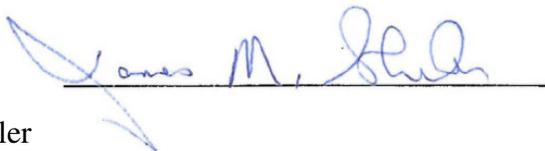




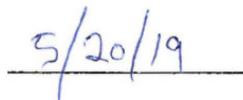
**Safety Evaluation Report
for
Initial Certification Review of the
Model 9981 Type AF Package Design
Safety Analysis Report for Packaging (SARP)
S-SARP-G-00020, Revision 0 (March 2019)**

Docket Number: 18-32-9981

Prepared by:



Date:



James M. Shuler

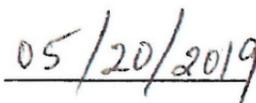
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ABBREVIATIONS AND ACRONYMS

ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
B&PVC	Boiler and Pressure Vessel Code
BTSP	Bulk Tritium Shipping Package
CFR	Code of Federal Regulations
CG	Center-of-Gravity
CL	Centerline
CGOC	Center-of-Gravity Over Corner
CGOT	Center-of-Gravity Over Top
CoC	Certificate of Compliance
CS	Carbon Steel
CSI	Criticality Safety Index
DA	Design Authority
DOE	Department of Energy
DOT	Department of Transportation
EPDM	Ethylene Propylene Diene Monomer
HAC	Hypothetical Accident Condition
LEU	Low Enriched Uranium
MNOP	Maximum Normal Operating Pressure
M&O	Management and Operating Contractor
NCT	Normal Conditions of Transport
NNSA	National Nuclear Security Administration
NRC	Nuclear Regulatory Commission
PSD	Power Spectral Density
PSI	Pounds per Square Inch
PRG	Packaging Review Guide
PT&TE	Packaging Technology & Transportation Engineering
QA	Quality Assurance
QAP	Quality Assurance Program
QAPD	Quality Assurance Program Description
RG	Regulatory Guide
SARP	Safety Analysis Report for Packaging
SRS	Savannah River Site

SRNS	Savannah River Nuclear Solutions, LLC
SS	Stainless Steel
SST	Safe Secure Trailers
SRNL	Savannah River National Laboratory
TI	Transportation Index
TRR	Technical Review Report
VTD	Vertical Top Down
VTU	Vertical Top Up
TID	Tamper-Indicating Device
UN	United Nations
UNC	Unified National Coarse

PREFACE

By memorandum dated March 9, 2018, the Savannah River Operations Office requested Department of Energy (DOE) certification of the Model 9981 Type AF package design, based on Revision 0A of the Safety Analysis Report for Packaging (SARP), S-SARP-G-00020, dated February 6, 2018, prepared by the Savannah River National Laboratory (SRNL). The SARP was subsequently revised and supplemented by SRNL and Revision 0, dated March 11, 2019, of the SARP was submitted to DOE on March 13, 2019. Revision 0 of the SARP, supersedes in its entirety Revision 0A.

The Model 9981 is a new Type AF package design developed by Savannah River National Laboratory (SRNL) for the transport of Type A quantities of fissile material over public highways, within the continental United States. The package is designed to ship uranium metals, oxides, and other solid compounds. The initial package contents are materials defined as the Low Enriched Uranium Content Envelope, which consists of low-enriched uranium ingots, uranium regulus called “derbies,” and miscellaneous metal waste with up to 1.25% enrichment of U-235 and a maximum mass of 160 kg.

This Safety Evaluation Report (SER) summarizes the results of an independent technical review and confirmatory analysis of the SARP by Department of Energy Packaging Certification Program (PCP) staff.

The SARP documents the full-scale testing and analysis of the package design to demonstrate compliance with 10 CFR Part 71 in accordance with DOE Order 460.1D, *Hazardous Materials Packaging and Transportation Safety*. Offsite shipments (in commerce) of the package must comply with the applicable requirements in DOE Order 460.2A, *Departmental Materials Transportation and Packaging Management* and DOE M 460.2-1, *Radioactive Material Transportation Practices Manual*.

All subsequent references in this SER to Chapter(s) Section(s), Table(s), Figure(s), Drawing(s), or Appendix refer to the SARP and all references to package(s) or packaging(s) refer to the Model 9981, unless otherwise specified.

1. General Information Review

1.1 Areas of Review

This section of the SER documents PCP staff's review of Chapter 1, *General Information*.^[1-1]. Staff review includes an evaluation of the SARP with respect to the requirements specified in 10 CFR 71.^[1-2].

The following elements of the *General Information* chapter were reviewed. Details of the review are provided below in SER Section 1.3.

Included in the General Information Review were the following:

1.1.1 Introduction

- Purpose of Application
- Summary Information
- Statement of Compliance
- Summary of Evaluation

1.1.2 Package Description

- Packaging
- Contents
- Special Requirements for Plutonium
- Operational Features

1.1.3 Appendices

- Drawings
- Other Information

1.2 Regulatory Requirements

The requirements of 10 CFR 71, applicable to the *General Information* review of the package, include:

- An application for package approval must be submitted in accordance with Subpart D of 10 CFR 71. [§71.0(d)(2)]
 - An application for modification of a previously approved package is subject to the provisions of §71.19 and §71.31(b). All changes in the conditions of package approval must be approved. [§71.19, §71.31(b), §71.107(c)]
 - The application must include a description of the packaging design in sufficient detail to provide an adequate basis for its evaluation. [§71.31(a)(1), §71.33(a)]
 - The application must include a description of the contents in sufficient detail to provide an adequate basis for evaluation of the packaging design. [§71.31(a)(1), §71.33(b)]
-

- The application must reference or describe the quality assurance program applicable to the package. [§71.31(a)(3), §71.37]
- The application must identify the established codes and standards used for the package design, fabrication, assembly, testing, maintenance, and use. In the absence of such codes, the application must describe the basis and rationale used to formulate the quality assurance program. [§71.31(c)]
- An application for renewal of a previously approved package must be submitted no later than 30 days prior to the expiration date of the approval to assure continued use. [§71.38]
- The smallest overall dimension of the package must not be less than 10 cm (4 in.). [§71.43(a)]
- The outside of the package must incorporate a feature that, while intact, would be evidence that the package has not been opened by unauthorized persons. [§71.43(b)]
- A package with a transport index greater than 10, a Criticality Safety Index greater than 50, or an accessible external surface temperature greater than 50°C (122°F) must be transported by exclusive-use shipment. [§71.43(g), §71.47(a), §71.47(b), §71.59(c)]
- The maximum activity of radionuclides in a Type A package must not exceed the A₁ or A₂ values listed in 10 CFR 71, Appendix A, Table A-1. For a mixture of radionuclides, the provisions of Appendix A, paragraph IV apply, except that for krypton-85, an effective A₂ equal to 10 A₂ may be used. [Appendix A, §71.51(b)]
- A fissile material packaging design to be transported by air must meet the requirements of §71.55(f).
- A fissile material package must be assigned a Criticality Safety Index for nuclear criticality control to limit the number of packages in a single shipment. [§71.59, §71.35(b)]
- Plutonium in excess of 0.74 TBq (20 Ci) must be shipped as a solid. [§71.63]
- The package must be conspicuously and durably marked with its Model number, serial number, gross weight, and package identification number. [§71.19, §71.85(c)]

1.3 Review Procedures

1.3.1 Introduction

1.3.1.1 Purpose of Application and Summary Information

The Model 9981 package was developed by SRNL for the transport of Type A quantities of fissile material over public highways within the continental United States. The package is designed to ship uranium metals, oxides, and other solid compounds. The initial proposed contents are materials that defined as the Low Enriched Uranium Content Envelope, which is low-enriched uranium ingots, derbies, and miscellaneous metal waste with up to 1.25% enrichment of U-235 and a maximum mass of 160kg.

The purpose for the submittal of the Model 9981 SARP is to obtain a DOE Certificate of Compliance (CoC) of the package design.

1.3.1.2 Statement of Compliance

The SARP includes statements and representation to demonstrate compliance with the requirements of Title 10 of the Code of Federal Regulations Part 71^[1-2] and is prepared in accordance with U.S. Department of Energy (DOE) Order 460.1D^[1-3] and in the format specified in the Nuclear Regulatory Commission (NRC) Regulatory Guides (RGs) 7.9^[1-4] and 7.10^[1-5].

1.3.2 Package Description

The Model 9981 is a Type AF package design for transport of fissile low enriched uranium ingots, uranium regulus called “derbies,” and miscellaneous metal waste.

1.3.2.1 Packaging

The package is composed of two primary assemblies: an insulated 55-gallon outer drum and an internal insulated 30-gallon drum. The 55-gallon drum incorporates a steel liner which serves as the form for polyurethane foam that provides thermal insulation and structural support. The 30-gallon drum, positioned centrally (both radially and axially) within the 55-gallon drum liner, secures the payload and provides containment for the radioactive contents. The 30-gallon drum is also outfitted with an internal steel liner and a polyurethane foam layer between the steel surfaces. An aluminum honeycomb cylinder is located between the top of the steel liner and the inside of the 30-gallon drum lid for energy absorbance.

Reinforced split ring devices provide secure closures for the 30- and 55-gallon drums. There are no external impact limiters nor any engineered structural features for lifting or tie-down. There are no designed packaging heat-transfer features. The 30-gallon drum honeycomb cylinder and internal foamed liner provide for payload load dispersal. Three weight limits apply to the Model 9981. The gross weight of a fully loaded package shall not exceed 650 lb. (295 kg.); the mass of the radioactive material shall not exceed 160 kg. (352 lb.); and the total payload mass (i.e., radioactive and non-radioactive contents) shall not exceed 166 kg. (365 lb.).

The 30-gallon drum closure lid includes a pressure relief device to ensure that an over pressure condition does not occur. This device does not permit continuous venting under normal conditions of transport (NCT).

The packaging design does not incorporate any specific shielding features. The distance between the contents and points external to the package provides sufficient dose-rate attenuation. Chapter 5 quantifies package dose rates under NCT and Hypothetical Accident Conditions (HAC).

The packaging design does not incorporate any specific criticality-control features. The design ensures subcriticality by limiting package contents and maintaining a minimum distance between adjacent fissile material sources. Chapter 6 explains how these restrictions prevent the criticality of both single packages and arrays of packages under NCT and under HAC.

Drums and Closures

The packaging design incorporates two commercial removable-head drums (30- and 55-gallon) produced in accordance with 49 CFR 178.504, *Standards for Steel Drums*, except for marking per 178.504(b)(1), which is not required because the drums are subsequently modified. The drums comply with the applicable provisions of 49 CFR 178.350, *Specification 7A; general packaging, Type A*. The 55-gallon drum is modified to include a steel liner welded to the inside of the drum body and under its closure lid. Polyurethane foam insulation fills the cavities formed between the liner and drum/lid components. The safety function of the 55-gallon drum assembly is to confine and protect the 30-gallon drum assembly. The safety function of the 30-gallon drum assembly is containment (i.e., confinement) boundary for the radioactive contents. Similar to the 55-gallon drum assembly, the 30-gallon drum also features a steel drum liner with polyurethane between the steel surfaces.

55-Gallon Outer Drum

The outside dimensions of the closed 55-gallon drum are nominally 25 ¾ inches in diameter by 34½ inches high. The drum body and lid both incorporate liners fabricated from carbon steel. The liner assemblies are welded to the inside of the drum body and lid forming cavities which are filled with polyurethane foam. Nondestructive methods are used to verify complete filling of each drum body and lid.

The drum body is fabricated from 16-gauge carbon steel and the welded liner is fabricated from 16- and 18-gauge carbon steel. The drum lid and its liner are fabricated from 16-gauge carbon steel. The drum bottom and lid feature ¼ inch diameter steel welded reinforcing rods. Additionally, the drum top roll and bottom chime are reinforced with ⅛ inch fillet welds. The welded rods and crimped and rolled drum chimes increase the rigidity of the drum under HAC impacts. The cavities formed by the liner between the drum and lid are filled with the 24 lb./ft³ Dow Automotive polyurethane foam (i.e., BETAFOAM™). The polyurethane foam is used for thermal insulation and energy (shock) absorption. The weight of the drum without its lid is approximately 140 lb. The drum lid weighs approximately 24 lb. When installed, the lid assembly extends into the drum body liner. An ethylene propylene diene monomer (EPDM) gasket seals the closure.

The drum body and lid include external penetrations that permit venting of gases generated from the thermal decomposition of the polyurethane foam in a fire. The drum wall includes nine ½ inch diameter holes uniformly spaced axially and circumferentially. Two holes are placed in the bottom of the drum, a 1¼ inch diameter hole used for filling the drum with foam and a ½ inch diameter hole used for a vent. The drum lid includes a single 1¼ inch diameter hole used for filling the lid with foam. All holes are covered with a waterproof tape to prevent water or moisture from entering the drum through the holes under NCT, even though the polyurethane foam is not functionally affected by the presence of moisture. During the HAC-fire the tape disintegrates.

The drum assembly is closed with a split ring closure device which secures the closure lid to the drum. The closure consists of two identical half or split rings fabricated from 12-gauge carbon

steel connected by bolted lugs. The closure device is similar to standard commercial C-ring closures used on commercial removable-head drums but is halved and incorporates two 1 inch flange extensions, one extending horizontally and the other vertically from the C-ring. Lugs are welded at each end of the two split rings. Each split ring is identical, with one 1½ inch lug threaded with ⅝-11UNC-2B thread and the other with a ¾ inch diameter through hole. The closure device secures the closure lid to the drum via two 3½ inch long, ⅝ carbon steel hex head bolts and jam nuts. Each lug includes a 0.13 inch diameter hole to receive a tamper indicating device (TID). The split ring closure weighs approximately 9.8 lb. The nominal weight of the 55-gallon assembly (body, closure lid and split ring closure device) is 177.4 lb.

30-Gallon Containment (i.e., confinement) Drum

The general outside dimensions of the closed 30-gallon drum are 18.6 inches in diameter by 29 inches high. The usable cavity in the drum is nominally 15⅜ inches in diameter by 18 inches high. The drum and its closure lid are fabricated from 18- and 16-gauge carbon steel, respectively. The drum liner is fabricated from 18-gauge carbon steel liner. The cavity formed between the liner and drum is filled with the 24 lb./ft³ Dow Automotive polyurethane foam (i.e., BETAFOAM™). A removable aluminum honeycomb cylinder is inserted at the top of the drum prior to installing the lid. The honeycomb is covered on the top and sides with silicone rubber for handling purposes. A steel disk is attached to the bottom of the honeycomb for impact load dispersal. The polyurethane foam and honeycomb cylinder are used for energy absorption. The drum lid incorporates a standard commercially stamped and threaded 2 inch diameter bung-hole flange. The 2 inch bung-hole is fitted with a formed neoprene gasket and a 2 inch pressure release device that is designed to open between 12-15 psig to limit buildup of internal pressure during HAC. A formed silicon gasket between the drum and lid seals the drum closure. The nominal weight of the drum assembly is 89.3 lb.

The drum split ring closure device design is similar to the closure device used on the 55-gallon drum except for the smaller size and low-profile lugs welded at each end of the two split rings to permit greater clearance for installing the 30-gallon assembly into the 55-gallon drum. The 30-gallon split ring closure weighs approximately 7.2 lb.

Insulation Components

Two additional thermal insulation components are used in the packaging. Both components are made from a soft ceramic fiber mat sandwiched and sewn between 2 layers of flexible fiberglass woven cloth. The removable *Insulation Cover Assembly* (Drawing R-R4-G-00186) is placed between the 30-gallon drum assembly top and the 55-gallon drum closure lid to protect the 30-gallon drum from thermal HAC. The cover assembly is approximately 21½ inches in diameter by ½ inch thick and weighs approximately 1 lb.

The *30-Gallon Drum Insulated Bag Assembly* (Drawing R-R4-G-00189) is a bag installed permanently between the 30-gallon drum inner wall and foam insulation for additional thermal protection. The bag assembly is approximately 18¼ inches diameter by 28 inches high, and includes a removable top disk approximately 18 inches diameter by ½ inch thick. The bag is

closed with a nylon cinch cord sewn into the top edge of the bag. The entire bag assembly weighs approximately 9.7 lb.

1.3.2.2 Contents

The contents of the package (i.e., payload) includes all radioactive (fissile and non-fissile) and non-radioactive materials contained within the 30-gallon drum. The radioactive material and payload mass limits for the package are defined in Table 1.1, *Low Enriched Uranium Content Envelope*, as shown below. The maximum mass of radioactive material is 160 kg, based on low enriched uranium (LEU) with up to 1.25% of U-235. The LEU material is solid in the form of ingots, derbies, and miscellaneous metal waste.

Table 1.1 - Low Enriched Uranium (LEU) Content Envelope $\leq 1.25\%$ U-235

Feature	Material	Mass (g)
Radioisotopes	Tc-99	4.00E+00
	Th-228	6.72E-09
	Th-230	3.84E-03
	Th-232	1.76E+00
	U-232	6.13E-08
	U-234	2.20E+01
	U-235	2.00E+03
	U-236	1.72E+02
	U-238 ^a	1.58E+05
	Np-237	6.15E-02
	Pu-238	1.22E-06
	Pu-239	5.63E-03
	Pu-241	3.41E-05
	Am-241	9.97E-07
Total Mass ^a	Radioactive Material	1.60E+05
	Package Payload	1.66E+05

a.) Includes contributions from daughter products, e.g., Th-234, etc.

b.) The LEU material described in Table 1.1 was analyzed for Pu-240 and Pu-242. Results indicate quantities below the detection limit.

Payload Limits and Restrictions

The following limits apply to the package contents:

- Payload decay heat is limited to a maximum of 6 milliwatts.
- Radioactive material mass is limited to a maximum of 160 kg. (352 lb.).

- Payload mass is limited to a maximum of 166 kg. (365 lb.).
- Moisture within the payload is limited to a maximum of one weight percent.

The following forms of materials are prohibited as package contents:

- Pyrophoric materials
- Cryogenic liquids
- Compressed gasses
- Visible liquids
- Chemically reactive substances

Payload includes all radioactive and non-radioactive material; non-radioactive contents may include secondary containers, wrapping, convenience cans, plastic bagging, polyurethane foam, polyethylene, vermiculite packing, and other dunnage material.

The following are requirements for content packing configurations:

- Sharp edged waste must be padded if shipped without handling containers.
- Handling containers must be vented and packed with closures upright.

1.3.2.3 Special Requirement for Plutonium

Plutonium contents in excess of 0.74 TBq (20 Ci) per package must be in solid form. The SARP does not evaluate plutonium (Pu) contents, in excess of the Pu included in the LEU (approximately 3.8 mCi of total Pu), for transport in the package; therefore, this condition is not applicable.

1.3.2.4 Operational Features

Split ring Closure Installation

Installation of the split ring requires striking each half with a rubber hammer as the bolts are torqued, and the process continues until sustaining torque values of 40 ft-lb \pm 5 ft-lb in accordance with Drawings R-R1-G-0093 and R-R1-G-00094 in Appendix 1.1. The simultaneous striking and torque is necessary to overcome the static friction between the drum closure and split ring connection. When the required torque is applied the ends of the split ring halves must retain a visually discernible gap. Jam nuts are then tightened against the unthreaded lugs on the 55-gallon drum. (The 30-gallon split ring closure does not include jam nuts.)

Drum Hoisting

A lifting device is necessary for safely loading the 30-gallon drum into the 55-gallon drum. A lifting device design is provided in Drawing R-R4-G-00180. Users may design their own lifting

device, but must obtain final approval of the design from the Certificate Holder’s Design Authority (DA), prior to use, so as not to damage the packaging.

1.3.3 Regulatory Compliance Summary

The SARP documents that the package satisfies the regulatory safety requirements of 10 CFR 71 for the transport of fissile radioactive material by Public Highway—49 CFR Part 177 and Parts 390 through 397 *Carriage by Public Highway*.

