form (Content Number (No.) 01). The applicant proposed to add solid-metallic ^{99}Mo (Content No. 02) with its daughter products as an authorized content for the Model No. MIDUS. In Section 1.2.2 of the application, the applicant noted that the safety analyses presented in Chapters 2 through 8 of the application also apply to Content No. 02.

[1] Approximated length, since the application includes the packaging dimensions in millimeters.

1.1.2.2 Maximum quantity of material per package

For Content No. 02, the maximum product activity per package at the time of shipment is 4,400 curies (Ci) of ^{99}Mo. In Section 9.2 of the application, the applicant mentioned that the maximum specific activity for Content No. 02 is 60 Ci per milliliter (Ci/ml) of ^{99}Mo at the time of shipment.

The maximum product activity and maximum specific activity for Content No. 02 are the same as for Content No. 01. In Section 9.2, “Content #2 – Structural Evaluation,” of the application, the applicant noted that the weight limit of Content No. 02 is 1.0kg, which is less that the design payload weight of 1.1kg.

1.1.3 Drawings

Table 1 of this safety evaluation report (SER) includes the changes completed by the applicant to the licensing drawings of the Model No. MIDUS. The two parallel lines of unequal length above the weld symbol reference line was changed to a single line to represent an essentially "flush or flat" weld contour.

Table 1. Revised Drawings for the Model No. MIDUS Package.

Licensing Drawing No.	Drawing Title	Revision No.	Sheet No.
TYC01-1601	“General Arrangement of Packaging and Contents”	2	1
			2
TYC01-1602	“General Arrangement of Cask Assembly”	2	1
			2
			3
			4
TYC01-1604	“Containment System”	3	1
TYC01-1605	“Closure Devices”	1	1
TYC01-1606	“Gamma Shielding”	1	1

2.0 STRUCTURAL EVALUATION

The purpose of the structural review is to verify that the changes proposed by the applicant to the Model No. MIDUS package and the inclusion of Content No. 2 meet the requirements of 10 CFR Part 71 as these changes relate to the structural performance of the package, including the tests and conditions for NCT and HAC.

2.1 Description of Structural Design

The structural design of the Model No. MIDUS remained unchanged from the previously approved design. However, the staff evaluated changes in the application to ensure the structural design remained unaffected and assumptions remained valid such as:

a. Charpy V-Notch test for depleted uranium used as shielding material,

b. material properties and specifications,

c. chemical and galvanic reactions, and

d. fabrication and examination processes.

The following sections summarize the staff's structural evaluation.

2.2 Materials

The purpose of the materials review is to verify that the changes proposed by the applicant to the Model No. MIDUS and the inclusion of Content No. 02, meet the requirements of 10 CFR Part 71 as these changes relate to the materials used for the fabrication and operation of the package. The staff finds that the applicant will use materials for preventing or mitigating galvanic or chemical reactions, tolerating subzero temperatures without undesirable metallurgical consequences, and processing in accordance with acceptable industry codes and standards. Therefore, the staff finds that the applicant meets the requirements of 10 CFR 71.43(e). This section of the SER includes the staff's materials evaluation for the proposed changes to Model No. MIDUS package.

2.2.1 Materials Properties and Specifications

The materials used for the construction of the packaging can be classified into four major categories:

(1) structural materials,

(2) shielding material depleted uranium,

(3) shock absorbing foam materials, and

(4) other materials.

The applicant provided the specifications of materials for the packaging assembly and its components in Table 2-11, "Packaging Material Specification," of the application. The staff reviewed the information presented in the engineering drawings and found it was consistent with the materials specifications listed in Table 2-11 of the application.

The staff also reviewed information related to the materials used for the construction of structural components. Table 2 of this SER includes the material specifications of the main structural components, which includes high strength steel alloys.

The staff finds that the mechanical properties of these materials conform to the American Society of Mechanical Engineers (ASME) Code, Section II, "Materials," Part D, "Properties," and are summarized in Tables 2-12 through 2-18 of the application. These mechanical properties include:

(1) design stress intensity,

(2) yield strength,

(3) tensile strength,

(4) modulus of elasticity, and

(5) coefficient of thermal expansion.

Table 2. Material Specifications for Structural Components of the Model No. MIDUS Package.[2]

Packaging Structural Component	Materials Specifications
Package Body Shell	ASTM[3] A240, Type 304 or Type 316 stainless steel
Closure Lid	ASME SA-240 or SA-479, Type 304 or Type 316 stainless steel
Closure Bolts	ASME SA-320, Grade L43
Shield Lid Plates	ASTM A240 or A479, Type 304 or Type 316 stainless steel
Overpack Inner and Outer Shells	ASTM A240, Type 304 or Type 316 stainless steel

The applicant considered a temperature range from -40 Celsius (ºC) to 93ºC in the package analyses. The staff reviewed the information provided by the applicant regarding the materials selected as part of the design of the Model No. MIDUS and determined that these are acceptable.

The staff notes that future licensing actions requested for the Model No. MIDUS should be clearer about the meaning of the phrase "standard industry practices" by referencing and reasonably explaining the applicability of consensus standards and/or manufacturer's specification(s) in the application.

2.2.1.1 Charpy V-notch Impact Energy

The applicant proposed using a depleted uranium alloyed with 2% by weight of molybdenum (i.e., U-2%Mo) for fabricating the shielding components of the package. The applicant requested changing the fracture toughness evaluation (the Charpy V-notch impact energy) from 10ft-lb at 70°F to 6ft-lb at 70°F based on the current availability of depleted uranium feed material in the U.S. (The applicant included this change in Section 2.1.2.5, "Brittle Fracture," of the application.) The staff asked the applicant to provide an evaluation to justify the reduction of the previously approved fracture toughness, considering that the calculations and inspections remained unchanged in the application. The applicant noted that there should not be a new concern regarding chemical, galvanic, or other types of reactions because the following reasons:

[2] The list of components in Table 2 of this safety evaluation do not include all the components of the Model No. MIDUS package. The source of the information was Table 2-11 of the application.
[3] American Society for Testing and Materials.

(a) the current CoC and associated safety analysis report already specify U-2% Mo; and

(b) there are 30 operating MIDUS units.

The staff also reviewed the SER corresponding to Revision 0 of the CoC for the Model No. MIDUS to confirm the applicant's response. As discussed in Section 2.3 of the initial SER, it is unlikely that the depleted uranium shield would fracture in an accident and result on a through-wall streaming path because:

(a) the fracture would stay within an annulus with a very small void space, and

(b) any direct streaming path would be very small.

Accordingly, the staff concludes that applicant provided reasonable assurance that the depleted uranium shield would not fracture under HAC, and that (in the unlikely event that it did fracture) the post-accident dose rates would not exceed the regulatory dose limits of 10 CFR Part 71.

2.2.2 Chemical and Galvanic Reactions

Section 2.2.2 of the application includes the evaluation of chemical, galvanic, and other reactions, including stress corrosion cracking. The applicant specifies the material of construction of the package along with the conclusion that the contents of the package will not cause significant chemical, galvanic, or other reaction in an air, nitrogen, or water atmosphere. In some instances, the staff also addressed reactions related to liquid ^{99}Mo to apply the lessons learned from similar reviews. The staff did not evaluate liquid ^{99}Mo as a proposed content, since this content was previously approved for transport in the Model No. MIDUS.

2.2.2.1 Content No. 01

The staff asked the applicant to clarify its analyses related to significant chemical or other reaction(s) between the liquid ^{99}Mo payload (Content No. 01) and the stainless steel payload internals. The staff also asked the applicant for the rationale of not including the material specifications for the product bottle in its safety analysis report. The applicant noted the following reasons for not specifying the type of stainless steel used for the product bottle and payload internals in the application:

(a) to allow operational flexibility in the event that material changes were necessary to meet the needs of the isotope producer (including the effects of adverse reactions).