1.3.3.1 General Standards for all Packages – 10 CFR 71.43

Compliance with the performance criteria for the package as specified by 10 CFR 71.43, *General Standards for all Packages*, are met as demonstrated in Sections, 1.2, 2.1, 2.2, 2.3, 2.4, 2.6, 2.7, 3.3, and 3.4.

1.3.3.2 Structural Requirements for Lifting and Tie-Down Devices – 10 CFR 71.45

Compliance with 10 CFR 71.45 is met because the packaging does not incorporate lifting or tie-down devices as a structural part of the packaging (see Section 2.5).

1.3.3.3 External Radiation Requirements – 10 CFR 71.47

The package radiation dose rate limits are met for NCT and HAC for the defined content envelope as shown in Section 5.1 and listed in Table 5.1.

1.3.3.4 General Requirements for Fissile Material Packages – 10 CFR 71.55 and §71.59

The NCT and HAC criticality evaluations provided in Chapter 6 for compliance with 10 CFR 71.55 (a-d) and §71.59 demonstrate that the package is subcritical for all fissile material configurations (single or array). The CSI for the package is 1.4.

1.3.3.5 Special Requirements for Plutonium Packages – 10 CFR 71.63

This condition is not applicable; the SARP does not evaluate plutonium contents in the package in excess of the Pu included in the LEU (approximately 3.8 mCi), for transport.

1.3.3.6 Structural and Thermal Performance under 10 CFR 71.55, §71.71 and §71.73

The structural and thermal performance under the general requirements for fissile material packages, NCT, and HAC are met as demonstrated in Sections 2.6, 2.7, 3.3, and 3.4.

1.3.4. Appendices

Engineering Drawings of the packaging design are the property of the Certificate Holder (DOE Savannah River). The Engineering Drawings provided in Appendix 1.1 and listed below comply with NUREG/CR-5502.^[1-6]

Drawing No.	Rev	Title
R-R5-G-00013	1	Model 9981 Type AF Package Tree
R-R1-G-00092	0	9981 Type AF Packaging Assembly (U)
R-R1-G-00093	0	9981 Type AF 55-Gallon Drum Overpack Assembly (U)
R-R1-G-00094	0	9981 Type AF 30-Gallon Drum Assembly (U)
R-R1-G-00101	0	9981 Type AF 30-Gallon Drum Split Ring Assembly (U)
R-R2-G-00128	0	9981 Type AF 55-Gallon Drum Lid Subassembly and Weldment (U)

R-R2-G-00129	2	9981 Type AF 55-Gallon Drum Body Subassembly and Weldment (U)
R-R2-G-00130	1	9981 Type AF 30-Gallon Drum Lid Subassembly (U)
R-R2-G-00131	3	9981 Type AF 30-Gallon Drum Subassembly (U)
R-R3-G-00094	0	9981 Type AF 55-Gallon Drum Split Ring Assembly (U)
R-R4-G-00179	2	9981 Type AF 30-Gallon Drum Insert Subassembly (U)
R-R4-G-00181	0	9981 Type AF 30-Gallon Drum Lid Gasket (U)
R-R4-G-00182	0	9981 Type AF 55-Gallon Drum Identification Plate Detail (U)
R-R4-G-00183	0	9981 Type AF Package Honeycomb Subassembly (U)
R-R4-G-00186	0	9981 Type AF Package Insulation Cover Assembly (U)
R-R4-G-00187	0	9981 Type AF Package 30-Gallon Drum Liner Detail (U)
R-R4-G-00189	0	9981 Type AF Package 30-Gallon Drum Insulation Bag Assembly (U)

1.4 Evaluation Findings

1.4.1 Findings

Based on review of the statements and representations in the SARP, PCP staff concludes that the SARP provides an adequate basis for the evaluation of the package against 10 CFR Part 71 requirements for each technical discipline.

1.4.2 Conditions of Approval

With the exception of the packaging design drawings, the contents and associated payload mass limits and restrictions delineated above, there are no additional Conditions of Approval required in the DOE Certificate of Compliance (CoC).

1.5 References

- [1-1] *Safety Analysis Report for Packaging, Model 9981 Type AF Shipping Package*, Savannah River National Laboratory, S-SARP-G-00020, Revision 0 (March 2019).
- [1-2] *Packaging and Transportation of Radioactive Material*, Code of Federal Regulations, Title 10, Part 71, Washington, DC (January 2017).
- [1-3] *Packaging and Transportation Safety*, DOE Order 460.1D, U.S. Department of Energy, Washington, DC (December 20, 2016).
- [1-4] *Standard Format and Content of Part 71 Applications for Approval of Packaging for Radioactive Material*, Regulatory Guide 7.9, Revision 2, U. S. Nuclear Regulatory Commission, Washington, DC (March 2005).
- [1-5] *Establishing Quality Assurance Programs for Packaging Used in the Transport of Radioactive Material*, Regulatory Guide 7.10, Revision 2, U.S. Nuclear Regulatory Commission, Washington, DC (March 2005).
- [1-6] *Engineering Drawings for 10CFR Part 71 Package Approvals*, NUREG/CR-5502, U.S. Nuclear Regulatory Commission, Revision 6, (May 1998).

2. Structural Evaluation

2.1 Areas of Review

This section of the SER documents PCP staff's review of Chapter 2, *Structural Evaluation*.^[2-1] Staff review includes an evaluation of the SARP with respect to the requirements specified in 10 CFR 71.^[2-2]

The following elements of the *Structural Evaluation* chapter were reviewed. Details of the review are provided below in SER Section 2.3.

2.1.1 Description of Structural Design

- Design Features
- Codes and Standards

2.1.2 Materials of Construction

- Material Specifications and Properties
- Prevention of Chemical, Galvanic, or Other Reactions
- Effects of Radiation on Materials

2.1.3 Fabrication, Assembly, and Examination

- Fabrication and Assembly
- Examination

2.1.4 General Considerations for Structural Evaluations

- Evaluation by Test
- Evaluation by Analysis

2.1.5 Structural Evaluation of Lifting and Tie-Down Devices

- Lifting Devices
- Tie-Down Devices

2.1.6 Structural Evaluation for Normal Conditions of Transport

- Heat
- Cold
- Reduced External Pressure
- Increased External Pressure
- Vibration
- Water Spray
- Free Drop

- Corner Drop
- Compression
- Penetration
- Structural Requirements for Fissile Material Packages

2.1.7 Structural Evaluation for Hypothetical Accident Conditions

- Free Drop
- Crush
- Puncture
- Thermal
- Immersion-Fissile Material
- Immersion—All Packages

2.1.8 Structural Evaluation for Special Conditions

- Special Requirement for Packages $>10^5 A_2$
- Analysis of Pressure Test

2.1.9 Appendices

2.2 Regulatory Requirements

The regulatory requirements of 10 CFR 71 applicable to the structural review of the package are as follows:

- The package must be described and evaluated to demonstrate that it meets the structural requirements of 10 CFR 71. [§71.31(a)(1), §71.31(a)(2), §71.33, §71.35(a)]
- The application must identify the established codes and standards used for the package design, fabrication, assembly, testing, maintenance, and use. In the absence of such codes, the application must describe the basis and rationale used to formulate the quality assurance program. [§71.31(c)]
- The package must be made of materials of construction that assure there will be no significant chemical, galvanic, or other reactions, including reactions due to possible in-leakage of water, among the packaging components, among package contents, or between the packaging components and the package contents. The effects of radiation on the materials of construction must be considered. [§71.43(d)]
- The package design must meet the lifting and tie-down requirements of §71.45.
- The performance of the package must be evaluated under the tests specified in §71.71 for normal conditions of transport. [§71.41(a)]

- The package must be designed, constructed, and prepared for shipment so there would be no loss or dispersal of contents, no significant increase in external surface radiation levels, and no substantial reduction in the effectiveness of the packaging under the tests specified in §71.71 for normal conditions of transport. [§71.43(f), §71.51(a)(1)]
- A package for fissile material must be so designed and constructed and its contents so limited as to meet the structural requirements of §71.55(d)(2) through §71.55(d)(4) under the tests specified in §71.71 for normal conditions of transport.
- The performance of the package must be evaluated under the tests specified in §71.73 for hypothetical accident conditions. [§71.41(a)]
- The package design must have adequate structural integrity to meet the internal pressure test requirement specified in §71.85(b).

2.3 Review Procedures

PCP staff's structural review included the following:

- Description of Structural Design: Chapter 1 and Sections 2.1 through 2.3 describe all major structural components of the packaging and contents or payloads in sufficient detail to accurately define the design and provide an adequate basis for evaluation. The design/fabrication detail in the engineering drawings of Appendix 1.1 provide the conditions of approval for the certificate of compliance.
- Materials of Construction: Tables 2.4, 2.5, 2.6, and Section 2.2 identify all structural materials of the package. Section 2.2 also discusses galvanic reaction (dissimilar contacting materials are identified in Table 2.7) and radiation effects on the package materials.
- Fabrication, Assembly, and Examination: Section 2.3 describes the fabrication and examination methods.
- General Considerations for Structural Evaluations: Section 2.4 shows how the package meets the requirements of minimum package size, tamper indication, and positive closure.
- Structural Evaluation of Lifting and Tie-Down Devices: Section 2.5 indicates that the outer packaging does not incorporate any engineered structural features for lifting the package or that could serve as tie-down devices.
- Structural Evaluation for NCT: Section 2.6 evaluates the package performance under NCT: heat, cold, reduced and increased external pressure, vibration, water spray, free drop, corner drop, compression, and penetration.
- Structural Evaluation for HAC: Section 2.7 discusses potential package damage under HAC: free drop, crush, puncture, thermal, and water immersions. Section 2.7.8 summarizes the potential damage.
- Deep Water Immersion Test: Section 2.7.7 states that the package contains less than 10^5 A₂ radioactivity and is therefore exempt from the deep immersion test.

- Structural Evaluation for Air Transportation of Plutonium: Section 2.8 states that the package is not designed for air transport. This evaluation is not applicable.
- Structural Evaluation for Air Transportation of Fissile Materials: Section 2.9 states that the package is not designed for air transport. This evaluation is not applicable.
- Special Form: The package contents are normal form and not limited to special-form contents. This evaluation is not applicable.
- Fuel Rods: The package does not credit fuel-rod cladding for containment. This evaluation is not applicable.
- Appendices: There are no appendices.
- The following procedures were employed in the review of Chapter 2, i.e., *Structural Evaluation*. These procedures generally correspond to the Areas of Review listed above in SER Section 2.1.

The structural review ensures that the package design has been adequately described and evaluated under the NCT and the HAC to demonstrate sufficient structural integrity to meet the requirements of 10 CFR 71.

Additional detail is provided following the format specified in the DOE's *Packaging Review Guide for Reviewing Safety Analysis Reports for Packagings*,^[2-3] (PRG).

The structural review is based in part on the descriptions and evaluations presented in the *General Information* and *Thermal Evaluation* chapters of the SARP. Similarly, results of the structural review are considered in the review of all other sections of the application.

2.3.1 Description of Structural Design

2.3.1.1 Design Features

The packaging consists of two principal structural components: a foam insulated 55-gallon drum containing a foam insulated 30-gallon containment drum. The outer drum functions to protect the inner 30-gallon drum under regulatory NCT and HAC events. Carbon steel liners within the 55-gallon and 30-gallon drum provide structural integrity and a form for the foam insulation, and protect the foam from abrasion during normal loading/unloading operations. The 30-gallon drum provides containment for the package payload during regulatory NCT and HAC events.

The outer drum design is identical to that used in the Model 9979 Type AF package (with the exception of the 55-gallon split ring lugs) and is nominally 25¾ inches in diameter and 34½ inches high, per Figure 1.2.

The 30-gallon drum and the 55-gallon drum incorporate 12-gauge steel split ring closure devices to seal the lids to the drum bodies and provide added structural resistance to drum deformation. The 30-gallon drum lid features a commercial pressure-relieving device to release pressure under HAC.

The packaging includes two forms of thermal insulation. The insulating materials used in the drums are Dow BETAFOAM™ 87100/87124 [Chapter 2, Reference 5] and Thermal Ceramics

Kao-Tex™ Quilt fabric. The BETAFOAM™ components react when mixed to form a closed cell, high density, polyurethane structural foam. Kao-Tex™ Quilt Insulation, consisting of a quilt made of Superwool Plus ceramic fiber for batting and E-glass fiberglass material (produced by Morgan Thermal Ceramics Company) for the top and backing, provides added thermal protection to the 30-gallon drum lid and closure.

The inside of the 30-gallon drum is surrounded by a Kao-Tex™ Quilt two-piece insulation bag. The lower portion consists of a sewn cylinder, 18¼ in diameter by 28 inches high sewn to a bottom disk. The top of the bag is fitted with an 18¼ inches diameter top that folds in on the bag. The top of the bag is closed with a cinch cord. Drawing R-R4-G-00189 defines the bag design.

Drawing R-R1-G-00092 defines the packaging assembly, and Table 2.4 lists the material specifications. Additional material requirements and fabrication specifications are detailed in Section 2.3.1.

2.3.1.2 Codes and Standards

The codes and standards used for design of the package are identified in the Engineering Drawings in Appendix 1.1. Criteria employed in the design of the package comply with applicable Type AF package requirements of 10 CFR 71 Subpart E, *Package Approval Standards*, and the applicable DOT requirements of 49 CFR Part 177, *Carriage By Public Highway*. Performance testing results and structural analysis of the package presented in this SARP demonstrate compliance with the requirements and 10 CFR 71.

To meet the requirements of 10 CFR Part 71 for NCT and HAC, the evaluated performance criteria for the package is based on the loading conditions Table 2.1 specified by Regulatory Guide (RG) 7.8 and amended to include NUREG 1609. The structural performance of the package is qualified principally by full-scale testing of four package prototypes. Table 2.2 details the test matrix used to comply with load combinations specified in Table 2.1. The package is evaluated for increased and reduced external pressures, and the vibration normally incident to transportation in M-CLC-G-00474. These conditions are evaluated with criteria equivalent to American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (B&PVC), Section III-NB level A service conditions.

The performance of the package subjected to the thermal fire event is also evaluated by analysis. Containment of the package contents within the 30-gallon drum under the influences of both NCT and HAC is demonstrated in the evaluation.

To address brittle fracture, the package is physically tested for the HAC 30-foot drop, crush and puncture with the package initially below -20F. The use of the ASME code for design follows the recommendation of RG 7.11^[2-4] and NUREG/CR 3854^[2-5] for fabrication.

2.3.1.3 Weights and Centers of Gravity

Section 2.1.3 Table 2.3 provides the following average measured weights of prototype packaging components and content: the 55-gallon outer drum assembly, 181.6 lb; 30-gallon drum assembly, 91.1 lb., and the maximum content payload, 362.2 lb. The total weight is 634.9 lb.

The Center of Gravity of the package without the payload content is located 17.7 inches above the package bottom along the vertical axis. The asymmetric loading of the package could move the C.G. vertically and/or laterally. These shifts are: 6.0 inches below to 2.9 inches above and 3.2 inches radially from the empty C.G.

The Packaging is designed for a maximum weight of 650 lb. The Prototypes SN-001X through SN-004X were used in the Regulatory Tests. The maximum prototype weight was 646.8 lb.

2.3.1.4 Identification of Codes and Standards for Package Design

The package was designed specifically for the loadings identified in 49 CFR 173.465 and 10 CFR 71.73 for Type AF packages. Table 2.1 lists the details of these loading conditions. NUREG/CR-3854 specifies acceptable fabrication criteria for transporting Category III material as ASME B&PVC, Section VIII, Division 1 or ASME B&PVC Section III, Subsection NF.

The fabrication drawings included in Appendix 1.1 identify specific codes/standards that apply to the production of packaging. Fabrication, examination and testing of packaging components are compliant with established Industry Standards.

2.3.2 Materials of Construction

The major structural features of the package, such as the 55-gallon outer drum body/bottom/cover, the 55-gallon drum and lid metal lining, the 55-gallon drum split ring closure and lugs, and the 30-gallon drum body/bottom/lid, are constructed with CRCQ carbon steels. Table 2.4 identifies ASME/ASTM material specifications for the structural components. This Table also provides similar information for the impact absorbing and/or thermal insulating commercial products used in the package.

2.3.2.1 Material Specifications and Properties

ASME BPVC Section II^[2-4, 2-5] is the source for the essential properties, allowable stresses, and temperature limits of all materials with ASTM/ASME specifications. Similar information for the commercial products is from the suppliers and manufacturers.

2.3.2.2 Prevention of Chemical, Galvanic, or other Reactions

Section 1.2.2 limits package contents and prohibits the presence of free liquids, pyrophoric materials, and materials subject to chemical, galvanic, or other chemical reactions. The packaging is constructed of materials that do not react with packaging components or with package contents. However, gamma radiation emitted by the contents does interact with the moisture present and organic packaging materials to radiolytically-generate hydrogen and other gasses. The matrix presented in Table 2.7 summarizes the contact between dissimilar packaging materials, and Chapter 4 addresses the radiolytic-generation of gasses.

2.3.2.3 Effects of Radiation on Materials

The only packaging components potentially damaged by radiation are elastomeric materials (e.g., the silicone gasket for the 30-gallon drum, the Ethylene Propylene Diene M-class (EPDM) gasket for the 55-gallon drum, the EPDM gaskets on all the bung-hole flanges in the 30-gallon drum lid, and the silicon skin surrounding the aluminum honeycomb insert). A radiation dose in excess of 10^7 rad is needed before a significant change to physical properties of the elastomeric

seals would be observed [Chapter 2, Reference 24]. The calculated dose to these components from Chapter 5 is significantly less than 10^6 rads/yr.; therefore, radiation will have no significant effect on elastomer performance.

2.3.3 Fabrication, Assembly, and Examination

The metallic components follow the requirements of the American Welding Society (AWS) Structural Welding Code- Sheet Steel D1.3^[2-6], AWS C1.4 Specification for the Resistance Welding of Carbon and Low-Alloy steels,^[2-7] and SRNL Data Sheets M-DS-A-00079^[2-8], M-DS-A-00078,^[2-9] M-DS-A-00077^[2-10] [Chapter 2, References 26 and 38 through 42] in fabrication, assembly, and examination. The 30-gallon and 55-gallon drums are designed, fabricated, and tested in accordance with United Nations (UN) Drum specification 1A2, as directed by 49 CFR 178 Subpart L for solid and liquid type drums. The polyurethane foam, thermal insulation material, gaskets, honeycomb cylinder and silicone rubber sheets are produced according to the supplier's specifications and procedures.

2.3.3.1 Fabrication and Assembly

PCP staff confirmed that appropriate fabrication specifications are prescribed by codes or standards, and that the codes and/or standards are identified on the engineering drawings, or in the text of the SARP. For components for which no fabrication code or standard is specified, control of the fabrication will be maintained by implementation of the Quality Assurance Plan through the procedural methodology described in Chapter 9.

2.3.3.2 Examination

PCP staff confirmed that the examination methods and acceptance criteria are dictated by the same codes and/or standards used for the fabrication of a component. For components for which no fabrication code or standard is specified, the examination will be controlled by implementation of the Quality Assurance Plan through procedural methodology described in Chapter 9.

2.3.4 General Considerations for Structural Evaluations

The package exceeds the minimum package size requirement. A split ring closure device secures each closure lid to each drum body. The split ring closure uses two threaded fasteners torqued to design specifications. The bolt torques and applicable TIDs prevent accidental opening of the package and insure that it is tamper-proof. Each of these operations meets the requirement of positive closure.

2.3.4.1 Evaluation by Test

The structural performance of the package under NCT and HAC were demonstrated mainly by test. Four prototypes, referring to as SN-001X through SN-004X, were used. The payload of each drum was simulated with a 362 lb. steel slug.

2.3.4.2 Evaluation by Analysis

Analyses were used for evaluating pressure and thermal effects on the packaging. The pressure evaluation appears in the calculation report M-CLC-G-00474 (Chapter 2, Reference 35), while the thermal evaluation is in Chapter 3.

2.3.5 Lifting and Tie-Down Standards

The package design does not incorporate any engineered structural features for lifting the package. Also, the package design does not incorporate any engineered structural features that could serve as tie-down devices. Therefore, this section is not applicable.