(b) the product bottle and other payload internals are user-supplied items and not part of the certified packaging, as stated in Section 3.3.2, "Maximum Normal Operating Pressure," of the application.

Therefore, the applicant did not take credit of the product bottle and/or the payload internals as barriers in the safety analyses for the Model No. MIDUS.

In terms of chemical or galvanic reactions, the applicant noted that it considered the following assumptions in its analyses:

(a) possible of interactions between the product and stainless steel for transport and service conditions at the medical isotope facility (Table 2-24, “Summary of MIDUS Material Interactions,” of the application);

(b) the risk of stress corrosion cracking in the material used for manufacturing the product bottle and payload internals is not credible because their temperature remains below 95°C during NCT; and

(c) the maximum temperature of the product bottle and payload internals is approximately equal to the bulk average temperature of the gas inside the package cavity. The package cavity gas bulk average temperature remains below 80°C under NCT heat (see Figure 3-3, “NCT Heat Temperature Transient Results,” of the application).

The applicant noted that it was not aware of significant reactions between the liquid payload and stainless steel product bottle in its 10 years of operational experience using the Model No. MIDUS package. Therefore, based on its experience using approximately 30 MIDUS units in weekly shipments worldwide, the applicant concluded that chemical reactions between the contents, the stainless steel product bottle, and the payload internals, such as stress corrosion cracking, will not occur during NCT.

The staff finds the liquid payload of ^{99}Mo acceptable during NCT and not susceptible to adverse chemical reactions including risk of stress corrosion cracking based on the discussion above.

2.2.2.2 Content No. 02

The possibility of galvanic reactions between the different metals used in the fabrication of the Model No. MIDUS is low, based on the conditions of use. Further, packaging users perform visual inspections of the payload cavity during loading/unloading operations, and provide reasonable assurance against any considerable corrosion that may occur unnoticed. Therefore, for Content No. 02, the staff finds that, all structural components fabricated of austenitic stainless steel and at low temperature would not cause detrimental effects on the performance of the Model No. MIDUS packaging materials.

2.2.2.3 Exposure to Water and Air

During its review, the staff also considered corrosion caused by contact with water or air. Continuous or frequent exposure to moisture or intrusion of water is not likely to occur in great quantities. Also, the staff is not aware of significant chemical or galvanic reactions that would occur in air for the materials used in the Model No. MIDUS package. For example, the ethylene propylene O-ring material provides good resistance to sodium hydroxide and sodium nitrate in the payload liquid solution. The radioactive ^{99}Mo should not precipitate from the payload solution when the service temperature is below the freezing point, which ensures that the specific activity would not increase under cold temperature conditions. The staff concludes that, during NCT, the Model No. MIDUS internals would not be subject to chemical or galvanic reactions due to moisture or air exposure. Therefore, the applicant met the regulatory requirements of 10 CFR 71.43(d).

2.2.2.4 Properties and specifications of the "ANTI-SIEZE" coating

The staff requested the applicant to provide the properties and specifications of the "ANTI-SIEZE" coating, verify the spelling of the word "ANTI-SIEZE," and clarify if it is a trademark name. The applicant stated that:

(a) Detailed properties and specifications for the thread lubricant are not provided on drawing No. TYC01-1605, Sheet 1, Revision 1, because:

  i) the drawings provided in the application are in agreement with the guidance in NUREG/CR-5502, “Engineering Drawings for 10 CFR Part 71 Package Approvals,” and

  ii) the information related to the coating materials would not affect the package safety evaluation.

(b) The correct spelling is "anti-seize" and this material is not a trademark.

The applicant revised the spelling of the “anti-seize" coating in the safety analysis report for the Model No. MIDUS package submitted in October 2016.

Table 2-24 of the application shows the material interactions considered during the evaluation of the package's materials of construction that also consider possible galvanic, chemical, and other reactions. The applicant evaluated the pure nickel thread lubricant for contact with decontamination fluid, stainless steel, and nickel-chromium-molybdenum (Ni-Cr-Mo) fasteners (thread inserts).

The applicant did not provide the material properties and specifications (as specified in Regulatory Guide 7.9, “Standard Format and Content of Part 71 Applications for Approval of Packages for Radioactive Material”) of the "anti-seize" coating. The absence of this information should not affect the safe handling of the package. The staff notes that pure nickel anti-seize compound is typically used for threaded fasteners where high temperature service is required and it provides resistance to corrosion and oxidation.

The staff finds pure nickel anti-seize lubricants to be acceptable for use as a sealant to protect the binding surfaces from corrosion and oxidation with no detrimental effects, based on the applicant’s evaluation of the contact material, various material specifications, and material safety data sheets describing the chemistry and operating conditions in terms of temperature. In addition, bolts are considered redundant in the package’s design. (Generally, bolts are not considered as fracture-critical components, as multiple load paths exist.)

2.2.3 Effects of Radiation on Materials

The payload of the Model No. MIDUS package is heavily shielded. For this reason, the staff expects negligible radiation exposure to the overpack, the elastomeric containment seal materials (ethylene propylene O-rings), and the polyurethane foam. The stainless steels and depleted uranium alloys are known to resist radiation without degrading their mechanical properties. For the ethylene propylene O-rings, exposures to 1×10^6 rads show little deterioration effects. This means that these O-rings can withstand hundreds of loading cycles and normal wear (not radiation) is the primary factor for their replacement frequency of once a year. Conversely, the cleanliness seal (which is not part of the containment boundary) may be susceptible to radiation damage because it is directly irradiated by the payload. The cleanliness seal is replaced in every shipment to ensure that it is not adversely affected by the payload's radiation. The lubricant used for threaded fasteners is a nickel-based lubricant, which is suitable for the radiation environment. In terms of the polyurethane foam, it can resist radiation exposures up to 2×10^8 rads with no effect on its density and crush strength. Water absorption would not affect these properties of the foam, assuming radiation exposures up to 1×10^7 rads. The staff finds that there will be no deleterious radiation effects on the containment seal. Moreover, the staff does not expect significant degradation of the mechanical properties of the materials used for the construction and operation of the package under the radiation field produced by the approved contents.

2.2.4 Fabrication and Examination

2.2.4.1 Brittle Fracture

In Section 2.1.2 of the application, the applicant specifies that all the metal components of the package are fabricated from austenitic stainless steel, which is not susceptible to brittle fracture at low temperatures. Austenitic stainless steel:

(a) does not undergo a ductile-to-brittle transition in the temperature range of interest down to -20°F (-29°C);

(b) can be suitable for sub-zero (ambient) temperatures and locations (typically down to -40°C) resulting from the face-centered cubic (FCC) atomic structure (a consequence of the nickel addition to these steels); and

(c) does not exhibit an impact ductile/brittle transition, but a progressive reduction in Charpy impact values as the temperature decreases. (See additional discussion below related to the impact of the "Charpy" concerning value of the depleted uranium.)

As stated in Regulatory Guide 7.11, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)," (1991):

> "Since austenitic stainless steels are not susceptible to brittle failure at temperatures encountered in transport, their use in containment vessels is acceptable to the staff and no tests are needed to demonstrate resistance to brittle fracture."

Bolts are not considered as fracture-critical components because multiple load paths exist and bolting systems are generally redundant per Section 5 of NUREG/CR-1815, "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inch Thick," August 1981.

It is relevant to note that as temperature decreases, the strength and hardness of metals increase; the magnitude of the change depends on the material. However, ductility may or may not decrease noticeably. Metals having a face-centered cubic (FCC) structure, such as austenitic stainless steel, remain tough and ductile at very low temperatures. Metals possessing a body-centered cubic (BCC) structure (e.g., iron/structural steel) undergo a marked decrease in ductility at some temperature ranges, which varies with the material as well as environmental and operating conditions.