2.3.6 Structural Evaluation for Normal Conditions of Transport

The package was evaluated to have adequate structural capacity to comply with the requirements of 10 CFR 71 under NCT:

- No loss or dispersal of radioactive contents
- No significant increase in external radiation
- No substantial reduction in the effectiveness of the packaging, and
- No activity release limit dependent on active filter or mechanical cooling system

2.3.6.1 Heat, Cold, Reduced and Increased External Pressures

Chapter 3 shows that under the NCT heat condition, the maximum temperature in the package is 158°F and the maximum pressure is 5.06 psig. The maximum temperatures are insufficient to cause meaningful change in material properties, while the pressure is insufficient to result in unacceptable stress in the package structure. The package is very similar to the 9979 package design. Calculations for the 9979 indicate no significant thermal or material gradients due to differential thermal expansion. Because of the negligible internal heat generation of the payload and the similarity of the package to the 9979 package, no significant thermal or material gradients due to differential thermal expansion will occur in the package. The temperature and pressure conditions shown in Table 2.8 are combined with the 10 CFR 71 reduced and increased external pressure conditions. A bounding stress calculation is performed in M-CLC-G-00474 to ASME III-NB Service-A criteria (or equivalent for non-code materials). The results show minimal loading on the drum components and acceptable drum performance. Package performance at 100°F was demonstrated by heating package SN-002X in an environmental chamber prior to testing and by thermal analysis in Chapter 3.

Section 2.1.2 addresses the performance of the materials under low temperature conditions, i.e., NCT cold conditions. Stress conditions are bounded by the temperature and pressure extremes comprising the load cases in calculation M-CLC-G-00474. The packaging materials of the package are nearly identical to those of the Model 9979 package; therefore, additional testing to -40°F was not performed. SN-001X was, however, cooled to below -20°F in an environmental chamber prior to HAC testing.

Sections 2.6.3 and 2.6.4 also demonstrate by analysis that the package is acceptable for reduced and increased external pressures.

The package is evaluated under the conditions of reduced ambient (external) pressure of 3.5 psia per 10 CFR 71.71(c)(3). The effect of evaluating the package design to air transport at 35,000 feet (3.5 psia) under NCT conditions (insolation, 100°F ambient, maximum wattage) results in a differential pressure of 16.26 psig (19.76 - 3.5 psia) in the 30-gallon drum, shown in Section

3.3.2. Under these conditions the pressure-relieving device opens until the differential pressure drops and the device reseals. However, air transport is not permitted.

The package design is also evaluated for ground transport. Evaluating the highest route elevation in the United States (Loveland Pass, Hwy.6, 11,990 feet) under the same NCT conditions (insolation, 100°F ambient, maximum wattage) results in a differential pressure of 10.41 psig (19.76 - 9.35 psia). Under this condition, the pressure-relieving device in the 30 gallon drum will not open. Evaluation for all reduced external pressure conditions, combined with a maximum internal pressure, show that the pressures are within the capacity of both the 55 gallon drum and the 30-gallon drum.

The evaluation for increased external pressure conditions are documented in M-CLC-G-00474. The results show that the worst-case demand from external pressure, combined with minimum internal pressure, is adequately within the buckling and geometric instability limits of either drum.

2.3.6.2 Vibration

Shipping and vibration loads are evaluated in M-CLC-G-00474 and by comparison to other packages of similar design. The vibration levels are prescribed by the composite over-the-road power spectral density (PSD) depicting random accelerations of the Safe-Secure Trailers (SST) and Safeguards Transporters (SGT) normally used to transport drum-type packages. The PSD is obtained from Appendix F of SG-100 [Chapter 2, Reference 28]. Vibration/shock load levels on the drum shell, insulation foams, and lid closure bolting were evaluated. Since the load levels from vibration/shock in these components are significantly less than the elastic load limits of the components, the cyclic loading/unloading from vibration will not cause fatigue in packaging components. Therefore, the structural evaluation demonstrates that the performance of the package components, including bolts, is not susceptible to fatigue from cyclic loading.

Vibration and shock testing were performed on prototype 9977 and AT-400 packages at Sandia National Laboratory and on the Bulk Tritium Shipping Package (BTSP) at Clemson University [Chapter 2, References 32-34]. These packages incorporate polyurethane foam within their design for impact and thermal protection similar to the package. Following vibration tests, these packages were subjected to NCT and HAC testing. Package evaluations performed following these tests showed no indication of upset to their package configurations. By similarity, the polyurethane foam construction of the package will not be affected by over-the-road vibration and shock loads.

Additionally, 30- and 55-gallon drum fabrication specified by 49 CFR 178.500 are vibration tested in accordance with 49 CFR 178.601(c)(1) and 49 CFR 178.608.

The drum split ring closures are torqued to 40 ft-lb. when assembled. The calculated vibratory loads produced by over the road vibration and shock do not exceed 4G and are not sufficient to overcome the prevailing bolt torque during transportation.

2.3.6.3 Water Spray

The packaging consists of insulated 55-gallon outer drum and 30-gallon drum assemblies. Polyurethane foam is located between the 55-gallon drum and liner, between the 55-gallon drum lid and drum liner, and between the 30-gallon drum wall and liner. The foam insulation in the outer drum is protected by the steel liners and drum wall. Additionally, the foam is impervious to water due to its closed-cell structure. Both drum closures are gasketed so the water-spray tests have no significant effect on the outer drum structure.

One prototype (SN-004X) was subjected to the one-hour water spray test. The water spray was significantly greater than the rate of 2 inches/hr. required by 10 CFR 71.71(c)(6). The well formed by the drum lid and closure remained full and overflowing with water on the drum for the duration of testing. Based on packaging weights taken before/after the test and post-test examination, water did not penetrate the 55-gallon drum and the NCT water spray test had no adverse effect on the package; consequently, the compression test was performed on SN-004X after the test rather than after the 4ft free drop.

2.3.6.4 Free Drop

Three packages (SN-002X, SN-003X, and SN-004X) were tested in NCT free drop conditions. SN-002X was tested at an initial temperature of greater than 100°F and the others were tested at ambient temperature (South Carolina winter conditions). Package orientations for the drops are outlined in Table 2.2.

Unyielding Surface

10 CFR 71.71(c)(7) and 71.73(c)(1) require packages to be dropped onto an unyielding surface. The International Atomic Energy Agency (IAEA) Regulations (Para. 717)^[2-11] describes an unyielding surface as a “flat, horizontal surface of such a character that any increase in its resistance to displacement or deformation upon impact by the specimen would not significantly increase damage to the specimen.” The IAEA Advisory Material^[2-12] further specifies an example of an unyielding target as a steel plate at least 1.57 inches thick floated to a concrete block mounted on firm soil or bedrock, where the combined mass of the steel and the concrete is at least 10 times that of the test package (Para. 717.2).

The NCT drop tests were performed using an 8 ft. x 12 ft. x 6.5 inch thick rectangular steel plate bonded to the abandoned concrete foundation of Building 8343 in N-Area at the SRS. The steel pad floats on approximately 1¼ inches of grout. The weight of the base plate is approximately 25,500 lb. The 25,500 lb. pad weight is greater than 39 times the maximum weight of the package (650 lb.).

Four-Foot Drop Results

Package prototype SN-002X was slung in a CG-over-top (CGOT) orientation for the drop. The drum was angled such that one of the split ring lugs was oriented down for maximum damage to the 55-gallon drum closure. During the drop, the drum first contacted the unyielding surface at the split ring closure lug and then rotated to impact the bottom of the drum in a slap-down motion. The drop scuffed the 55-gallon drum lug and split ring, and slightly warped the end of

the split ring. The secondary point of contact dented the bottom chime and rolling rings on the 55-gallon drum. No evidence of closure loosening was evident.

SN-003X was slung in a vertical-top-down (VTD) orientation to maximize the impact of the payload on the 55-gallon and 30-gallon drum lids. The VTD orientation also maximized damage to the honeycomb impact absorber. During the drop, the package impacted the unyielding surface directly on the top of the split ring closure and the 55-gallon drum lid.

After the initial impact, the package rebounded slightly, yet remained oriented VTD until rest. Damage to the top of the package was not assessed immediately after the drop due to the package's orientation. No damage was evident on the side or bottom of the package.

Following the water spray and compression tests, SN-004X was slung in a CGOT orientation for the drop. The drum was angled such that one of the split ring lugs was oriented down for maximum damage to the 55-gallon drum closure. The orientation was identical to that used in testing SN-002X. During the drop, the drum first contacted the unyielding surface at the split-ring closure lug and then rotated to impact the bottom of the drum in a slap-down motion. The drop scuffed the lug and split ring and the secondary point of contact dented the bottom chime and rolling rings on the 55-gallon drum. No evidence of closure loosening was evident. Damage to the drum was consistent with that observed in SN-002X.

2.3.6.5 Corner Drop

Per 10 CFR71.71(c)(8), the corner drop test is only applicable to fiberboard, wood, or fissile material rectangular packages not exceeding 110 lb. and fiberboard, wood, or fissile material cylindrical packages not exceeding 220 lb. Since the package is cylindrical and weighs approximately 267.2 lb. empty, the corner drop tests are not required.

2.3.6.6 Compression

Per 10 CFR71.71(c)(9), packages weighing under 11,000 lb. must withstand a compressive test in which a compressive load of 5x the weight of the package must be applied uniformly for 24 hours to the top and bottom of the package in the position in which the package would normally be transported. The maximum weight of the package (incorporating maximum weights from calculations and prototypes, see Table 2.3, fully loaded, is 646.8 lb., so the test must be done with a minimum compressive load of 3250 lb. (650 lb. x 5). The compressive test was performed using a concrete block weighing 3310 lb.

The compression test was performed on the same concrete foundation used for drop testing. SN-004X was tested approximately 1-hour after the conclusion of the water spray test. Upon conclusion of the test, no damage was evident on package SN-004X.

2.3.6.7 Penetration

Three package prototypes (SN-002X, SN-003X, and SN-004X) were subjected to the penetration test following the 4 ft. free drop. Per Table 2.2, SN-002X and SN-004X were positioned horizontally and SN-003X was positioned VTD. The penetration bar (13.1 lb.) was dropped from 40 inches once on SN-002X and SN-003X, and twice on SN-004X. In the horizontal orientations, the penetration bar was targeted at the central foam vent hole between the central

rolling rings. This orientation was determined to be the position of greatest vulnerability due to minimal reinforcement. The penetration bar was dropped on SN-003X such that the bar impacted the bottom of the drum.

Damage to all three drums was minimal. The single dent in the side of SN-002X and the two dents in the side of SN-004X were approximately 1/8 inch in depth. The indentation in the bottom of SN-003X was approximately 1/4 inch deep. In each of these cases, the damage did not extend beyond the 55-gallon drum. The indentations received from the penetration tests did not initiate buckling or continued deformation under the subsequent HAC events. These superficial indentations will have no effect on package performance under NCT or HAC.

2.3.7 Structural Evaluation for Hypothetical Accident Conditions

The Table 2.2 test matrix was used to demonstrate that the package design complies with 10 CFR 71.55(e) and 71.59(a)(2) when subjected to HAC.

2.3.7.1 Free Drop

Four prototypes, SN-001X through SN-004X, were subjected to 30-ft drop impacts, each followed by the crush-plate impact. Per Table 2.2, SN-001X was tested at an initial temperature less than -20°F, SN-002X was tested at an initial temperature of greater than 100°F, and the remaining two were tested at ambient temperature (South Carolina winter conditions).

Temperatures of -20°F and 100°F were achieved in an environmental chamber to demonstrate package performance at bounding temperatures. The payload for each of the drums was simulated using a steel slug weighing an average of 362.2 lb. All tests were performed per procedure and documented via high-speed video and photography.

End Drop

Prototype SN-004X was tested in a VTD orientation such that the load on the aluminum honeycomb structure and drum lid was maximized. A top-down drop bounds the potential damage of a Vertical-Top-Up (VTU) drop, due to the foam and liner support at the bottom of both the 55- and 30-gallon drums.

Prototype SN-004X impacted the drop pad directly on the split ring closure and 55-gallon drum lid. During the impact, the package rebounded slightly, but remained positioned VTD after the drop. As a result of the drop, the split ring closure device was bent slightly out-of-plane as the foam insulation crushed and the drum skin deformed locally. The closure bolts were also slightly bent; however, they remained intact and secured the drum lid to the body. The deformation in the bolts rendered the closure unable to be removed with a wrench. No breaches in the lug welds were found. Additionally, the top surface of the 55-gallon closure was scuffed and scratched, and one of the stiffening rods was slightly indented into the lid. The impact neither breached the skin of the drum, nor loosened the closure.

Side Drop

Prototype SN-001X was cooled within a modified refrigerated environmental chamber (Tenney Model T40S-2) to achieve a uniform temperature of less than -20°F prior to the 30 ft. horizontal

drop (Figure 2.12). In order to accommodate the weight and size of the package, the control volume of the environmental chamber was modified with insulating materials.

Thermocouples were used to measure the temperature of the chamber at several points around the package during cooling prior to the testing. Thermocouple temperature data logging was terminated when the drum was removed from the environmental chamber and transported for testing. To minimize heat gain during transport, SN-001X was immediately wrapped in a thermal blanket after being removed from the environmental chamber. The side drop was the first test performed after removal from the chamber. The package was oriented such that one set of lugs was facing down, ensuring that the impact was primarily directed at the lugs and bolts. The ambient temperature at the time of HAC testing was approximately 37°F.

As a result of the drop, the split ring lugs were pressed into the drum body creating a local indentation. The outer 55-gallon drum surface was torn locally near the lugs and polyurethane foam was exposed. Due to the indentation of the lugs into the drum, the ends of the split rings were locally raised from the drum; however, the lid and closure remained secured to the 55-gallon drum body. A secondary “slap-down” effect following the initial contact on the split ring closure lugs created a flattening effect on the bottom chime. There was no tearing of the 55-gallon drum wall in this area due to the welded chime of the package. There was no evidence of any brittle metal behavior or other detrimental effects from the -20°F initial temperature condition.

Corner Drop

The last two Prototypes, SN-002X and SN-003X, were dropped in a CGOT orientation in which the closure lugs were positioned to make first contact with the drop pad. This was determined to be the most vulnerable orientation for the CGOT orientation. Package SN-002X was heated to a temperature of greater than 100°F in the same environmental chamber setup as used for cooling SN-001X.

In both prototypes, the impact drove the corner of the drum inward approximately 1 to 2 inches and the split ring lugs into the adjacent rolling ring. The set of lugs which made first contact during the drop punched through the outer 55-gallon drum wall and tore the sheet steel. The split ring closure; however, was not loosened and the deformation of the clamshell conformed to that of the lid. This effectively sealed both 55-gallon drum lid to the body in the areas of highest deformation. As a result of the secondary impact caused by drum rebounding and rotation, the bottom chimes of each prototype were slightly deformed. No tearing of the drum wall was evident at these locations. SN-003X experienced slight lid bulging at the conclusion of the drop due to the internal impact between the 30-gallon containment drum and the 55-gallon drum liner. Results from prototypes SN-002X and SN-003X were consistent.

Oblique Drops

Oblique drops, otherwise known as “slap-down” impacts, are often the most severe for drum-type packages with open head closures secured by industry standard bolt/nut/ring closure device. Oriented at a shallow-angle from horizontal, the bottom of the package impacts first, followed by an accelerated impact at the top of the package. However, the split ring closure device is

significantly more robust as demonstrated in “shallow-angle” impact testing of 640 lb., DOT 6M packages; therefore, package testing did not include oblique-orientation drop impacts.

Summary of 30-ft Drop Results

The 30 ft. free-drop testing of the package design used prototypes SN-001X through SN-004X. The horizontal impact (SN-001X) was performed at a boundary condition temperature of -20°F. Damage to SN-001X included warping of the split ring closure, indentation of the closure lugs and tearing of the 55-gallon drum, indentation of the bottom chime, and general scuffing of the package. The top-down CG over corner impact (SN-002X, SN-003X) produced the most dramatic deformation, with the lug region of the closure pushed significantly into the side of the drum to contact the uppermost drum rolling hoop. SN-002X was dropped at a boundary condition warm temperature of 100°F. Buckling of the drum wall was evident near the lugs and tearing of the 55-gallon drum wall occurred at these locations, slightly exposing the polyurethane foam. The deformation of the lid and split ring closure effectively sealed the 55-gallon drum at these locations of highest deformation. The VTD impact (SN-004X) scuffed the drum and bent the closure bolts. Furthermore, the drum lid and closure top were asymmetrically indented. Overall, the 30 ft. free-drop impact testing of these design prototypes locally breached the outer skin of the drum but did not loosen or remove the split ring closure devices. The inner liner of the 55-gallon drum was largely unscathed, with the only damage occurring due to indentation of the closure lugs. There was no tearing of the 55-gallon drum liner. Damage was largely superficial considering the scope of the testing. All similarly tested pre-development packages have demonstrated this characteristic, including packages designed with significantly less robust structures. Table 2.10 summarizes the conditions and results from the 30 ft. HAC drop tests.

2.3.7.2 Crush

A crush test per 10 CFR 71.73(c)(2) is required for the package design per the criteria in Table 2.10. Four prototypes received crush-plate impacts following the 30 ft. drop event: One at an initial temperature condition below -20°F (SN-001X), one at an initial temperature condition of above 100°F (SN-002X), and the remaining two at ambient temperature (South Carolina winter conditions). The crush plate used was a 40 inch square by 2½ inch thick, carbon steel plate with a measured weight of 1,135 lb.

Targeted CGOB Crush

Prototype package SN-002X was oriented upright and canted such that the 1100 lb. crush plate targeted the same closure bolt impacted in the 30 ft. drop with the line of action going through the package CG. Package SN-002X was pre-conditioned to a bounding temperature condition of 100°F. The crush plate depressed the lugs at the targeted corner approximately 2½ inches below the top of the package. Both the top corner of the drum and the closure plastically deformed into one another, effectively clamping the lid to the drum body. Due to the depression caused by the plate, the opposite side of the lid experienced a prying action, thus bending the split ring closure upward. The closure bolt was bent and was rendered unable to be removed without cutting. The bottom corner of the drum was also damaged to a slightly lesser degree; however, no tearing or fracture occurred. The split ring closure remained attached to the drum.

Targeted Side Crush

Two prototype packages, SN-001X and SN-003X, were oriented horizontally for the crush test (Figure 2.17). Both packages were oriented such that the closure lugs were in line with the fall path of the crush plate. This was determined to be the orientation with the potential for greatest damage. Package SN-001X was pre-conditioned to a bounding temperature condition of -20°F.

The bottom of the 55-gallon drum of prototype package SN-001X was “ovalized” due to contact with the crush plate. The package top largely maintained a circular geometry due to additional stiffness provided by the split ring closure and hoop welds. Both sides of the package (the side in contact with the crush plate and the unyielding surface) were flattened. Due to a secondary impact of the crush plate’s lifting hook on the package, an approximately ½ inch dent was created in the side of the package near the drum chime. The 55-gallon drum lid buckled slightly, and the split rings warped near the contact point between the lugs and the drop pad.

Furthermore, both closure bolts were bent, most notably the bolt which made primary contact with the crush plate. The portion of the 55-gallon drum lid near the drop pad slightly buckled as a result of the drop. There was no significant additional breach in the 55-gallon drum wall or lid due to the crush event. There was no loosening of the closure bolts and the split ring remained firmly fixed to the drum. The results of SN-003X were consistent with SN-001X.

Targeted End Down Crush

Prototype SN-004X was oriented vertically during the impact from the 1100 lb. crush plate. The impact drove the split ring closure device into the drum and buckled the skin of the drum generating circumferential deformation near the top rolling ring.

The drum was shortened by approximately 1½ inches in some locations. The closure bolt damage from the crush progressed slightly from the 30-ft drop damage; however, the impact neither breached the skin of the drum, nor loosened the closure.