In order to demonstrate compliance with 10 CFR 71.71(b), the applicant tested the performance of the package at ambient temperature, no brittle fracture was observed. The applicant did not note observable differences in the structural test results (e.g., drop test results) for the low temperature test versus the ambient temperature test. Therefore, with the exception of the closure lid bolts, the staff finds that all structural components fabricated of austenitic stainless steel have no detrimental effects on the performance of the packaging at low temperatures encountered during in-service operations.

2.2.4.2 Welding

The staff reviewed the drawings submitted in the application to verify if the applicant followed the appropriate industry standards and practices. The following paragraphs include a discussion of the staff's evaluation of the information submitted by the applicant as part of the licensing action requested for the Model No. MIDUS.

(a) Drawing No. TYC01-1602, Sheet 1 of 4

The staff requested to verify whether Note 4 of drawing No. TYC01-1602, Sheet 1 of 4, was a resistance "seam weld" as identified in the American Welding Society (AWS) standard A2.4, "Standard Symbols for Welding, Brazing, and Nondestructive Examination," weld symbols or simply "jargon" used to describe a "groove weld." The applicant removed the word "seam" from Note 4 for clarity.

(b) Drawing Nos. TYC01-1602, Sheets 2 to 4, and TYC01-1603, Sheet 2 of 3

The staff requested the applicant to discuss the use of weld symbols on drawing No. TYC01-1602, Sheet 2 of 4, and all the drawings submitted in the application. The applicant noted that the use of the complete joint penetration (CJP) symbol for the welds on drawing No. TYC01-1602, Sheets 2 and 3 of 4, allows the fabricator to use the weld joint that is best for the position in which the weld will be made. The call-out for the single bevel welds on drawing Nos. TYC01-1602, Sheet 4 of 4, and TYC01-1603, Sheet 2 of 3, is due to a stepped joint. The two parallel lines of unequal length above the reference line were changed to a single line representing an essentially "flush or flat" weld contour.

(c) Drawing No. TYC01-1602, Sheet 4 of 4

The applicant noted that local melting of the polyurethane foam during welding would not contaminate the welds because the pour-hole cover and the overpack shell have a mating step that forms a backing to the casing plate weld. The staff requested the applicant to explain the process of welding the casing plate to the shield lid related to drawing No. TYC01-1602, Sheet 4 of 4.

The applicant revised drawing Nos. TYC01-1602, Sheet 1 of 4; TYC01-1602, Sheets 2 to 4; and TYC01-1603, Sheet 2 of 3. Therefore, the staff finds the information provided by the applicant acceptable. The staff also finds that the stepped backing design is acceptable based on welding into sold base material.

2.2.4.3 Brazing

The applicant mentioned that standard industry practices are used for the fabrication of the depleted uranium alloy gamma shield components, the overpack base thermal spider, and its brazed connections to the overpack base shells. The applicant also noted the following in response to the staff's questions related to the brazing process:

(a) The inside surface of the overpack is cleaned following brazing operations, and prior to installation of the polyurethane foam to ensure proper installation.

(b) Performance of a sectioned test article and follow up examination confirmed that the foam uniformly filled the cavity surrounding the thermal spider.

(c) Brazing symbols were not placed on the drawing in order to allow the fabricator to qualify either furnace or torch brazing procedures.

The staff finds the codes and standards used as part of the inspection criteria for the brazing process to be acceptable. The brazing process would be addressed during quality assurance inspections of the fabrication process of the Model No. MIDUS.

2.3 Structural Evaluation under Normal Conditions of Transport and Hypothetical Accident Conditions

In terms of the proposed content, the pressure and temperature loads in the containment boundary are less for Content No. 02 (solid form of ^{99}Mo) than Content No. 01 (liquid form of ^{99}Mo). The applicant noted that the weight, pressure, and thermal loads due to Content No. 02 are less than the ones previously analyzed for Content No. 01. Therefore, the applicant asserted that they did not need to perform further structural analyses because the previous analysis bounds the structural performance of the package for Content No. 02.

In order to verify the applicant's approach, the staff reviewed the structural analyses corresponding to Revision 2 and Revision 3 of the CoC including the resultant weight, pressure, and temperature loads due to Content No. 01 and compared these to the same parameters for Content No. 02. Because the weight, pressure, and thermal loads due to Content No. 02 are less than those due to Content No. 01, the staff concludes that the applicant's approach is acceptable for the NCT and HAC analyses of Content No. 02.

2.4 Evaluation Findings

Based on the review of the statements and representations in the application, the applicant's revised drawings, and the codes and standards used for the inspection criteria of the brazing process, the staff concludes that the applicant adequately described and evaluated the structural design and integrity of the package in the application. Therefore, the applicant met the requirements of 10 CFR Part 71 related to the structural evaluation of the package.

3.0 THERMAL EVALUATION

The purpose of this thermal evaluation is to verify that changes to the design of the Model No. MIDUS transport package and the inclusion of Content No. 02:

1. provide adequate protection against the thermal tests specified in 10 CFR Part 71, and

2. meet the thermal performance requirements of 10 CFR Part 71 under NCT and HAC.

The thermal design of the package described in Section 3.1.1, “Design Features,” of the application has not changed from the previous approval.

3.1 Thermal Evaluation under Normal Conditions of Transport and Hypothetical Accident Conditions

The previously approved thermal analysis in Sections 3.3, “Thermal Evaluation Under Normal Conditions of Transport,” and 3.4, “Thermal Evaluation Under Hypothetical Accident Conditions,” of the application used a decay heat of 17.8 Watts based on 4,500 Ci of ^{99}Mo. The maximum activity of Content No. 02 is 4,400 Ci of ^{99}Mo. Therefore, the staff concludes that the decay heat used in the thermal analysis in Sections 3.3 and 3.4 of the application, as well as the predicted NCT and HAC temperature results from the thermal analysis, are bounding for Content No. 02.

The staff previously approved the package internal pressures for NCT and HAC included in Table 3-3, “Summary Table of Maximum Pressures in the Containment System,” of the application. The applicant calculated the values in Table 3-3:

a. using the bulk average temperature of the gases within the containment system,

b. using a bounding decay heat as described above, and

c. considering gas generation due to radiolysis.

There is no radiolytic gas generation for Content No. 02 because it is solid metallic form. Therefore, the staff concludes that the pressures calculated in Table 3-3 of the application are bounding for Content No. 02.

3.2 Evaluation Findings

Based on review of the statements and representations in the application, the staff concludes that the applicant adequately described and evaluated the thermal design and that the thermal performance of the package meets the thermal standards of 10 CFR Part 71.

4.0 CONTAINMENT EVALUATION

The purpose of this containment evaluation is to ensure that changes to the design of the Model No. MIDUS transport package and the inclusion of Content No. 02 satisfy the containment requirements of 10 CFR Part 71 under NCT and HAC.

4.1 Containment under Normal Conditions of Transport and Hypothetical Accident Conditions

Section 4.1.1, “Description of the Containment System,” of the application did not change from the previous approval. The package containment criterion to the American National Standards Institute (ANSI) N14.5, “American National Standard for Radioactive Materials—Leakage Tests on Packages for Shipment,” leaktight criterion, 1×10^{-7} ref-cm^3/s, under NCT and HAC has not changed from the previous approval. The package containment criterion is leaktight. Therefore, Content No. 02 does not need to be evaluated based on radionuclide inventory.

The leakage rate tests described in Section 4.4, “Leak Rate Tests for Type B Packages,” and Chapters 7 and 8 of the application have not changed from the previous approval, except for the pre-shipment leakage rate test. The staff noted that the application and licensing drawing No. TYC01-1605 did not have a consistent description of the pre-shipment leakage rate test acceptance criterion for this package. The applicant clarified that the pre-shipment leakage rate test acceptance criterion is no detected leakage when tested to a sensitivity of at least 1×10^{-3} ref-cm^3/s as described in Section 7.6.4 of ANSI N14.5. The applicant agreed to make these changes in its letter dated March 20, 2007, “Application for MIDUS Transportation Package Approval, Response to Request for Additional Information (TAC. No. L24039),” (ADAMS Accession No. ML070880131). The applicant mentioned that it was an inadvertent omission. The applicant incorporated these changes in its application submitted by letter dated July 14, 2016.