Summary of Crush Testing Results

The package prototypes resisted the crush impacts with minimal overall deformation. In all tests, the deformation levels were within the geometric limits of the rigid foam structure (e.g., never more than 3 inches of deformation). The maximum radial damage occurred to SN-001X as would be expected due to the low ductility of carbon steel and horizontal orientation of the package. The maximum circumferential damage occurred to SN-004X, which was crushed in the VTU orientation. The drum skin tearing caused by the 30 ft. drop did not visibly progress during crush testing. The 55-gallon drum wall damage and subsequent “ovalizing” of the bottom of the drum had no effect on the ability of the drum to confine the 30-gallon drum. The welded bottom chime of the outer drum was never breached and the welded inner liner remained intact. Based on the drop and subsequent crush damage, as depicted in the above sections, it is concluded that a maximally loaded 30-gallon drum remains closed and un-breached due to drop and crush events. In all cases there was no indication of 30-gallon drum failure.

2.3.7.3 Puncture

Continuing the sequence of HAC event tests, three prototype packages were subjected to the puncture test according to Table 2.2. Each package was dropped 40 inches (1 meter) onto a 6 inch diameter puncture bar. The puncture bar was positioned on the “unyielding” drop pad to maximize package damage during secondary impacts. SN-001X was cooled to below -20°F and was dropped in a VTU orientation. The package was dropped such that the bottom of the drum was centered on the puncture bar. SN-002X was heated to above 100°F and was dropped horizontally onto the puncture bar. The puncture drop in the horizontal configuration were targeted at the mid-height of the outer drum, which was predicted to cause the greatest damage to the package because the 16-gauge drum shell is the thinnest gauge material on the exterior of the package and least supported by other structural members of the package. Last, SN-004X was dropped at ambient temperature in a VTD orientation and was positioned such that the package impacted the puncture bar at one of the stiffening rods in the drum lid. This was determined to be the positioning of greatest damage in the VTD configuration due to the potential of the stiffening rods punching through the lid liner.

The puncture test results were similar to the 9979 puncture testing; that is, the puncture test is not a significantly challenging test for foam-filled steel drum type packages. A puncture test targeted at the split ring closure was not considered to cause more damage to the drum or result in a closure failure for the following reasons: 1) the split ring closure has a thicker gauge than the drum wall, 2) the welded drum liner structure provides reinforcement to the split ring closure, 3) the welded foam filled lid assembly provides reinforcement, and 4) as observed in tests of the pre-prototype 9979 packages, where there was occasionally significant damage to the closure, there was no evidence of closure failure.

Each of the three drums resisted the puncture test without additional breach of the outer drum. All three of the packages experienced general scuffing at the impact site and a minimal dent 6 inches in diameter and less than ¼ inch in depth from the puncture bar. Package SN-004X was relatively unaffected by the test targeted at the stiffening rods. There was no evidence of the stiffening rods punching through the lid liner upon package disassembly. None of the packages were damaged significantly due to the secondary impact of the packages on the “unyielding target.”

2.3.7.4 Thermal

The prototype packages were not subjected to the 10 CFR 71.73(c)(4) thermal test, but the Chapter 3, *Thermal Evaluation* demonstrates compliance with 10 CFR Part 71 by analysis and comparison in with similar package designs for thermal HAC. The thermal analysis shows that thermal HAC will not compromise the containment capability of the 30-gallon drum. The SARP uses the results of previous thermal testing of polyurethane foam packages (e.g., 9977, AT400, and Bulk Tritium Shipping Package) to surmise that heat from the HAC pool fire fully consumes the outer drum’s foam insulation leaving only a matrix of ash/char. Increased gas pressure due to the fire and decomposition of the contents within the 30-gallon drum is mitigated by the pressure-relieving device in the drum lid. The 55-gallon drum structural liner and shell configuration are not affected by the HAC fire and continue to provide criticality spacing control for the 30-gallon drum even with the complete loss of insulation in the outer drum.

Summary of Pressures and Temperatures

During thermal HAC, the waterproof tape on the 55-gallon drum wall, top, and bottom are burned or otherwise rendered incapable of sustaining a pressure differential; the drum gasket degrades, and the internal volume of the 55-gallon drum is incapable of sustaining pressure. The pressure relief device on the 30-gallon drum vents pressure developed during thermal HAC. Table 2.12 summarizes the temperature and pressure for each drum during thermal HAC.

Differential Thermal Expansion

Under the thermal HAC, the BETAFOAM™ decomposes to a gas/charred state. Decomposition gases vent through the outer drum vent and foam fill holes. There are no other identified structural concerns with differential thermal expansions from HAC conditions.

Stress Calculations

Stress calculations are not required because the package design does not identify a pressure boundary that would sustain a load under the thermal HAC.

Comparison with Allowable Stresses

Not applicable.

Package Destructive Evaluation

Following the HAC free drop, crush, and puncture tests the prototype packages were disassembled and examined to determine if the inner 30-gallon drum closure was compromised. Disassembly of the 55-gallon drum closure in each prototype case required cutting the closure bolt and prying off the split ring closure to gain access to the 30-gallon drum. Each packaging component was visually examined with a black light for release of the fluorescent powder/flour mixture contained within the 30-gallon drum. In prototypes SN-002X and SN-004X, the insulation cover was pinched between the 30-gallon and 55-gallon drum walls, effectively tearing and releasing the inner blanket material; however, no fluorescent powder was found on either drum body.

In conclusion, physical examination of the drums yielded no visual evidence that the 30-gallon drum closure was compromised or surrogate material released. A full description of each package disassembly is provided in the Model 9981 test report (Chapter 2, Reference 29).

2.3.7.5 Immersion — Fissile Material

The package design is not leak-tight. Criticality analysis of an array of damaged and fully loaded packages assumed water flooding of the package and water reflection on all sides.

2.3.7.6 Immersion — All Packages

The package design is not leak-tight. Criticality analysis of an array of fully loaded packages assumed water flooding of the package and water reflection on all sides.

2.3.7.7 Deep Water Immersion Test (for Type B packages containing more than $10^5 A_2$)

The package is Type AF. Therefore, this section is not applicable.

2.3.7.8 Summary of Damage

The major packaging damage observed in the prototype units resulted from the HAC free drop and crush tests. The puncture testing resulted in superficial damage to the outer packaging. Evaluation of the package design included structural analysis and prototype testing, but not thermal testing. Thermal analysis and comparison with similar package designs shows the package temperatures before, during, and after thermal HAC is sufficient to surmise complete consumption of the outer drum foam. The 30- and 55-gallon drums are designed to release internal pressure and gasses generated during thermal HAC; consequently the geometry of the 30- and 55-gallon drums is essentially maintained.

Based on the observed and calculated conditions of the package following HAC, the package design assures containment of content, maintains shielding, and remains subcritical under all NCT and HAC performance test requirements.

2.3.8 Accident Conditions for Air Transport of Plutonium

The SARP does not evaluate the package design for the accident conditions specified in §71.74; therefore, this section is not applicable.

2.3.9 Accident Conditions for Fissile Packages for Air Transport

The SARP does not evaluate the package design for the accident conditions specified in §71.55(f) therefore, this section is not applicable.

2.3.10 Special Form

The package is not limited to radioactive material in special form; therefore, this section is not applicable.

2.3.11 Fuel Rods

The SARP does not evaluate fuel rods as radioactive contents and does not credit fuel-rod cladding for containment; therefore, this section is not applicable.

2.3.12 Appendices

None.

2.4 Evaluation Findings

2.4.1 Findings

Based on the review of the statements and representations in the SARP, PCP staff has concluded that the structural design has been adequately described and evaluated and that the package design meets the structural requirements of 10 CFR 71.

2.4.2 Conditions of Approval

PCP staff has concluded that no additional structural-related conditions of approval are required in the CoC.

2.5 References

- [2-1] *Safety Analysis Report for Packaging, Model 9981 Type AF Shipping Package*, Savannah River National Laboratory, S-SARP-G-00020, Revision 0 (March 2019).
- [2-2] *Packaging and Transportation of Radioactive Material*, Code of Federal Regulations, Title 10, Part 71, Washington, DC (January 2017).
- [2-3] *Packaging Review Guide for Reviewing Safety Analysis Reports for Packaging*, Revision 3, February 2008, UCID-21218, Revision 3.
- [2-4] *Container Categories*, Table 1, Regulatory Guidance 7.11, U.S. Nuclear Regulatory Commission, Washington, DC (June, 1991).
- [2-5] *Fabrication Criteria for Shipping Containers*, NUREG/CR 3854, U.S. Nuclear Regulatory Commission, Washington, DC (March, 1985).
- [2-6] American Welding Society (AWS) D1.3:2018, Structural Welding Code- Sheet Steel, 6th Edition.
- [2-7] American Welding Society (AWS) C1.4:2017, Specification for the Resistance Welding of Carbon and Low-Alloy steels, 3rd Edition.
- [2-8] *9979 and 9981 Package Arc Welding Data Sheet*, M-DS-A-00079, Revision 0B (February 4, 2019).
- [2-9] *9979 & 9981 Package Resistance Mash Welding Data Sheet* M-DS-A-00078, Revision 0A (January 25, 2019).
- [2-10] *9979 and 9981 Package Stud Welding Data Sheet*, M-DS-A-00077, Revision 0B (February 4, 2019).
- [2-11] *Regulations for the Safe Transport of Radioactive Material, 2012 Edition*, Specific Safety Requirements No. SSR-6, International Atomic Energy Agency
- [2-12] *Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition)*, Specific Safety Guide No. SSG-26, International Atomic Energy Agency

3. Thermal Evaluation

3.1 Areas of Review

This section of the SER documents PCP staff's review of Chapter 3, *Thermal Evaluation*.^[3-1] Staff review includes an evaluation of the SARP with respect to the requirements specified in 10 CFR 71.^[3-2]

The following elements of the *Thermal Evaluation* chapter were reviewed. Details of the review are provided below in SER Section 3.3.

3.1.1 Description of Thermal Design

- Design Features
- Decay Heat of Contents
- Codes and Standards
- Summary Table of Temperatures
- Summary Table of Maximum Pressures

3.1.2 Material Properties, Thermal Limits, and Component Specifications

- Material Properties
- Temperature Limits
- Component Specifications

3.1.3 General Considerations for Thermal Evaluations

- Evaluation by Analysis
- Evaluation by Test

3.1.4 Thermal Evaluation under Normal Conditions of Transport

- Initial Conditions
- Effects of Tests
- Maximum and Minimum Temperatures
- Maximum Normal Operating Pressures
- Maximum Thermal Stresses

3.1.5 Thermal Evaluation under Hypothetical Accident Conditions

- Initial Conditions
- Effects of Thermal Tests
- Maximum Temperatures and Pressures
- Maximum Thermal Stresses

3.1.6 Thermal Evaluation of Maximum Accessible Surface Temperature

3.1.7 Appendices

- Description of Test Facilities and Equipment
- Test Results
- Applicable Supporting Documents or Specifications
- Details of Analyses

3.2 Regulatory Requirements

The requirements of 10 CFR 71 applicable to the thermal review of the package are as follows:

- The package design must be described and evaluated to demonstrate that it satisfies the thermal requirements of 10 CFR 71. [§71.31(a)(1), §71.31(a)(2), §71.33, §71.35(a)]
- The application must identify the established codes and standards used for the package design, fabrication, assembly, testing, maintenance, and use. In the absence of such codes, the application must describe the basis and rationale used to formulate the quality assurance program. [§71.31(c)]
- The package must be made of materials of construction that assure there will be no significant chemical, galvanic, or other reactions, including reactions due to possible in-leakage of water, among the packaging components, among package contents, or between the packaging components and the package. The effects of radiation on the materials of construction must be considered. [§71.43(d)]
- The package must be designed, constructed, and prepared for transport so that in still air at 38°C (100°F) and in the shade the accessible surface temperature does not exceed 50°C (122°F) in a nonexclusive-use shipment or 85°C (185°F) in an exclusive-use shipment. [§71.43(g)]
- The package design must not rely on mechanical cooling systems to meet containment requirements. [§71.51(c)]
- A fissile material packaging design to be transported by air must meet the requirements of §71.55(f).
- The performance of the package must be evaluated under the tests specified in §71.71 for normal conditions of transport. [§71.41(a)]
- The package must be designed, constructed, and prepared for shipment so there would be no loss or dispersal of contents, no significant increase in external surface radiation levels, and no substantial reduction in the effectiveness of the packaging under the tests specified in §71.71 for normal conditions of transport. [§71.43(f), §71.51(a)(1)]
- The performance of the package must be evaluated under the tests specified in §71.73 for hypothetical accident conditions. [§71.41(a)]

3.3 Review Procedures

The following subsections describe the PCP staff's thermal review of the SARP.

3.3.1 Description of Thermal Design

3.3.1.1 Design Features

The applicant described the design of the packaging components that dictated the response of package to thermal environments. The primary packaging components consist of a 55-gallon outer drum and a nested 30-gallon drum. Each drum has a built-in metal liner and is filled with polyurethane foam between the liner and drum. The safety function of the 55-gallon drum is outer packaging for protection of the 30-gallon drum. The safety function of the 30-gallon drum is inner packaging for confinement of the contents. The 30-gallon drum lid is equipped with a pressure release device (set to release at 12-15psig) to relieve internal pressure during thermal HAC. The designs of these components are described in sufficient detail in Section 1.2, which provides a basis for the thermal evaluation of the package. The temperature and pressure limits for the packaging components under NCT and HAC are listed in Table 3.1.

Section 1.2.2 defined a maximum radioactive payload mass of 160 kg (353 lb.) for LEU radioactive material and 166 kg (366 lb.) combined LEU radioactive and non-radioactive materials. The payload is in solid form with up to one percent moisture, by weight.

3.3.1.2 Decay Heat of Contents

The total maximum decay heat rate of the LEU Content Envelope is 0.006 Watt. This value from Chapter 1 was used as the package decay heat limit for the NCT and HAC thermal evaluations in the Chapter 3.

3.3.1.3 Codes and Standards

The 55-gallon outer drum and 30-gallon drum-confinement are designed, fabricated, and tested in accordance with the 49 CFR 178 Subpart L standards for removable head steel drums (1A2). Likewise, drum fabrication and evaluation conform to Section VIII, Division 1 of the ASME B&PVC, and/or the AWS D1.3, AWS C1.4, and SRNL data sheets, as applicable (see Chapter 2 References 26 and 38 through 42). The polyurethane foam, i.e., BETAFOAM™, used in the drums, is a proprietary material of Dow Automotive. It is the same foam material used in the previously approved 9980 Type AF Packaging.

3.3.1.4 Summary Tables of Temperatures

The calculated maximum component temperatures of the package (0.006 Watt payload) for NCT, HAC, and post HAC cool-down period are listed in Table 3.2.

The component temperatures were calculated with a finite element method software-COMSOL.

The maximum temperature of the accessible surfaces of the package is the same as the ambient temperature of 100°F (38°C) in the shade; therefore, the package meets requirements of §71.43(g) for non-exclusive use shipment.

The maximum component temperatures for NCT were calculated in accordance with §71.71(c)(1).

The applicant assumed the minimum package components temperatures are the same as the cold condition of §71.71(c)(2) due to the small amount of decay heat generated by the contents.

The HAC transient simulation is based on an axisymmetric model of an undamaged package with 0.006 Watt heat source. The initial test condition for thermal HAC is the steady-state condition for the NCT Heat of “100 °F ambient with insolation.”

The post fire transient simulation is based on an axisymmetric model of the package with 0.006 Watt heat source, but the foam properties were modified in the model to account for decomposition of the foam from the fire. The initial test conditions for the post fire analysis are the component temperature at the end of 30-minute fire transient calculation and insolation.

For NCT, the maximum temperatures of 55-gallon drum, 30-gallon drum, gaskets and contents are predicted to be below their limiting temperatures with sufficient margin. For HAC, the 55-gallon drum and 30-gallon drum will maintain confinement of the contents.

3.3.1.5 Summary Tables of Maximum Pressures

The calculated Maximum Normal Operating Pressure (MNOP) and maximum pressure in the containment under HAC are listed in Tables 3-5 and 3-16 respectively.

The MNOP calculation for the 30-gallon confinement drum assumes the package is loaded at sea-level with 1% free water by weight (3.5 lb.), gas generation is negligible, and the highest NCT steady-state temperature of the contents from the thermal evaluation. The free space volume used in the MNOP calculation is defined as drum cavity space below the honeycomb assembly, the space between the honeycomb and the insulation bag, and the space above the insulation bag. The calculated MNOP in the confinement drum is 19.8 psia, which is less than the design limit calculation of 37.2 psia (22.5 psig) for the drum (Table 3.1).

The assumption that the gas generation of polyurethane foam and the packing material from thermal decomposition of organic materials and radiolysis is negligible is reasonable because the maximum NCT temperature near the contents is approximately 143°F, which is well below 248°F the maximum continuous service temperature (MCST) for many polymers.

3.3.2 Material Properties, Temperature Limits, and Component Specifications

3.3.2.1 Material Properties

The thermal properties for the materials used in construction of the packaging are listed in Section 3.1.

Polyurethane foam will burn during thermal HAC resulting in a change of its thermal properties. The decomposition characteristic of BETAFOAM™ foam is described in Section 3.2. The thermal properties of decomposed BETAFOAM™ foam are similar to the closed-cell rigid polyurethane foam in the fire-test of AT-400A^[3-3] packaging described in Section 3.4.2.1. A comparison of the thermal properties of the AT-400A foam and BETAFOAM™ foam is listed in Table 3.13.

The assumed thermal properties of burned/charred foam were reviewed by the PCP staff and determined to be acceptable.

3.3.2.2 Temperature Limits

The temperature limits of the outer drum, confinement and thermal insulation (BETAFOAM™) are listed in Table 3.1.

3.3.2.3 Component Specifications

PCP staff verified that the component specifications of the drums and the additional thermal insulation are presented in sufficient detail in SARP. The emissivity and absorptivity values of the drum surfaces given in the SARP are deemed appropriate by staff.

3.3.3 General Considerations for Thermal Evaluations

3.3.3.1 Evaluation by Test

There were no thermal tests performed.

3.3.3.2 Evaluation by Analysis

The applicant used COMSOL Multiphysics®,^[3-4] which is a commercial general purpose finite element analysis (FEA) simulation software for mechanical, thermal, fluid, etc. The quality assurance benchmarking for COMSOL Multiphysics software and its test documentation are referenced in the appendices of thermal calculation sheet M-CLC-A-00621. COMSOL Multiphysics® software has been used for previously DOE approved shipping packages.

The thermal properties of the packaging components, including thermal insulation and aluminum honeycomb as the functions of temperature are listed in Section 3.2. PCP staff has deemed these properties are appropriate for the NCT and HAC thermal analyses.

PCP staff also concluded that the mathematical formulas describing convection and radiation at the package boundaries are appropriate. The thermal model descriptions and assumptions are given in Section 3.3.1.1.

Two dimensional axisymmetric models were used for package thermal simulations. Analyses were performed on an undamaged package. The methodology was cross referenced and validated with other DOE approved packages of similar design in Section 3.4.2.

The initial temperature state of the package at the start of the 30-minute HAC fire simulation came from NCT calculation. The initial temperature state of the package in post-fire cool-down simulation used the temperatures at the end of the 30-minute HAC fire simulation for most components, but with modified thermal properties of the foam as noted in Section 3.4.1.

3.3.4 Thermal Evaluation for Normal Conditions of Transport

3.3.4.1 Initial Conditions

The applicant performed thermal evaluations of the package in NCT conditions, with insolation on the outside surfaces of the package in 100°F still air. The insolation values are those specified in 10 CFR 71.71(c) for a 12 hour time period. The absorptivity of the carbon steel drum surface was assumed to be 0.5, while the surface emissivity was assumed to be 0.75. PCP staff concurs with these values.

3.3.4.2 Effects of Tests

No thermal tests were performed.

3.3.4.3 Maximum and Minimum Temperatures

The minimum temperature of -40°C in the package is assumed to be the steady-state ambient temperature 40°C and ignoring 0.006 Watts decay heat inside confinement. As noted in Section 3.3.1.4 above, the *Cold* condition of -40°C ambient temperature will not result in a degradation of the package or any of its components.