4.2 Evaluation Findings

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

5.0 SHIELDING EVALUATION

The purpose of this shielding evaluation is to ensure that changes to the design of the Model No. MIDUS transport package and the inclusion of Content No. 02 meet the shielding requirements of 10 CFR Part 71 under NCT and HAC.

5.1 Description of Shielding Design

The package assembly provides some radiation shielding from the contents. The package consists of a steel and depleted uranium package body assembly, a steel package closure lid assembly, and a steel and depleted uranium shield lid assembly that provides additional radiation shielding in the axial direction. The package body assembly consists of the payload cavity and radial and axial depleted uranium shields sheathed in stainless steel. The applicant did not take credit for the additional shielding provided by the product cladding and secondary container in its shielding analysis.

5.2 Radiation Source

Molybdenum-99 (^{99}Mo) and its daughter products, technetium-99 (^{99}Tc), and technetium-99m (^{99m}Tc), emit photons and electrons (beta particles). (The package design does not include neutron sources.) The beta particles slightly contribute to the external dose rates of the package due to the interaction of bremsstrahlung radiation with the source materials. The applicant found that the external dose rate could increase by 0.06% due to bremsstrahlung radiation. Since the applicant assumed a total source activity increase greater than 0.06%, the applicant's analysis conservatively predicts external dose rates. The applicant estimated the photon source term by conservatively assuming a bounding product activity of 4,500 Ci of metallic ^{99}Mo. The maximum activity allowed in the Model No. MIDUS is 4,400 Ci. Table 5-5, "Photon Source," of the application includes the photon source sorted by energy and power.

5.3 Shielding Model

The applicant used several models to analyze NCT considering the possible range of source positions and configuration as well as various package orientations. The applicant conservatively modeled the source at its maximum allowable specific activity to minimize self-shielding. The applicant also assumed a spherical configuration. The dose rates calculated by the applicant were well below the regulatory limits.

5.4 Shielding Evaluation

The applicant evaluated the package analytically using MCNP5, a general-purpose Monte Carlo n-particle (MCNP) code that is commonly used to model photon transport and to perform three-dimensional shielding analyses. This code accounts for a wide range of photon interactions, and also for secondary photon production. The applicant used the flux-to-dose conversion factors from ANSI/ANS 6.1.1-1977, "American National Standard for Neutron and Gamma-Ray Flux to Dose Rate Factors," as specified in NUREG-1609.

The applicant adequately accounted for streaming paths present in the package assembly. The applicant considered manufacturing tolerances in the significant shielding components, such as the depleted uranium, to model the least shielded condition. The manufacturing tolerances for the steel components are very small because the package is precision-machined. Therefore, the applicant modeled the nominal thicknesses for the steel components of the package.

The staff evaluated several source configurations to conduct a comparative analysis to the results of the previous analysis. The staff performed an evaluation using the spherical form assumed by the applicant and evaluated two additional source configurations: 1) cylindrical and 2) fluid. In all cases, the staff modeled the source material assuming the following:

a. a volume of 75 milliliters (ml) to match the maximum specific activity, 60 Ci/ml, permitted in the package,

b. minimum self-shielding, and

c. molybdenum metal at a density of 10.28 grams per cubic centimeter (g/cm^3).

The staff's results showed that, for a given source volume, specific activity, and configuration, the proposed addition of metallic ^{99}Mo targets (i.e., Contents No. 02) is bounded by the previous evaluation of Contents No. 01.

5.4.1 Shielding Evaluation under Normal Conditions of Transport and Hypothetical Accident Conditions

The applicant did not change the HAC from the previous evaluation.

5.5 Evaluation Findings

Based on review of the statements and representations in the application, the staff concludes that the applicant adequately described and evaluated the shielding design, and that the shielding performance of the package meets the radiation protection standards of 10 CFR Part 71.