The applicant calculated the steady-state package component temperatures in the shade as well as under insolation in ambient 100°F (38°C). The maximum component temperatures are given in Table 3.2. As described in SER Section 3.3.1.4 above, the maximum temperatures of the package components during NCT do not exceed their temperature limits.

3.3.4.4 Maximum Normal Operating Pressure

MNOP is discussed in SER Section 3.3.1.5 above. The MNOP is below the design pressure of the confinement drum.

3.3.4.5 Maximum Thermal Stresses

The thermal stresses in package components due to the differential thermal expansions within packaging materials between the package components are not evaluated, as explained in Sections 2.6.1.2 and Section 3.4.4. The rationale is that major components like drum body, liner, and lid are fabricated from carbon steel and there are sufficient radial and axial clearances between the outer 55-gallon drum and 30-gallon drum containing a low heat source to preclude mechanical interference at cold and hot normal operations conditions. PCP staff finds that assumption is acceptable.

3.3.5 Thermal Evaluation under Hypothetical Accident Conditions

3.3.5.1 Initial Conditions

The applicant performed thermal evaluations of package in the thermal HAC fire by FEA simulations.

The methodology for fire simulations of the package were referenced with several similar DOE certified packages where the relevant material models had been previously benchmarked in fire tests. The peak temperatures of package during and after the fire are listed in Table 3.4.

The initial temperature of package at the start of the HAC fire is the steady-state result of NCT with insolation. The HAC fire numerical simulation model uses modified insulation properties to represent partial polyurethane foam burnt during the fire.

A separate simulation model is used for HAC post-fire cool-down analysis. A different variation of modified insulation properties with lower density is used in the model to reflect the fact more foam is lost during cool down. The initial component temperatures of the package for HAC post fire are obtained from the simulation at the end of the 30 minute fire.

3.3.5.2 Effects of Thermal Test

The applicant used the information of AT-400A Packaging tests conducted at Sandia National Laboratory,^[3-3] with similar solid closed-cell rigid polyurethane foam insulation.

A comparison between tested foam in AT-400A Packaging and BETAFOAM™ foam has showed they are similar in foam density, thermal conductivity and specific heat. This comparison provided the basis for the foam property models in HAC 30 minutes fire and post-fire cool down simulation of the package without need for further testing.

3.3.5.3 Maximum Temperatures and Pressures

The maximum temperatures estimated for package components during HAC 30 minute fire and post-fire are listed in Table 3.2, and the maximum temperatures from thermal HAC of all the major structural components are below their respective design temperature limits in Table 3.1.

The 30-gallon confinement drum includes a pressure release device in the drum lid that opens between 12-15 psig to release gas pressure generated during thermal HAC; consequently the maximum pressure during HAC is 15 psig.

3.3.5.4 Maximum Thermal Stresses

Thermal stress between components of the package during the fire and post-fire cool down is not a concern because the major components are made of carbon steel and there are sufficient radial and axial clearances between the outer 55-gallon drum and 30-gallon drum to ensure no mechanical interference during thermal HAC.

3.3.6 Thermal Evaluation of Maximum Accessible Surface Temperature

The calculated maximum accessible surface temperature of the package loaded with 0.006 Watt decay heat is 100°F, and was determined with the consideration of the surface heat flow by natural convection and thermal radiation to the environment. Since this temperature is less than 122°F, the package meets the surface temperature requirements for non-exclusive use shipment. PCP staff concurs with this analysis and conclusion.

3.3.7 Appendix

There is one Appendix associated with Chapter 3: *Appendix 3.1 - NCT and HAC Thermal Analysis for a 9981 Package, M-CLC-A-621, Revision 0.*

3.3.7.1 Description of Test Facilities and Equipment

There was no fire testing performed of the package.

NCT thermal testing was not performed for the package because the decay heat of proposed content is very low with respect to the packaging materials of construction.

The applicant used the component 30 minute fire test data of AT-400A packaging with similar solid closed-cell rigid polyurethane foam as the thermal property reference for the insulation foam used in the package design.

3.3.7.2 Test Reports

There were no thermal test reports.

3.3.7.3 Applicable Supporting Documents or Specifications

Supporting documents of thermal models and component burn test reports are listed in Appendix 3.1.

Engineering drawings are referenced in Appendix 1.1.

3.3.7.4 Details of Analyses

The COMSOL Modules used in the thermal analyses of the package for NCT and HAC in 30 minute fire are described in Appendix 3.1.

The COMSOL Multiphysics® code used for thermal analysis of the package design was benchmarked with the Models of 9975 and 9977 packages using MCS.Patran Thermal™ software described in Section 3.3.1.1.3. It has been verified that the COMSOL Multiphysics® Model with 44,382 elements generates converged results.

The input parameter of simulation models including geometry and material thermal properties are listed in Appendix 3.1. This appendix also provides the convection correlation parameters and surface radiation properties, as well as the data of decay heat and heat flux imposed on the outside surfaces of the package.

The analyses of the package using the COMSOL modules were performed to simulate the packages under NCT in the shade at an ambient temperature of 100 °F; under insolation at an ambient temperature of 100 °F; as well as the HAC 30 minute fire & post-fire cool down. The analytical models for NCT and HAC are 2D axisymmetric and components thermal properties are a function of temperature.

The HAC 30 minute fire simulation used the initial temperatures of the package under NCT with insolation. There are two transient numerical models, one for the 30 minute fire of package filled with modified polyurethane foam properties and the other uses a different version of modified foam properties for post-fire cool down where it was assumed the foam that was burned could be replaced with air. The initial temperature state of the package in post-fire cool-down simulation used the temperatures at the end of the 30-minute HAC fire simulation for most components, but with modified thermal properties of the foam as noted in Section 3.4.1. These calculations are in Appendix 3.1.

3.4 Evaluation Findings

3.4.1 Findings

Based on review of the statements and representations in the SARP, PCP staff concludes that the thermal design has been adequately described and evaluated, and that the thermal performance of the package meets the thermal requirements of 10 CFR 71.

3.4.2 Conditions of Approval

PCP staff has concluded that no additional thermal-related conditions of approval are required in the CoC.

3.5 References

- [3-1] *Safety Analysis Report for Packaging (SARP) — Model 9981 Type AF Shipping Package*, Savannah River National Laboratory, Savannah River Nuclear Solutions, S-SARP-G-00020, Rev. 0, (March 2018).
- [3-2] *Packaging and Transportation of Radioactive Material*, Code of Federal Regulations, Title 10, Part 71, Washington, DC (January 2017).
- [3-3] R.E. Glass, A.R. York II, and J.H. Gieske, *AT-400A Development Report*, SAND97-0118, Sandia National Laboratories (1999).
- [3-4] *COMSOL Multiphysics Version 5.2a*, COMSOL, Inc., Burlington, Massachusetts (2016).

4. Containment Review

4.1 Areas of Review

This section of the SER documents PCP staff's review of Chapter 4, *Containment*.^[4-1] Staff review includes an evaluation of the SARP with respect to the requirements specified in 10 CFR 71.^[4-2]

The following elements of the *Containment* chapter were reviewed. Details of the review are provided below in SER Section 4.3.

4.1.1 Description of the Containment Design

- General Considerations for Containment Evaluations
 - Fissile Type A (Type AF) Packages
 - Type B Packages
 - Combustible-Gas Generation
- Design Features
- Codes and Standards
- Special Requirements for Plutonium
- Special Requirements for Spent Fuel

4.1.2 Containment under Normal Conditions of Transport

- Containment Design Criteria
- Demonstration of Compliance with Containment Design Criteria

4.1.3 Containment under Hypothetical Accident Conditions

- Containment Design Criteria
- Demonstration of Compliance with Containment Design Criteria

4.1.4 Leakage Rate Tests for Type B Packages

4.1.5 Appendices

4.2 Regulatory Requirements

The requirements of 10 CFR 71 applicable to the containment review of the package are as follows:

- The package design must be described and evaluated to demonstrate that it meets the containment requirements of 10 CFR 71. [§71.31(a)(1), §71.31(a)(2), §71.33, §71.35(a)]

- The application must identify the established codes and standards used for package design, fabrication, assembly, testing, maintenance, and use. In the absence of such codes, the application must describe the basis and rationale used to formulate the quality assurance program. [§71.31(c)]
- The package must include a containment system securely closed by a positive fastening device that cannot be opened unintentionally or by pressure that may arise within the package. [§71.43(c)]
- The package must be made of materials and constructed to assure that there will be no significant chemical, galvanic, or other reactions, including reactions due to possible in-leakage of water, among the packaging components, among package contents, or between the packaging components and the contents. The effects of radiation on the materials of construction must be considered. [§71.43(d)]
- Any valve or similar device on the package must be protected against unauthorized operation and, except for a pressure relief valve, must be provided with an enclosure to retain any leakage. [§71.43(e)]
- The package must be designed, constructed, and prepared for shipment to ensure no loss or dispersal of radioactive contents under the tests specified in §71.71 (“Normal conditions of transport”). [§71.43(f)]
- The package may not incorporate a feature intended to allow continuous venting during transport. [§71.43(h)]
- A Type B package must meet the containment requirements of §71.51(a)(1) under the tests specified in §71.71 for Normal Conditions of Transport.
- A Type B package must meet the containment requirements of §71.51(a)(2) under the tests specified in §71.73 for Hypothetical Accident Conditions.
- The maximum activity of radionuclides in a Type A package must not exceed the limits of 10 CFR 71, Appendix A, Table A-1. For a mixture of radionuclides, the provisions of Appendix A, paragraph IV apply, except that for krypton-85, where an effective A_2 equal to $10A_2$ may be used. [Appendix A, §71.51(b)]
- Compliance with the permitted activity release limits for Type B packages may not rely on filters or on a mechanical cooling system. [§71.51(c)]
- For packages that contain radioactive contents with activity greater than 10^5A_2 , the requirements of §71.61 must be met. [§71.51(d)]
- A Type B package containing more than 10^5A_2 must be designed so that its undamaged containment system can withstand an external water pressure of 2 MPa (290 psi) for a period of not less than 1 hour without collapse, buckling, or in-leakage of water. [§71.61]
- A package containing plutonium in excess of 0.74 TBq (20 Ci) must have the contents in solid form for shipment. [§71.63]

4.3 Review Procedures

The following subsections describe the PCP staff's containment review of the SARP.

4.3.1 Description of the Containment Design

4.3.1.1 General Considerations for Containment Evaluations

4.3.1.1.1 Fissile Type A Packages

The package is a Type AF package design. PCP staff verified that the contents, Table 1.2.2, do not exceed a Type A quantity of radioactive material as specified by Appendix A to 10 CFR 71.

This package is designed to meet the requirements of §71.55.

4.3.1.1.2 Type B Packages

Not applicable.

4.3.1.1.3 Combustible-Gas Generation

Combustible gas generation and accumulation in the package is addressed in Section 4.5, where there is a reference to the calculation sheet *Hydrogen Gas Generation and Permeation for the 9981 Type AF Package*, M-CLC-A-00644, dated August 16, 2018.^[4-3] This calculation considers radiolytic hydrogen gas generation due to gamma radiolysis of the polymeric materials within the confinement drum and permeation of the hydrogen out of the confinement drum. The calculation results show that the free volume in the 30-gallon confinement drum is sufficient to preclude the accumulation of 5% hydrogen within one year.

Confirmatory calculations by PCP staff involved developing and solving the governing differential equations for the generation, permeation, and accumulation of hydrogen within the confinement drum. These results gave the hydrogen concentration as a function of time for the various contents. These results demonstrated that the package will not accumulate hydrogen to a concentration of 5% within 2 years, and therefore according to the guidance in the NRC information Notice 84-72,^[4-4] the shipment duration does not need to be limited to less than one year.

4.3.1.2 Design Features

4.3.1.2.1 Containment Boundary

Confinement of the contents is provided by the inner 30-gallon Drum Assembly.

Based on the material to be transported in the package, Regulatory Guide (RG) 7.11^[4-5] specifies the level of safety as 'Category III'. NUREG/CR 3854^[4-6] specifies acceptable fabrication criteria for packages used for transporting 'Category III' material as ASME B&PVC, Section VIII, Division 1 or ASME B&PVC Section III, Subsection NF, and Department of Transportation (DOT) Specifications for drums used in the design.

Confinement in the package is provided by an insulated 30-gallon drum fabricated per 49CFR178.504 and qualified as a DOT Specification 7A Type A Container, with a closure sealed by a high temperature silicone gasket. The drum is rated for pressure retention of 21.7 psig (150 KPa), and the closure is secured by a patented split ring closure device (Patent U.S.

8,844,748 B2). The closure lid of the 30-gallon drum includes a 2 inch ‘bung-hole’ flange. The 2 inch flange is closed with a Rieke S-220-2, VISEGRIP II pressure-relieving device with an EPDM gasket that limits drum pressures between 12-15 psig. The 30-gallon drum assembly is protected by the 55-gallon drum. The 55-gallon split ring closure includes two sets of $\frac{5}{8}$ inch thick by $1\frac{1}{2}$ inch diameter steel lugs used to close the 55-gallon drum. Each lug includes a through-hole to facilitate installation of a tamper indicating device (TID); upon closure the drum cannot be opened unintentionally.

The 30-gallon and 55-gallon drums are designed, fabricated, and tested in accordance with United Nations (UN) Drum Specification 1A2, as directed by 49 CFR 178 Subpart L for solid and liquid type drums. The 55-gallon drum design satisfies the performance requirements specified for a solid filled drum and the 30-gallon drum satisfies the requirements for both solids and liquids. The 30-gallon and 55-gallon drums meet the performance standards for Packing Group I tests (designated by the letter ‘X’ in the 1A2 drum designation). The 30-gallon drum also meets the Packing Group II tests for a liquids drum (designated by the letter ‘Y’ in the 1A2 drum designation). Additionally, the 30- and 55-gallon drums are constructed per 49 CFR 178.504(b) and fabricated in accordance with standards used for DOT 7A, Type A drums.

The 30-gallon drum assembly is fabricated from 16-gauge CRCQ CS per ASTM A1008. The 30-gallon closure lid (16-gauge) incorporates a standard 2 inch threaded ‘bung-hole’ flange with an EPDM gasket. The 2 inch flange is sealed with a threaded 2 inch steel pressure-relieving device, Rieke S-220-2, which limits internal pressure by relieving gases between 12-15 psig. An EPDM gasket seals the pressure-relieving plug to the flange.

The 30-gallon drum liner is fabricated from 18-gauge CRCQ CS per ASTM A1008 and is foamed in place with Dow BETAFOAM™ 87100/87124. The liner is positioned with hardened polyurethane foam guides that become merged with the liquid of the polyurethane foam once poured. Per Drawing R-R4-G-00187, 2 inch sections from each side of the liner roll are removed to provide ample space for insertion of the foaming nozzle during foaming operations.

A high temperature silicone gasket (compound S7426-60, approximately 60 shore durometer) seals the 30-gallon drum body to the lid, Drawing R-R4-G-00181. Figure 1.3 illustrates the 30-gallon drum assembly detailed in Drawing R-R1-G-00094.

4.3.1.2.2 Seals and Welds

4.3.1.2.2.1 Seals

The confinement boundary of the package does not include sealing features designed to retain pressure. The 30-gallon closure lid (16-gauge) incorporates a standard 2 inch threaded ‘bung-hole’ flange with an EPDM gasket. The 2 inch flange is sealed with a threaded 2 inch steel pressure-relieving device, Rieke S-220-2, which limits internal pressure by relieving gases between 12-15 psig. An EPDM gasket seals the pressure-relieving plug to the flange.

The lid of the 30-gallon drum is secured to the body with a split ring closure. The split ring closure device is fabricated from 12-gauge ASTM-1008 CRCQ CS and tested in accordance with industry standards for drum closures. The 2-piece closure devices have a threaded lug welded to one end and a lug with a through-hole on the other ($\frac{3}{4}$ inch outer diameter [OD] $\times \frac{5}{8}$ inch thick

for 55-gallon, ½ inch OD × ½ inch thick for 30-gallon) fabricated from ASTM A108 carbon steel. The carbon steel split rings are finished with powder coat gray paint.

The 30-gallon drum split ring lugs are threaded with ½-13UNC-2B thread and secured with two 2½ inch long ASTM A574, ½-13UNC-2A socket-head screws. Each screw passes through the unthreaded lug of one segment to mate with the threaded lug of the other segment (Drawing R-R1-G-00101, Appendix 1.1).

4.3.1.2.2 Welds

The 55-gallon drum roll and chime is circumferentially welded with ⅛ in. fillet welds for additional stiffening. The 55-gallon and 30-gallon drums longitudinal seam is welded as a “resistance mash seam weld” per data sheet M-DS-A-00078 and visually examined per AWS C1.4. Alternatively, the longitudinal seam may be a GTAW per AWS D1.3 and Arc Welding Datasheet, M-DS-A-00079 and Drawing R-R2-G-00129.

4.3.1.2.3 Containment Closure

The lid of the 30-gallon drum is secured to the body with a split ring closure. The split ring closure device is fabricated from 12-gauge ASTM-1008 CRCQ CS and tested in accordance with industry standards for drum closures. The 2-piece closure devices have a threaded lug welded to one end and a lug with a through hole on the other (¾ inch OD × ⅝ inch thick for 55-gallon, ½ inch OD × ½ inch thick for 30-gallon) fabricated from ASTM A108 carbon steel. The carbon steel split rings are finished with powder coat gray paint.

4.3.1.3 Codes and Standards

Confinement in the package is provided by an insulated 30-gallon drum fabricated per 49 CFR 178.504 and qualified as a DOT Specification 7A Type A Container, with a closure sealed by a high temperature silicone gasket.

The material to be transported in the package is Category III per Regulatory Guide (RG) 7.11 NUREG/CR 3854 which specifies acceptable fabrication criteria for packages used for transporting ‘Category III’ material as ASME B&PVC, Section VIII, Division 1 or ASME B&PVC Section III, Subsection NF, and DOT Specifications for drums used in the design.

The 30- and 55-gallon drums are designed, fabricated and tested in accordance with United Nations (UN) Drum Specification 1A2, as directed by 49 CFR 178 Subpart L for solid and liquid type drums. The 55-gallon drum design satisfies the performance requirements specified for a solid filled drum and the 30-gallon drum satisfies the requirements for both solids and liquids. The 30-gallon and 55-gallon drums meet the performance standards for Packing Group I tests (designated by the letter ‘X’ in the 1A2 drum designation). The 30-gallon drum also meets the Packing Group II tests for a liquids drum (designated by the letter ‘Y’ in the 1A2 drum designation). Additionally, the 30- and 55-gallon drums are constructed per 49 CFR 178.504(b) and fabricated in accordance with standards used for DOT 7A, Type A drums.

The 30-gallon drum assembly is fabricated from 16-gauge CRCQ CS per ASTM A1008. The 30-gallon drum liner is fabricated from 18-gauge CRCQ CS per ASTM A1008 and is foamed in place with Dow BETAFOAM™ 87100/87124.

4.3.1.4 Special Requirements for Plutonium

Since the package is not designed to transport plutonium, there are no special requirements for plutonium that apply to the package.

4.3.1.5 Special Requirements for Spent Fuel

Since the package is not designed to transport spent fuel, there are no special requirements for spent fuel that apply to the package.

4.3.2 Containment under Normal Conditions of Transport (NCT)

4.3.2.1 Containment Design Criterion

Fissile Type A packages under NCT must have no loss or dispersal of radioactive material as specified in 10 CFR 71.43(f).

4.3.2.2 Demonstration of Compliance with Containment Design Criterion

The Structural and Thermal Evaluations of the package design demonstrate that the confinement boundary remains intact following all NCT scenarios, showing that there is no loss or dispersal of the solid radioactive material under NCT. Testing of fully loaded prototype packages is described in Section 2.6 and visual inspections of the test specimens demonstrated no loss or dispersal of (simulated) radioactive contents (steel slug with fluorescent powder). After NCT impact testing, the outer drum closure bolts remained tight. Further, external impact damage amounted to little more than scuffed paint or a minor dent from a penetration test, consistent with no significant increase in external radiation levels. Fully loaded packages subjected to the series of water spray, free drop, and penetration impacts demonstrated no water entry and no degradation or loss of effectiveness of the 30-gallon drum.

The maximum pressure differential achievable under NCT is 5.06 psig, including MNOP and the effects of 10 CFR 71 reduced external pressure. This is less than the drum pressure rating of 22.5 psig. After NCT impact testing, the outer drum closure remained tight. External damage amounted to minor scuffing or a minor dent from a penetration test, consistent with no significant increase in external radiation levels. Fully loaded packages subjected to the series of water spray, free drop, and penetration impacts demonstrated no water entry and no degradation or loss of effectiveness of the 55-gallon outer drum.

4.3.3 Containment under Hypothetical Accident Conditions

4.3.3.1 Containment Design Criterion

§10 CFR 71.51(a)(2), requires that there is no escape of radioactive materials during HAC from the packaging that would occur in excess of A₂ in 1 week. This requirement is only applied for containment of Type B packages.

4.3.3.2 Demonstration of Compliance with Containment Design Criterion

The package has been designed to meet performance requirements under HAC by maintaining its overall configuration and preventing the loss of solid contents from the 30-gallon containment assembly. The §71.73(c) impact tests of package prototypes demonstrated no loss or dispersal of radioactive contents. Contents were simulated with a steel slug and fluorescent powder in

prototype testing. The impact tests produced localized denting and deformations of the 55-gallon drum and its closure as described in Section 2.7.

Following destructive opening of the 55-gallon drum, the 30-gallon drum had little damage and its closure remained tight. The criticality analysis assumes total loss of the outer drum and showed that an infinite array of fully loaded 30-gallon drums would remain subcritical.

The package was not tested to the §71.73(c)(4) requirements; however, the applicant demonstrated compliance by analysis and supplemental material testing. The analysis showed that the 30-gallon drum closure gasket service temperature limit will be exceeded (see Tables 3.1 and 3.2) during HAC; consequently, the applicant supplemented the analysis with material testing (Chapter 3, Reference 10). The material testing demonstrated that temperature excursions above HAC would not affect the ability of the drum gaskets to seal and confine the contents, as long as the drum lid and closure remained secure. The 30-gallon drum assembly components or contents are not adversely affected by HAC temperatures. Heat from the HAC fire is expected to consume the 55-gallon drum's foam insulation leaving a matrix of ash that will continue to provide insulation for the 30-gallon drum. The 55-gallon drum structural configuration will not be affected by the fire event and continue to provide spacing control for the 30-gallon drum even with the thermal decomposition of the insulation.

4.3.4 Leakage Rate Tests for Type B Packages

Not applicable for Type AF packages.

4.3.5 Appendices

Appendix 4.1, *Content Description for the 9981*, demonstrates that for the proposed contents, which can be a mixture of nuclides, the sum of the fractions of the A_2 values for the contents is less than one; therefore, that the contents meet the requirement for a Type A package.

4.4 Evaluation Findings

4.4.1 Findings

Based on review of the statements and representations in the SARP, PCP staff concludes that the containment design has been adequately described and evaluated and that the package design meets the containment requirements of 10 CFR 71 for Type AF packaging.

4.4.2 Conditions of Approval

PCP staff has concluded that no additional containment-related conditions of approval are required in the CoC.

4.5 References

- [4-1] *Safety Analysis Report for Packaging, Model 9981 Type AF Shipping Package*, S-SARP-G-00020, Revision X (September 2019).
- [4-2] *Packaging and Transportation of Radioactive Material*, Code of Federal Regulations, Title 10, Part 71, Washington, DC (January 2017).
- [4-3] Flach, J. P., *Hydrogen Gas Generation and Permeation for the 9981 Type AF Package*, M-CLCA- 00644, Revision 0, Savannah River Nuclear Solutions, Aiken, SC 29803 (August 2018).
- [4-4] Clarification of Conditions for Waste Shipments Subject to Hydrogen Gas Generation, Information Notice No. 84-72, U.S. Nuclear Regulatory Commissions (September 1984).
- [4-5] *Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maxim Wall Thickness of 4 Inches*, U.S. Nuclear Regulatory Commission, Regulatory Guide 7.11, (June 1991).
- [4-6] *Fabrication Criteria for Shipping Containers*, NUREG/CR-3854, U.S. Nuclear Regulatory Commission (March 1985).

5. Shielding Evaluation

5.1 Areas of Review

This section of the SER documents PCP staff's review of Chapter 5, *Shielding Evaluation*, of the SARP.^[5-1] The review includes an evaluation of the SARP with respect to the requirements specified in 10 CFR 71.^[5-2]

The following elements of the *Shielding Evaluation* chapter were reviewed. Details of the review are provided below in SER Section 5.3.

5.1.1 Description of Shielding Design

- Design Features
- Codes and Standards
- Summary Table of Maximum Radiation Levels

5.1.2 Radiation Sources

- Gamma Source
- Neutron Source

5.1.3 Shielding Model

- Configuration of Source and Shielding
- Material Properties

5.1.4 Shielding Evaluation

- Methods
- Input and Output Data
- Flux-to-Dose-Rate Conversions
- External Radiation Levels

5.1.5 Appendices

5.2 Regulatory Requirements

The requirements of 10 CFR Part 71 applicable to the shielding review of the package are as follows:

- The package design must be described and evaluated to demonstrate that it meets the shielding requirements of 10 CFR 71. [§71.31(a)(1), §71.31(a)(2), §71.33, §71.35(a)]
- The application must identify the established codes and standards used for the package design, fabrication, assembly, testing, maintenance, and use. In the absence of such codes, the application must describe the basis and rationale used to formulate the quality assurance program. [§71.31(c)]

- Under the tests specified in §71.71 for normal conditions of transport, the external radiation levels must meet the requirements of §71.47(a) for nonexclusive-use or §71.47(b) for exclusive-use shipments. [§71.47]
- The package must be designed, constructed, and prepared for shipment so that the external radiation levels will not significantly increase under the tests specified in §71.71 for normal conditions of transport. [§71.43(f), §71.55(a), §71.51(a)(1)]
- Under the tests specified in §71.73 for hypothetical accident conditions, the external radiation level must not exceed 10 mSv/h (1 rem/h) at one meter from the surface of the package. [§71.55(a),§71.51(a)(2)]

5.3 Review Procedures

Chapter 5 includes the information essential for a package shielding evaluation in the form of the isotopic makeup of the contents of the Low Enriched Uranium (LEU) metallic waste. The LEU content was evaluated to determine its compliance with the external radiation limits set forth in 10 CFR Part 71. The shielding information in the SARP was reviewed by PCP staff for completeness and compliance with regulatory requirements.

5.3.1 Description of Shielding Design

5.3.1.1 Design Features

The packaging design consists of an insulated 55-gallon outer drum assembly surrounding a 30-gallon drum assembly, and designed to ship radioactive uranium metals, oxides, and other solid compounds. Split ring closure devices secure the drum closure lids. The outer drum provides protection and confinement of the 30-gallon drum and the 30-gallon drum provides protection and confinement of the contents. The design does not include any packaging components intended for radiation shielding.

The 55-gallon drum is nominally 22½ inches (571.5 mm) in diameter and 34½ inches (876.3 mm) in height. The 30-gallon drum is nominally 18¼ inches (463.6 mm) in diameter and 29 inches (736.6 mm) in height. The 30-gallon drum is "centered", both radially and axially, within the 55-gallon drum by insulating material and a welded liner. The 30-gallon drum is fitted with a carbon steel liner which houses the payload.

The SARP describes the payload as being LEU^[5-3] waste in metallic form. The maximum mass of uranium permitted is 160 kg at 1.25 weight percent U-235 thus allowing shipment of up to 2.0 kg of U-235. The uranium waste also contains smaller quantities of U-234 and U-236. In addition, there are trace amounts of isotopes of plutonium as well as americium, neptunium, and thorium. A small quantity of the long lived fission product, Tc-99, is also present.

5.3.1.2 Codes and Standards

The radiation source term was characterized using ORIGEN-ARP (ORNL/TM-2005/39, Version 6.1, Sect. D1, *ORIGEN-ARP: Automatic Rapid Processing For Spent Fuel Depletion, Decay, and Source Term Analysis*).^[5-4] The use of this code to generate both the neutron and gamma source terms and spectra is acceptable to the PCP staff.

The Monte Carlo N-Particle Transport Code (MCNP). MCNP 6.1 code package (LA-CP-13-00634, Rev. 0, *MCNP6™ USER'S MANUAL*)^[5-5] was used for three-dimensional Monte Carlo transport calculations to determine absorbed dose rates outside the package. The continuous energy cross sections from the ENDF/B-VII data set were used by the applicant in conjunction with MCNP to calculate the external dose rates.

The recommended ANSI/ANS-6.1.1-1977 flux to dose rate conversion factors were employed to convert the MCNP calculate neutron and gamma fluxes to dose rates.

The use of this combination of codes and the stated ANSI standard to perform radiation transport calculations and estimate external radiation levels is acceptable to PCP staff.

5.3.1.3 Summary Table of Maximum Radiation Levels

The bounding radiation levels at the surface of the package and at 1 meter from the surface were presented as 4.11 mrem/h and 0.24 mrem/h, respectively.

5.3.2 Radiation Sources

The applicant used bounding masses of the various isotopes derived from the PORTS-LE report^[5-3] to generate the source terms.

5.3.2.1 Gamma Source

The applicant used ORIGEN-ARP to generate source spectra in a 20 group structure over a period of fifty years. The applicant then used a spreadsheet to pick the maximum in each energy group to form a composite energy spectrum with each group having the maximum source strength. This conservative approach is acceptable to the PCP staff.

PCP staff used ORIGEN6.2^[5-6] to generate the gamma source term in a 77 group structure and obtained a similar spectrum and total source strength.

5.3.2.2 Neutron Source

The neutron source for this payload consists only of neutrons from spontaneous fission. The alpha-n source is absent since the contents are in metallic form. The applicant has used the same method used for gammas by picking the maximum source strength in each of the 47 groups over a period of 50 years.

PCP staff performed an independent calculation to confirm that the applicant's source spectrum is acceptable.

5.3.3 Shielding Model

5.3.3.1 Configuration of Source and Shielding

The applicant used two models with no materials other than the payload of 160 kg of uranium containing 2 kg of U-235 and 158 kg of U-238. The first model consisted of a sphere of uranium with a radius of 12.61 cm derived from the total mass of uranium and its density of 19.05 g/cc. The fluxes were tallied as surface fluxes on concentric spheres of radii 16.42 and 116.42 cm

representing the surface and 1 meter from surface locations, respectively. PCP staff performed the same calculation, but with tallies on the surface of the sphere and 1 meter from it.

Since the neutron contribution to the dose rate from this content is small, the applicant used a distributed source in a cylinder and re-evaluated the dose rate at the surface and 1 m from the surface of this cylinder. The cylinder had a radius of 24.13 cm and a height of 73.66 cm. Once again there were no materials included except for the source which was distributed in the cylinder with a density of 1.19 g/cc derived from the volume of the cylinder (1.347×10^5 cc). PCP staff found that this volume was not consistent with the payload cavity volume for the 30-gallon drum nor that of the 55-gallon drum, which are 4.740×10^4 cc and 1.531×10^5 cc, respectively. Staff concluded that given the conservative nature of this analysis, this is not an issue.

PCP staff used the full model of the package including all materials and a distributed source within the payload cavity to establish external radiation levels outside the package. These levels were much smaller than those produced by the applicant's distributed source model.

5.3.3.2 Material Properties

The applicant did not use any materials in their shielding models (see SER Section 5.3.3.1). The staff used a full model of the package to evaluate the external radiation levels (see SER Section 5.3.3.1).

5.3.4 Shielding Evaluation

5.3.4.1 Methods

The codes used in performing the shielding analyses are presented in SER Section 5.3.1.2.

The ORIGEN-ARP code is designed to decay various isotopes and produce both resulting isotopes as well as sources in spectral energy group structures and in time steps provided by the user. Neutron sources are typically from spontaneous fissions of actinides and/or, in the presence of light elements, from the alpha-n reactions resulting from alpha decays of actinides. Gamma sources are from the decay of isotopes or from the spontaneous fission of actinides. Bremsstrahlung radiation is also generated. Subcritical multiplication by neutrons and neutron induced gammas from radiative capture, inelastic scattering, etc., are not included in the source term but are accounted for during the radiation transport calculations.

MCNP is a continuous energy Monte Carlo radiation transport code that is a standard piece of software used to perform radiation transport calculations for various nuclear particles. It can treat complex geometries accurately.

The applicant has used these codes to perform the shielding analyses and PCP staff finds this acceptable.

5.3.4.2 Input and Output Data

The applicant provided the input and output data based on the model they developed. PCP staff verified that the input and output files are consistent with the applicant's model. The source

spectra used in the MCNP calculations are consistent with the output from the ORIGEN code. The MCNP calculations are well converged with acceptable statistical uncertainties.

5.3.4.3 Flux-to-Dose-Rate Conversion

The recommended ANSI/ANS-6.1.1-1977^[5-7] flux to dose rate conversion factors were used by the applicant.

5.3.4.4 External Radiation Levels

The neutron contribution and the neutron induced gamma contribution were negligible as would be expected with the given contents. The external radiation levels were entirely from gamma radiation from the source. The applicant performed two sets of calculations.

The first model was the bare source model described in SER Section 5.3.3.1. This model yielded a result of 2.56 mrem/h on the surface (3.81cm from the surface) and 0.04 mrem/h 1 meter from the surface. Using MCNP6.2,^[5-8] PCP staff reproduced these results. Staff also determined a dose rate of 6 mrem/h at the surface of the bare sphere, which is well below the NCT surface dose rate limit of 200 mrem/h.

The second set of calculations involved the distributed source in a cylinder described in SER Section 5.3.3.1. The resulting dose rates were 4.11 mrem/h at 3.81cm from the surface and 0.24 mrem/h one meter from it. Thus, the applicant presented this set of dose rates as bounding, resulting in a calculated Transport Index of 0.3. These external levels of radiation are well within the regulatory limits prescribed for non-exclusive shipments. As indicated earlier, the HAC limit of 1 rem/h at 1 meter from the package is also met.

PCP staff performed a set of calculations of the full model with a distributed source inside the 30-gallon payload cavity. This resulted in a dose rate on the surface of the 55-gallon drum of 1.7 mrem/h with the dose rate 1 meter from this surface of 0.08 mrem/h. These results are well below the applicant's estimates. PCP staff also performed calculations with the same distributed source in the 30-gallon payload cavity but with no other materials present. The surface dose rate outside the 30-gallon liner was calculated to be 5.2 mrem/h and 0.13 mrem/h at 1 meter.

In conclusion, both the applicant's dose rate estimates and those of PCP staff, using various conservative models yielded results that are well below regulatory limits for non-exclusive use transport.

5.3.5 Appendices

Chapter 5 included one appendix to a calculation sheet detailing the calculations performed and the respective input files. The applicant also provided separate electronic copies of the input and output files to the PCP staff.

5.4 Evaluation Findings

5.4.1 Findings

Based on review of the statements and representations in the SARP, PCP staff concludes that the shielding design has been adequately described and evaluated and that the package meets the external radiation requirements of 10 CFR 71.

5.4.2 Conditions of Approval

PCP staff has concluded that no additional shielding or external radiation level-related conditions of approval are required in the CoC.

5.5 Reference

- [5-1] *Safety Analysis Report for Packaging, Model 9981 Type AF Shipping Package*, S-SARP-G-00020, Revision 0 (March 2019).
- [5-2] *Packaging and Transportation of Radioactive Material*, Code of Federal Regulations, Title 10, Part 71, Washington, DC (January 2017).
- [5-3] *Technical Basis for Radiological Properties Low Enriched Uranium (LEU) Fernald Metal* PORT-LPP000024 Rev. 1, July 2010. (OUO)
- [5-4] Gauld, I.C., Bowman, S.M. and Horwedel, J.E., *ORIGEN-ARP: Automatic Rapid Processing for Spent Fuel Depletion, Decay, And Source Term Analysis*, ORNL/TM-2005/39, Version 6.1, Section D1, Oak Ridge National Laboratory, Oak Ridge, TN (June 2011).
- [5-5] Pelowitz, D.B., Ed., *MCNP6TM USER'S MANUAL*, LA-CP-13-00634, Rev. 0, Los Alamos National Laboratory, Los Alamos, NM (May 2013).
- [5-6] Reardon, B. T. and Jessee, M. A., Editors, *Scale Code System, Version 6.2.3*, ORNL/TM-2005/39, Oakridge National Laboratory (March 2018).
- [5-7] *Neutron and Gamma-Ray Flux-to-Dose Rate Factors*, ANSI/ANS-6.1.1-1977, American Nuclear Society, Le Grange Park, IL (March 1977).
- [5-8] *MCNP Users Manual - Code Version 6.2*, C.J. Werner (editor), Los Alamos National Laboratory, report LA-UR-17-29981 (2017).

6.0 Criticality Evaluation

6.1 Areas of Review

This section of the SER documents PCP staff's review of Chapter 6, *Criticality Evaluation*.^[6-1] Staff review includes an evaluation of the SARP with respect to the requirements specified in 10 CFR 71.^[6-2]

The following elements of the *Criticality Evaluation* chapter were reviewed. Details of the review are provided below in SER Section 6.3.

Included in the Criticality Review were the following:

6.1.1 Description of Criticality Design

- Design Features
- Summary Table of Criticality Evaluation
- Criticality Safety Index

6.1.2 Fissile Material Contents

6.1.3 General Considerations

- Model Configuration
- Material Properties
- Computer Codes and Cross-Section Libraries
- Demonstration of Maximum Reactivity

6.1.4 Single Package Evaluation

- Configuration
- Results

6.1.5 Evaluation of Undamaged-Package Arrays under Normal Conditions of Transport

- Configuration
- Results

6.1.6 Evaluation of Damaged-Package Arrays under Hypothetical Accident Conditions

- Configuration
- Results

6.1.7 Fissile Material Packages for Air Transport

6.1.8 Benchmark Evaluations

- Applicability of Benchmark Experiments
-

- Bias Determination

6.1.9 Appendices

6.1.10 References

6.2 Regulatory Requirements

The requirements of 10 CFR 71 applicable to the criticality review of the package are as follows:

- The package design must be described and evaluated to demonstrate that it meets the criticality requirements of 10 CFR 71. [§71.31(a)(1), §71.31(a)(2), §71.33, §71.35(a)]
- The application must identify the established codes and standards used for the package design, fabrication, assembly, testing, maintenance, and use. In the absence of such codes, the application must describe the basis and rationale used to formulate the quality assurance program. [§71.31(c)]
- A single package must be subcritical under the conditions of §71.55(b), §71.55(d), and §71.55(e).
- A fissile material packaging design to be transported by air must meet the requirements of §71.55(f). (*not applicable for 9981 Content*)
- An array of undamaged packages must be subcritical under the conditions of §71.59(a)(1).
- An array of damaged packages must be subcritical under the conditions of §71.59(a)(2).
- A fissile material package must be assigned a criticality safety index for nuclear criticality control to limit the number of packages in a single shipment. [§71.59(b), §71.59(c), §71.35(b)]
- The package must be designed, constructed, and prepared for shipment so that there will be no significant reduction in the effectiveness of the packaging under the tests specified in §71.71 for Normal Conditions of Transport. [§71.43(f), §71.51(a)(1), §71.55(d)(4)]
- The package must be designed, constructed, and prepared for shipment so that there will be no significant reduction in the effectiveness of the packaging under the tests specified in §71.73 for Hypothetical Accident Conditions. [§71.73(a), §71.73(b)(1), §71.73(c)]
- Unknown properties of fissile material must be assumed to be those that will credibly result in the highest neutron multiplication. [§71.83]
- Qualification of Special Form of radioactive material. [§71.75]

6.3 Review Procedures

Chapter 6 includes the information essential for a criticality evaluation, including the drawings, the packaging materials and densities, and the fissile isotopic composition and mass. This criticality information was reviewed by PCP staff for completeness and compliance with regulatory requirements. Of particular importance are the subcriticality requirements per 10 CFR 71.55 and 10 CFR 71.59.