6.0 CRITICALITY SAFETY EVALUATION

There are no fissile materials authorized for transport in the Model No. MIDUS package, therefore, criticality safety is not a concern.

7.0 PACKAGE OPERATIONS

Section 7 of the application includes information regarding operations used to:

1. load the package and prepare it for transport,
2. unload the package, and
3. prepare an empty package for transport.

The applicant noted that Section 7 applies to Content No. 02. This section of the application includes the fundamental package operations consistent with the package evaluation in Sections 2 through 6, and to ensure that occupational radiation exposures are as low as reasonably achievable.

The applicant revised Section 7.4 to clarify that the acceptance criterion for the pre-shipment leakage rate test is no detected leakage when tested to a sensitivity of at least 1×10^{-3} ref-cm^3/s, to be consistent through the application (see Section 4.1 of this safety evaluation for additional details). The staff reviewed Section 7 of the application and confirmed that the package operations meet the requirements of 10 CFR 71.87.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

Section 8 of the application includes information regarding acceptance testing to assure that each packaging is consistent with the package evaluation in Sections 2 through 6, and a maintenance program to assure that the package maintains its ability to meet the regulatory requirements of 10 CFR Part 71 throughout its service life.

The applicant did not propose changes to Section 8 of the application and noted that the contents of this section also applies to Content No. 02, including Section 8.1.5.4 "Depleted Uranium," of the application. Section 8.1.5.4, the applicant notes that the depleted uranium used in the Model No. MIDUS should meet the acceptance criteria described in drawing No. TYC01-1606. The applicant proposed changing the Charpy V-notch impact energy from 10ft-lb at 70 °F to 6ft-lb at 70 °F based on the current availability of depleted uranium feed material in the U.S. Section 2.2 of this safety evaluation report includes the staff's evaluation of this change. This change did not affect the description in Section 8 of the application.

CONDITIONS

The following additional condition was included in the Certificate of Compliance:

Revised Condition No. 3.b. to add the date of consolidated application (i.e., October 20, 2016).

Revised Condition No 5.(a)(3), "Drawings," to include the current revision of the following drawings:

TYC01-1601, Sheets 1 and 2, Rev. 2	"General Arrangement of Packaging and Contents"
TYC01-1602, Sheets 1 through 4, Rev. 2	"General Arrangement of Cask Assembly"
TYC01-1604, Sheets 1 through 3, Rev. 3	"Containment System"
TYC01-1605, Sheets 1 and 2, Rev. 1	"Closure Devices"
TYC01-1606, Sheets 1 through 3, Rev. 1	"Gamma Shielding"

Added Condition No. 5.(b)(1)(ii) as follows:

> "Molybdenum-99 with its daughter products as solid, metallic molybdenum.
>
> The metal will be contained within a sealed aluminum target can and placed in an aluminum carrier. The total mass of the payload shall not exceed 1.0 kg, including the target cans and carrier."
>
> Consequently, revised the numbering of Condition No. 5.(b)(1) to 5.(b)(1)(i).

Revised Condition No. 5.(b)(2) as follows for clarity and to distinguish between the volume versus the mass of material per package:

Maximum activity	4,400 Ci ^{99}Mo
Maximum specific activity	60 Ci/ml ^{99}Mo
Liquid product volume	0 to 150 ml
Maximum mass of material	1.0 kg

The quantities allowed per package remained unchanged, since changes were editorial in Condition No. 5.(b)(2).

Deleted Condition No. 8, renumbered Condition No. 9 as No. 8, and revised the expiration date to November 30, 2021.

Revised the "REFERENCES" section to reflect the submittal of the consolidated application dated October 20, 2016.

CONCLUSION

Based on the statements and representations contained in the application, and the conditions listed above, the staff concludes that the Model No. MIDUS package meets the requirements of 10 CFR Part 71.

Issued with Certificate of Compliance No. 9320, Revision No. 3,
on, Nov. 14, 2016.