6.3.1 Description of Criticality Design

6.3.1.1 Design Features

The packaging design and consists of two primary assemblies: an insulated 55-gallon outer drum and an internal insulated 30-gallon drum.

The 30-gallon drum, positioned centrally (both radially and axially) within the 55-gallon drum liner, secures the payload and provides confinement of the radioactive contents. The 30-gallon drum is also outfitted with an internal steel liner and a polyurethane foam layer between the steel surfaces. An aluminum honeycomb cylinder is located between the top of the steel liner and the inside of the 30-gallon drum lid for energy absorbance. Reinforced split ring devices provide secure closures for the 30- and 55-gallon drums. There are no external impact limiters nor any engineered structural features for lifting or tie-down. There are no designed packaging heat transfer features. The 30-gallon drum honeycomb cylinder and internal foamed liner provide for payload load dispersal. The 55-gallon drum includes a steel liner welded to the inside of the drum body and under its closure lid. Polyurethane foam insulation fills the cavities formed between the liner and drum/lid components. The safety function of the insulated 55-gallon drum is to confine and protect the 30-gallon drum.

The package design does not incorporate any specific criticality-control features. The design ensures subcriticality by limiting contents and maintaining a minimum distance between adjacent fissile material sources.

The general outside dimensions of the closed 55-gallon drum are approximately 24 inches in diameter by 34½ inches high. The 55-gallon drum body is fabricated from 16-gauge carbon steel and the closure lid and the welded liner are fabricated from 16- and 18-gauge carbon steel.

The general outside dimensions of the closed 30-gallon drum are 18.6 inches in diameter by 29 inches high. The 30-gallon drum is made of 18-gauge carbon steel and outfitted with an internal 18-gauge carbon steel liner. The cavity formed between the liner and drum is filled with the 24 lb./ft³ Dow Automotive polyurethane foam (i.e., BETAFOAM™). The top of the 30-gallon drum is fitted with an aluminum honeycomb cylinder. There is also a quilted insulation cover (½ inch thick) installed between the 30-gallon drum and the 55-gallon drum.

The fissionable material content is mostly depleted uranium with a small amount of U-235.

The package uses the geometry of the packaging structure and control of the quantity and composition of the fissile material to ensure that the single-package contents are subcritical under NCT and HAC. In addition to the control of the geometry and specific fissile content, interaction control is also established by the fact that the confinement boundary is the 30-gallon

drum cavity, ensuring a center-to-center separation of at least the diameter of the drum in the lateral direction (perpendicular to the drum axis). Furthermore, the hydrocarbon-based insulating-spacing material (foam and composite materials) acts as a neutron moderator to further isolate a package from neighboring packages. These features ensure that the arrays of packages are subcritical under NCT and HAC.

PCP staff confirmed that the text and sketches describing the criticality design features are consistent with the engineering drawings and the models used in the criticality evaluation. Staff concludes that the SARP demonstrates that the package satisfies the standards specified in Subparts E and F of 10 CFR 71 and concurs that the applicant's calculated CSI of 1.4 is proper for the contents evaluated in the SARP.

6.3.1.2 Summary Table of Criticality Evaluation

Table 6.1, summarizes and addresses the following cases for the package: a single package, under the conditions of §71.55(b), (d), and (e); an array of undamaged packages, under the conditions of §71.59(a)(1); and an array of damaged packages, under the conditions of §71.59(a)(2). Table 6.1 includes the maximum value of the effective multiplication factor (k_{eff}) for the content, including two standard deviations. It also lists the safe value for the multiplication factor (k_{safe}), for which the appropriate bias, bias uncertainty and Area of Applicability (AOA) margin have been subtracted from 0.95 (which includes the accepted minimum subcritical margin of 0.05). It also lists the number of packages evaluated in the arrays. This table demonstrates appropriate subcriticality by showing that the value of k_{eff} is less than k_{safe} for this package.

In general, the k_{eff} values are much lower for solid metal cases than solution cases. For example, the k_{eff} value for a single package is low, less than (*or equal to*) 0.480 for solid metal and 0.792 for solutions.

For the NCT and HAC array for solution, the maximum k_{eff} values are less than (*or equal to*) 0.838 and 0.874, respectively. The content reflected by the package materials is judged to be less reactive than that with full water reflection.

6.3.1.3 Criticality Safety Index

A minimum criticality CSI of 1.4 is assigned to the package, based on the HAC-array calculations showing that the 2N=5x5x3 array has a multiplication factor plus bias and bias uncertainties, appropriate AOA and a 5% minimum subcritical margin (MSM) that is less than 1.0. This CSI value is consistent with the reported value in SARP. PCP staff concurs with this value.

6.3.2 Fissile Material Contents

The contents used in the criticality analyses are consistent with those specified in Chapter 1.

The contents consists of metal ingots, derbies, and miscellaneous metal waste. The maximum mass is 160 kg of mainly low enriched uranium with a small quantity of various thorium and plutonium isotopes (less than 3 grams total), as shown in Table 1.1. The U-235 content is 2000

grams, which translates to an enrichment value of $(2000/160000)*100 = 1.25$ wt.%. A theoretical density of 19.05 g/cc for U metal is used for criticality calculations.

The drum and all insulating material dimensions and compositions are well defined and appropriate.

6.3.3 General Considerations for Criticality Evaluations

6.3.3.1 Model Configuration

The configurations for the calculational models for a single package and for the arrays of packages used to perform the criticality evaluation of the package are described in Section 6.3.

The criticality modeling makes several assumptions for the package models for the single package evaluation and different package models for the NCT and HAC array analyses.

Single Package Model

The SCALE/KENO model for the single package is based on nominal dimensions of the inner outer drums. The drum was modeled as a right circular cylinder and did not include the rolling hoops (sides), the Drum Cover ring, or the bottom stacking ring. The simplified modeling of the drum as right circular cylinders is conservative.

The single drum model was evaluated as a single unit with 30 cm of water reflection surrounding the single unit.

Modeling the fissile material (LEU waste material) as a spherical configuration inside the 30-gallon drum was considered. For the flooding case packaging insulation was replaced by water. A second drum model configuration of the contents homogenized, to simulate many small pieces of metal, and water filling the volume of the 30-gallon drum liner was analyzed. Both models are conservative and bounding for any credible configurations. Tables 6.6 and 6.7 show a single package remains subcritical under NCT and HAC.

A series of calculations^[6-3] were performed by PCP staff to confirm the applicant's k_{eff} values for the most reactive cases.

Several cases were verified with MCNP:

- a. Both drums dry, insulation intact, sphere centered
- b. Inner drum liner dunnage as water or poly, insulation intact or replaced by water, sphere centered, and
- c. Fissile solution filling 50% to 80% of the inner drum liner, insulation replaced by water, and air or water above solution.

NCT Array Model

The NCT model was evaluated as an infinite array (triangular pitch) of undamaged single units. The model is based on nominal dimensions of the outer drum. Two types of content model similar to single package model, namely, one solid spherical unit and the other with content material uniformly mixed with water, were analyzed.

Similar to the case of single package model, the package was also modeled with water in the interior of the package in the flooded scenario. The NCT tests did not cause any damage to the packaging that significantly changed component dimensions and thereby affected criticality. Tables 6.8 and 6.9 show that an infinite number of undamaged packages remain subcritical under NCT.

A series of confirmatory calculations^[6-3] were performed by PCP staff to confirm the applicant's k_{eff} values for the most reactive cases. Several cases were verified with MCNP:

- a. Both drums dry, insulation intact, sphere centered
- b. Inner drum liner dunnage as water or poly, insulation intact or replaced by water, sphere centered, and
- c. Fissile solution filling 60% to 80% of the inner drum liner, insulation intact, and air or water above solution.

HAC Array Model

For the HAC array model, the applicant omitted all of the packaging materials beyond the 30-gallon drum, although the crush test results showed only minimal packaging deformation. Again, two types of content model similar to single packages models and NCT array model, namely, one solid spherical unit and the other with content material uniformly mixed with water, were analyzed.

An infinite array was used for the solid sphere cases. The solution model uses the 5x5x3 (hexagonal pitch configuration) array model, because the infinite array solution model exceeded the k_{safe} value; consequently the 5x5x3 triangular pitch array model used 30 cm of water reflection surrounding the array.

This case results in the closest interaction with respect to the fissile materials in other neighboring packages to maximize reactivity. Tables 6.10 and 6.11 show that an infinite array of damaged packages remain subcritical under HAC.

A series of calculations^[6-3] were performed by PCP staff to confirm the applicant's k_{eff} values for the most reactive cases. Several cases were verified with MCNP as shown in SER Section 6.3.6.2.

6.3.3.2 Material Properties

Accepted values for the density of all packaging materials are used in the Section 6.3.2. The "Standard Composition Library" in SCALE was used for some materials, while material technical specifications, such as Material Safety Data Sheet were used for others. The effect of a slight variation in composition for some materials (e.g., foam, Kao-Tex bag) is acceptable because of their negligible effect on reactivity.

A convenience can (slip lid can) holding the waste material is not modeled. The insulation bag (KAO-TEX) is modeled as SiO_2 with a density of 2.54 g/cc. Water density is conservatively taken as 1.0 g/cc instead of the nominal value of 0.9982 g/cc at 20°C to cover temperatures as low as 0° C. Polyethylene (C_2H_4) is conservatively used to represent plastic materials (dunnage),

as it has the highest hydrogen density among common types of plastic materials. The nominal polyethylene density is about 0.92 g/cc. This is conservative. Uranium metal with the theoretical density of 19.05 g/cc was conservatively used.

PCP staff concludes that the material property values used by the applicant are credible and that will cause the maximum neutron multiplication as required by §71.83.

6.3.3.3 Computer Codes and Cross-Section Libraries

The applicant used the configuration-controlled version of SCALE 6.1 KENO VI code system operating on the SRNS Criticality Safety Advanced Computing Center (CSACC).

The criticality studies used the 238-group Evaluated Nuclear Data Files (ENDF)/B-VII cross-section library with the CSAS6 driver in SCALE 6. The CSAS6 driver calls the BONAMI and CENTRM modules for the generation of a problem-dependent cross-sections library (accounting for resonance self-shielding) and the KENO VI module was used to perform the Monte Carlo k_{eff} calculations.

These computer codes and cross-section libraries are appropriate for the criticality calculations and are consistent with the neutron spectrum of the package. Also, these cross-section libraries properly account for resonance absorption and self-shielding effects. The benchmark evaluations and resulting biases were determined using the same codes and cross-section sets.

The applicant used sufficient neutron histories to obtain the k_{eff} values within a statistical uncertainty less than 0.002. The number of neutron histories was adequate to assure that the fissile systems analyzed were sampled in a statistically acceptable manner and that convergence was achieved.

Independent confirmatory calculations by PCP staff were performed with MCNP6 using the ENDF/B-VII cross-section set.

6.3.3.4 Demonstration of Maximum Reactivity

Maximum reactivity was demonstrated for single packages with solution. The k_{eff} value varies from 0.317 to 0.480 to 0.792 from dry solid to flooded solid to solution cases (Tables 6.6 & 6.7).

The maximum k_{eff} value for a single package is low. PCP staff's independent MCNP confirmatory calculations show that the k_{eff} value varies from 0.307 to 0.472 to 0.792 from dry solid to flooded solid to solution cases.

An infinite array of the NCT model k_{eff} values are slightly higher than the single package, confirming that the single units are, indeed, isolated. The k_{eff} value for the dry infinite array model increases from 0.429 to 0.481 to 0.838 from dry solid to flooded solid to solution cases (Tables 6.8 & 6.9). The maximum k_{eff} value for the NCT array is, therefore, 0.838. PCP staff's corresponding MCNP values vary from 0.444 to 0.472 to 0.849 from dry solid to flooded solid to solution cases.

The most reactive individual package appropriate to the specific conditions was used for HAC-array analyses and resulted in a k_{eff} value of 0.874 (Table 6.11). PCP staff's confirmatory calculation shows that the most reactive HAC k_{eff} value using MCNP is 0.876.

The k_{safe} value is 0.920. Therefore, adequate margins are available to ensure subcriticality.

Maximum reactivity was demonstrated for HAC-array analyses for the mass and position of fissile material, and for internal and interspersed moderation. The SARP analyzed the effect of various combinations of flooding scenarios.

PCP staff confirms that the applicant used the most reactive configuration in demonstrating subcriticality.

6.3.4 Single-Package Evaluation

PCP staff concludes that the package design conforms to the criticality safety requirements of §§71.43(f), 71.51(a), 71.55(b), 71.55(d), and 71.55(e).

6.3.4.1 Configuration

The NCT model was evaluated as a single package with 30 cm of water reflection. Modeling the fissile material as a sphere in a dry or flooded configuration inside the 30-gallon drum was conservative. Water was allowed to enter the drum and occupy internal clearance volumes during the flooded scenario.

6.3.4.2 Results

The k_{eff} is 0.317 for single package dry cases, and the k_{eff} value increases to about 0.480 for the flooded solid sphere cases.

The maximum k_{eff} value for the single-unit solution cases is 0.792 (Table 6.7).

PCP staff performed an independent confirmatory analysis with MCNP for a single unit model with full water reflection per §71.55(b)(3).

Staff's MCNP k_{eff} values for the 30-gallon dry/flooded cases are 0.307/0.472 (solid U sphere at the bottom center), and 0.792 Maximum k_{eff} for solution cases.

Staff's MCNP k_{eff} values are within 0.02 of the corresponding SARP values. It is noted that the MCNP model is slightly different from the SARP KENO model; although both codes use the same cross section set, the processing of the cross sections accounts for the difference.

The applicant and PCP staff's criticality results of the most reactive case for the single-package analysis are consistent. A summary of the applicant's results are discussed in SER Section 6.3.1.2. SER Table 6-1 is a side by side comparison of the results (max. values in **bold**).

Table 6-1 – Single Package Comparison

Case No.	Description	Staff MCNP6 ($k_{\text{eff}} + 3\sigma$)	SARP SCALE 6.1 ($k_{\text{eff}} + 2\sigma$)
1.	Both drums dry, insulation intact, and sphere centered.	0.307	0.317
2.	Inner drum liner flooded, insulation intact, and sphere centered.	0.454	0.462
3.	Inner drum liner dunnage modeled as poly, insulation intact, and sphere centered	0.465	0.475
4.	Inner drum liner dunnage modeled as poly, insulation replaced by water, and sphere centered	0.472	0.480
	Air above the fissile solution	-	-
5.	Fissile solution filling 60% of the inner drum liner & insulation replaced with water.	0.776	0.787
6.	Fissile solution filling 70% of the inner drum liner & insulation replaced with water.	0.785	-
7.	Fissile solution filling 80% of the inner drum liner & insulation replaced with water.	0.787	0.780
	Water above the fissile solution	-	-
8.	Fissile solution filling 60% of the inner drum liner & insulation replaced with water.	0.786	0.792
9.	Fissile solution filling 80% of the inner drum liner & insulation replaced with water.	0.792	0.784

The k_{eff} results from SCALE (SARP) and MCNP (PCP Staff) models in this evaluation agree (within 0.011 Δk) in spite of the fact that there are small differences in model geometry and material compositions. The MCNP models use the ENDF/B-VII cross section set, while the SARP SCALE models used the 238-group ENDF/B-VII cross section set. PCP staff's confirmatory calculations show that a single package will remain subcritical with enough margin.

The k_{safe} value is 0.920. PCP staff concludes that a significant reactivity margin is available for the single package cases due to conservative modeling, and concurs with the SARP that a single package will remain subcritical in accordance with §§71.43(f), 71.51(a), 71.55(b), 71.55(d), and 71.55(e), for highway transport.

6.3.5 Evaluation of Undamaged-Package Arrays (Normal Conditions of Transport)

The NCT tests did not result in water leakage into the 30-gallon drum or damage that significantly affected the criticality safety of the package. PCP staff concludes that the package is designed, constructed, and prepared for shipment so that there will be no significant reduction in the criticality safety of any package during NCT. PCP staff also concludes that the package conforms to the NCT criticality requirements for all packages, in accordance with §§71.59(a)(1) and 71.59(a)(3).

6.3.5.1 Configuration

The array model used the most reactive fissile contents from the single package model and analysis as the basis to evaluate an infinite array of these packages with each fissile mass located at the center of the package.

6.3.5.2 Results

The maximum k_{eff} value for dry cases is 0.429. Flooded cases with solid U produces a maximum k_{eff} value to 0.481 (Table 6.8).

The maximum value for solution cases is 0.838 (Table 6.9).

PCP staff performed independent confirmatory analyses of the NCT cases to verify the applicant's results. Staff's MCNP k_{eff} values for the NCT dry/flooded NCT cases are 0.444/0.472 (solid U sphere at the bottom center), and 0.849 maximum for solution cases.

Staff's MCNP k_{eff} values are within 0.02 of the corresponding SARP values. It is noted that the MCNP model is slightly different from the SARP KENO model; although, both codes use the same cross section set, the processing of the cross sections accounts for the difference.

The applicant and PCP staff's criticality results of the most reactive case for NCT arrays of packages are consistent. A summary of the applicant's results are discussed in SER Section 6.3.1.2. SER Table 6-2 is a side by side comparison of the results (max. values in **bold**).

Table 6-2 – NCT Arrays Comparison

Case No.	Description	Staff MCNP6 ($k_{\text{eff}} + 3\sigma$)	SARP SCALE 6.1 ($k_{\text{eff}} + 2\sigma$)
1.	Both drums dry, insulation intact, and sphere centered.	0.444	0.429
2.	Inner drum liner flooded, insulation intact, and sphere centered.	0.465	0.464
3.	Inner drum liner dunnage modeled as poly, insulation intact, and sphere centered	0.471	0.478
4.	Inner drum liner dunnage modeled as poly, insulation replaced by water, and sphere centered	0.472	0.481
	Air above the fissile solution	-	-
5.	Fissile solution filling 60% of the inner drum liner & insulation intact.	0.838	0.838
6.	Fissile solution filling 70% of the inner drum liner & insulation intact.	0.848	-
7.	Fissile solution filling 80% of the inner drum liner & insulation intact.	0.849	0.830
	Water above the fissile solution	-	-
8.	Fissile solution filling 60% of the inner drum liner & insulation intact.	0.833	0.827
9.	Fissile solution filling 80% of the inner drum liner & insulation intact.	0.842	0.824

The k_{eff} results for NCT infinite array models also agree well (within 0.02 Δk) in spite of the fact that there are small differences in model geometry and material compositions. PCP staff's confirmatory calculations show that NCT arrays of packages will remain subcritical with enough margin.

The k_{safe} value is 0.920. PCP staff concludes that a significant reactivity margin is available for the undamaged package array cases due to very conservative modeling, and concurs with the SARP that NCT arrays of packages will remain subcritical in accordance with §§71.59(a)(1) and 71.59(a)(3), for ground transport.

6.3.6 Evaluation of Damaged-Package Arrays (Hypothetical Accident Conditions)

PCP staff concludes that the package conforms to the HAC criticality requirements for all packages, in accordance with §§71.59(a)(2) and 71.59(a)(3).

6.3.6.1 Configuration

The most limiting case for the package was the HAC model. The applicant's HAC package model omits everything outside of the 30-gallon drum, so packages are spaced closer together in the HAC array model; consequently, this model overestimates HAC array k_{eff} values.

Two array models of the package were used for HAC: an infinite array model was used for solid sphere cases and a 5x5x3 array model was used for solution cases, because the infinite array model for solutions exceeds the k_{safe} value.

The 5x5x3 array model of 30-gallon drums was analyzed in a triangular pitch configuration with 30 cm water reflection surrounding the array.

6.3.6.2 Results

The maximum k_{eff} values for dry/flooded cases are 0.676/0.484 respectively (Table 6.10). The flooded solid sphere cases produce lower k_{eff} values than the dry cases due to isolation of contents between packages by water/poly material.

The maximum k_{eff} value for solution cases is 0.874 (Table 6.11).

PCP staff performed independent confirmatory analyses of the HAC cases to verify the applicant's results. The MCNP k_{eff} values for the dry/flooded HAC cases are 0.687/0.478 (sphere at the bottom center), and 0.876 maximum for the solution cases.

Staff's MCNP k_{eff} values are within 0.02 of the corresponding SARP values. It is noted that the MCNP model is slightly different from the SARP KENO model; although both codes use the same cross section set, the processing of the cross sections accounts for the difference.

The applicant and PCP staff's criticality results of the most reactive cases for HAC arrays of packages are consistent. A summary of the applicant's results are discussed in SER Section 6.3.1.2. SER Table 6-3 is a side by side comparison of the results (max. values in **bold**).

Table 6-3 – HAC Arrays Comparison

Case No.	Description	Staff MCNP6 ($k_{\text{eff}} + 3\sigma$)	SARP SCALE 6.1 ($k_{\text{eff}} + 2\sigma$)
1.	Drum dry and sphere centered.	0.687	0.676
2.	Drum liner flooded with water, sphere centered, and all insulation intact.	0.476	0.474
3.	Drum liner dunnage modeled as polyethylene, sphere centered, and all insulation intact.	0.478	0.484
4.	Drum liner dunnage modeled as polyethylene, sphere centered, insulation and bag modeled as water.	0.474	-
	Air above the fissile solution	-	-
5.	Fissile solution filling 60% of the inner drumliner & insulation intact.	0.866	0.874
6.	Fissile solution filling 70% of the inner drumliner & insulation intact.	0.876	-
7.	Fissile solution filling 80% of the inner drumliner & insulation intact.	0.875	0.867
	Water above the fissile solution	-	-
8.	Fissile solution filling 60% of the inner drumliner & insulation intact.	0.853	0.859
9.	Fissile solution filling 80% of the inner drumliner & insulation intact.	0.862	0.852

The k_{eff} results for HAC array models also agree well (within 0.011 Δk) in spite of the fact that there are small differences in model geometry and material compositions. The confirmatory calculations show that HAC arrays of packages will remain subcritical with enough margin.

The SCALE k_{safe} value is 0.920, whereas the MCNP k_{safe} values are 0.921. PCP staff concludes that a sufficient reactivity margin is available for the HAC array cases due to conservative modeling, and concurs with the SARP that HAC arrays of packages will remain subcritical in accordance with §§71.59(a)(2) and 71.59(a)(3), for ground transport

6.3.7 Air Transport

Not applicable for this content.

6.3.8 Benchmark Evaluations

The SARP used the same criticality computer code, hardware, and cross-section library sets to determine the bias values from benchmark experiments as those used to calculate the multiplication factors for the packages.

6.3.8.1 Applicability of Benchmark Experiments

The benchmark experiments used in this study were taken from the *International Handbook of Evaluated Criticality Safety Benchmark Experiments*^[6-4] and are appropriately referenced. This collection of benchmark experiments is the accepted standard in the criticality-safety-engineering community.

No critical experiments similar to the package system are available. Therefore, a wide range of critical experiments was chosen for validation.

PCP staff concurs that the uranium benchmark experiments used in the SARP are applicable to the actual packaging design and contents.

6.3.8.2 Bias Determination

NRC NUREG/CR-5661,^[6-5] recommends a minimum subcritical margin of 0.05 for packaging applications. The applicant used an additional AOA margin of 0.01 to develop k_{safe} values. Contributions from uncertainties in experimental data are included for all benchmark experiments reported in the Handbook. A sufficient number of appropriate benchmark experiments are analyzed and the results of these benchmark calculations are used to determine an acceptable bias^[6-6] and bias uncertainty for the U-235 fissile payload. These bias values are then used in the calculation of a k_{safe} value for the package payloads. The statistical and convergence uncertainties of the benchmark calculations and package evaluations are sufficiently essentially consistent.

The SARP determined an acceptable value for the bias for LEU solids and solutions. The most limiting value of 0.920 was chosen as the k_{safe} for low enriched uranium solids and solutions, including 0.01 as an additional AOA margin. Acceptable statistical analyses demonstrate that this value is accurate and conservative.

PCP staff concurs that the benchmark experiments and corresponding bias value are applicable, and conservative, as applied to the package as described in the SARP.

6.3.9 Appendices

There is one appendix for Chapter 6, *Nuclear Criticality Safety Evaluation: LEU Metal Waste in a 9981 Type AF Shipping Package (U)*, N-NCS-G-00173, Rev. 2. Chapter 6 is consistent with this appendix.

6.3.10 References

All references cited for the criticality evaluation are appropriate.

6.4 Evaluation Findings

6.4.1 Findings

Based on review of the statements and representations in the SARP, PCP staff concludes that the nuclear criticality safety design has been adequately described and evaluated and that the package meets the nuclear criticality safety requirements of 10 CFR 71.

6.4.2 Conditions of Approval

PCP staff has concluded that no additional criticality-related conditions of approval are required in the CoC.

6.5 References

- [6-1] *Safety Analysis Report for Packaging, Model 9981 Type AF Shipping Package, S-SARP-G-00020, Revision 0 (March 2019).*
- [6-2] *Packaging and Transportation of Radioactive Material, Code of Federal Regulations, Title 10, Part 71, Washington, DC (January 2017).*
- [6-3] D. Biswas, *Criticality Safety Confirmatory Calculations, Safety Analysis Report for Packaging, 9981 model, PSS Content, TP-2019-01 (December 2018).*
- [6-4] *International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03, OECD/NEA (2016).*
- [6-5] H. R. Dyer, C. V. Parks, *Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages, NUREG/CR-5661 (April 1997).*
- [6-6] *Validation of Neutron Transport methods for Nuclear Criticality Safety Calculations, ANSI/ANS-8.24-2007, American National Standard of the American Nuclear Society (2007).*

7. Package Operations Review

7.1 Areas of Review

This section of the SER documents PCP staff's review of Chapter 7, *Package Operations*.^[7-1] Staff review includes an evaluation of the SARP with respect to the requirements specified in 10 CFR 71.^[7-2]

The following elements of the *Package Operations* chapter were reviewed. Details of the review are provided below in SER Section 7.3.

7.1.1 Package Loading

- Preparation for Loading
- Loading of Contents
- Preparation for Transport

7.1.2 Package Unloading

- Receipt of Package from Carrier
- Removal of Contents

7.1.3 Preparation of Empty Package for Transport

7.1.4 Other Operations

7.1.5 Appendices

7.2 Regulatory Requirements

The requirements of 10 CFR 71 applicable to the package operations review of the package are as follows:

- The application must identify the established codes and standards used for the package design, fabrication, assembly, testing, maintenance, and use. In the absence of such codes, the application must describe the basis and rationale used to formulate the quality assurance program. [§71.31(c)]
- The application must include any special controls and precautions for transport, loading, unloading, and handling of a fissile material shipment, and any special controls in case of accident or delay. [§71.35(c)]
- The transport index of a package in a nonexclusive-use shipment must not exceed 10, and the sum of the Criticality Safety Indices (CSI) of all packages in the shipment must not exceed 50. [§71.47(a), §71.59(c)(1)]
- Packages that require exclusive-use shipment because of increased radiation levels must be controlled by providing written instructions to the carrier. [§71.47(b–d)]

- The sum of the CSIs for nuclear criticality control of all packages in an exclusive-use shipment must not exceed 100. [§71.59(c)(2)]
- The application must include Package Operations that ensure that the package meets the routine-determination requirements of §71.87. [§71.81, §71.87]
- Unknown properties of fissile material must be assumed to be those that will credibly result in the highest neutron multiplication. [§71.83]
- A package must be conspicuously and durably marked with the model number, serial number, gross weight, and package identification number. [§71.85(c), §71.19(a)(2), §71.19(b)(3)]
- Prior to delivery of a package to a carrier, any special instructions needed to safely open the package must be provided to the consignee for the consignee's use in accordance with 10 CFR 20.1906(e). [§71.89]
- Each type B(U) or Type B(M) package design must have on the outside of the outermost receptacle a fire resistance radiation symbol in accordance with 49 CFR 172.310(d).

With respect to operating procedures, 10 CFR 71 states two clear requirements for a SARP:

- §71.31 states that an application for an approval under 10 CFR 71 must include a package evaluation as required by §71.35. With respect to operating procedures for Fissile Class III shipment, §71.35 states that the application must include any proposed special controls and precautions for transport, loading, unloading, and handling, and any proposed special controls in the event of accident or delay.
- In addition, §71.31 states that an application for an approval under 10 CFR 71 must include a description of a quality assurance program as required by §71.37, which in turn requires, in part, that an applicant describe the quality assurance program (per Subpart H of 10 CFR 71) for the use of the proposed package. With respect to operating procedures, Subpart H states in §71.111 that activities affecting quality must be described by documented instructions, procedures, or drawings of a type appropriate to the circumstances.

In addition, 10 CFR 71 states requirements with respect to operating procedures for a package licensee, primarily in Subpart G. While these are stated as requirements to the licensee and not for the applicant, it is important that the applicant include discussion of some of these in the SARP.

Further recommendations for operating procedures in the SARP are given by NRC Regulatory Guide 7.9:

- Procedures for package loading
 - Procedures for package unloading
 - Preparation of empty package for transport
-

The primary regulations that govern operating procedures can be located in the following:

- 10 CFR 71, Subpart G (Operating Controls and Procedures)
- 10 CFR 71, Subpart H (Quality Assurance).

Additional regulations governing operating procedures can be found in the following:

- 10 CFR 19.12 (Reporting Requirements for Radiation Exposures)
- 10 CFR 20.1906 (Procedures for Receiving and Opening Packages)
- 10 CFR 71.47 (External Radiation Standards for All Packages)
- 49 CFR 173.428 (Empty Class 7 [Radioactive] Materials Packaging)
- 49 CFR 173.443 (Contamination Control)
- 49 CFR 173.475 (Quality Control Requirements Prior to Each Shipment of Class 7 [Radioactive Materials]).

7.3 Review Procedures

The operating procedures presented in the SARP were reviewed by PCP staff for completeness and compliance with regulatory requirements. The information provided by the applicant was in the format prescribed directly by NRC Regulatory Guide 7.9. The applicable information on operating requirements, general information, package loading, shipment preparation, package receipt, and package unloading was provided in the operating procedures chapter. Package operations will be accomplished by using documented and approved procedures. Supplemental information on inspection and maintenance and on records and reporting requirements has been provided in Chapters 8 and 9, respectively.

7.3.1 Package Loading

7.3.1.1 Preparation for Loading

The steps for preparing to load the package are provided in Sections 7.1.1.1 and 7.1.1.2. The primary activities in these sections are (1) packaging preparation, and (2) content/payload preparation.

7.3.1.2 Loading of Contents

Facility-specific operating procedures for loading radioactive contents into the 30-gallon drum must include, as a minimum, the operational elements listed in Section 7.1.1.2 (Operational Elements 1-9 below). Integration of these procedural elements into facility-specific requirements must incorporate as low as reasonably achievable (ALARA) principles.

In preparation for loading the 30-gallon drum, all of the steps identified in Sections 7.1.1.1 and 7.1.1.2 must have been completed, and all packaging hardware, lifting equipment, and other required apparatus must be staged and ready.

1. Verify that the weight of the payload (i.e., everything to be placed into the 30-gallon drum, excepting drum components) does not exceed 166 kg. (365 lb.) and that when

combined with the packaging (Figure 7.1) does not exceed the authorized gross weight of 650 lb.

2. Place the contents within the 30-gallon drum via lifting equipment, as required. The acceptable payload configuration is described in Section 1.2.2.
3. Verify the aluminum honeycomb spacer is in good condition with no damage to the silicone rubber coating that would prevent safe handling.
4. Install the aluminum honeycomb spacer steel plate inside the 30-gallon drum.
5. Place the insulation bag cover on top of the honeycomb spacer.
6. Close the insulation bag by pulling the draw-string.
7. Install the 30-gallon closure lid and mount the 30-gallon split ring closure device.
8. Torque the split ring closure socket head screws to 40 ± 5 ft-lb. in accordance with the closure requirements listed on Drawing R-R1-G-00094 and Appendix 1.1.
9. If required per facility operations, both sets of lugs of the split ring closure include provision for installation of a wire Tamper Indicating Device (TID) as shown (blue lines) in Figure 7.3.

7.3.1.3 Preparation for Transport

Package closure must be performed in accordance with a written procedure that includes the following elements:

1. Health Protection personnel must survey the outer surfaces of the loaded 30-gallon drum and must provide verification that the contamination limits specified in 10 CFR 835, Appendix D are not exceeded. Health Protection personnel must document the results of the survey. If the surface contamination measurements exceed the allowable limits, Stop Work and implement the appropriate contamination control procedures.
2. If required, attach a drum lifting device to the 30-gallon drum split ring closure device as illustrated in Section 1.2.4.
3. Lift and lower the 30-gallon drum into the 55-gallon drum.
4. Place the insulation cover over the 30-gallon drum closure as shown in Figure 7.1.
5. Install the 55-gallon closure lid and mount the 55-gallon split ring closure device.
6. Torque the split ring closure bolts to 40 ± 5 ft-lb. in accordance with the closure requirements listed on Drawing R-R1-G-00093 and Appendix 1.1.
7. Tighten the jam nut against the unthreaded lug of the split ring closure device in accordance with the closure requirements listed on Drawing R-R1-G-00093 and Appendix 1.1.
8. Install a wire TID through the 0.13 inch diameter holes in each of the two sets of lugs of the 55-gallon split ring closure assembly as shown (blue lines) in Figure 7.4.
9. Health Protection personnel must survey the outer surfaces of the 55-gallon drum for surface contamination per §71.87(i). Health Protection personnel must document the results of the survey.
10. Health Protection personnel must perform and document (record) a radiological survey of the closed 55-gallon drum per §71.87(j); including the following:
 - a. Determine the maximum radiation level at 1 meter from the drum top, side, and bottom surfaces, in mrem/hr. This is defined as the Transport Index, per §71.4.

- b. Record the Transport Index on the Transport Record and on the drum's shipping label.
 - c. If the Transport Index is greater than 10, the package must be transported by exclusive-use shipment.
11. Verify that the gross package weight is 650 lb. or less.
 12. Attach radiation tags and labels to the drum, as specified in 49 CFR 172, Subparts D and E.
 13. Ensure that any special instructions necessary for safe opening of the package, per §71.89, are provided to the consignee prior to shipment of the package.

7.3.2 Package Unloading

Implementation of the following procedures must incorporate ALARA principles. Package receipt must be performed in accordance with written procedures that include the following elements.

7.3.2.1 Receipt of Package from Carrier

The routine steps performed upon receipt of a package from a carrier are listed in Section 7.3.2.1 Steps 1-3. Instructions for reporting package damage discovered by the consignee upon receipt of a shipment is addressed in 7.3.2.1 Step 4.

7.3.2.2 Removal of Contents

Packages may be directly disposed of without removing the contents. Unloading procedures for removal of contents must include the following elements:

1. Document the removal of the TID per the receiving site procedures.
2. Open the 55-gallon drum by loosening the jam nut and loosening or removing the two split ring closure bolts.
3. Remove the split ring closure device and the drum closure lid.
4. Survey the bottom surface of the drum closure lid for contamination.
5. Remove the insulation cover on the 30-gallon drum.
6. Survey the insulation cover and the top surface of the 30-gallon drum closure lid for contamination.
7. Remove the 30-gallon drum using a drum lifting device. A typical lifting device is illustrated in Figure 7.3. **NOTE:** The 30-gallon drum could be pressurized. Using appropriate facility precautions, the 2 inch plug may be backed out to relieve any internal pressure.
8. Open the 30-gallon drum by removing or loosening the two split ring closure bolts and remove its closure lid.
9. Survey the bottom the 30-gallon closure lid surface for contamination.
10. Open the insulation bag and remove the insulation bag cover.
11. Remove the aluminum honeycomb spacer.
12. Survey the bottom of the aluminum honeycomb spacer for contamination.
13. Remove any packing/dunnage and contents from the 30-gallon drum.

14. Compare the package contents and configuration with the shipping papers and the Certificate of Compliance and note any discrepancies. These discrepancies must be reported to the Certifying Authority in accordance with 10 CFR 71.95.
15. Survey the interior surface of the 30-gallon drum for contamination to verify that it does not exceed radioactive contamination limits specified in 10 CFR 835, Appendix D.

7.3.3 Preparation of Empty Package for Transport

After first use, empty packaging meeting the requirements of 49 CFR 173.428, *Empty Class 7 (radioactive) Materials Packaging* may be shipped in accordance with the Section 7.3.3.1 and §173.428. Section 7.3.3.2 addresses the procedural requirements for shipping empty packaging that are too contaminated internally to meet §173.428.

7.3.4 Other Operations

There are no special operational controls or restrictions for shipping the package.

7.3.4.1 Packaging Storage

Store the packaging in a facility that provides protection from:

- the effects of temperature extremes and humidity (to prevent condensation),
- chemical vapors,
- accelerating forces,
- physical damage and airborne contamination (e.g., rain, snow, dust accumulation, dirt, salt spray and fumes).

Drum assemblies are to be stored with the vent-hole plugs in place and the closure lid in place and the split ring closure device installed.

7.3.4.2 Records and Reporting

The Package Loading Record must be prepared in accordance with the requirements of §71.91, maintained in accordance with Section 9.17, and must include as a minimum:

- identification of the packaging by model number and serial number;
 - verification that there are no significant defects in the packaging, as shipped;
 - type and quantity of licensed material in each package and the total quantity of each shipment;
 - date of the shipment;
 - any special controls exercised;
 - name and address of the transferee;
 - address to which the shipment was made; and
-

- results of the determinations required by §71.87 and by the conditions of the package approval.

Records are valid only if stamped, initialed or signed, and dated by authorized personnel or otherwise authenticated.

7.3.5 Appendices

None.

7.4 Evaluation Findings

7.4.1 Findings

Based on review of the statements and representations in the SARP, PCP staff concludes that the package operations described meet the requirements of 10 CFR 71 and are adequate to assure that the package will be operated in a manner consistent with its evaluation for approval.

7.4.2 Conditions of Approval

PCP staff has concluded that no additional operations-related conditions of approval are required in the CoC.

7.5 References

- [7-1] *Safety Analysis Report for Packaging, Model 9981 Type AF Shipping Package, S-SARP-G-00020, Revision 0 (March 2019).*
- [7-2] *Packaging and Transportation of Radioactive Material, Code of Federal Regulations, Title 10, Part 71, Washington, DC (January 2017).*

8. Acceptance Tests and Maintenance Program Review

8.1 Areas of Review

This SER documents PCP staff's review of Chapter 8, *Package Acceptance Tests and Maintenance Program*.^[8-1] Staff review includes an evaluation of the SARP with respect to the requirements specified in 10 CFR 71 Subpart G.^[8-2]

Chapter 8 information is presented in the format specified in the U.S. Nuclear Regulatory Commission Regulatory Guide (RG) 7.9. The acceptance tests and the maintenance program comply with the QA requirements presented in SARP Chapter 9.

Review of the acceptance tests and maintenance program activities described in Chapter 8 includes evaluation of the roles and responsibilities, as applicable, of the Cognizant Technical Function (CTF), the Design Authority, the Owner, and the Purchasing Organization.

The following elements of the *Acceptance Tests and Maintenance Program* chapter were reviewed. Details of the review are provided below in SER Section 8.3.

8.1.1 Acceptance Tests

- Visual Inspections and Measurements
- Weld Examinations
- Structural and Pressure Tests
- Leakage Tests
- Component and Material Tests
- Shielding Tests
- Thermal Tests
- Miscellaneous Tests

8.1.2 Maintenance Program

- Structural and Pressure Tests
- Leakage Tests
- Component and Material Tests
- Thermal Tests
- Miscellaneous Tests

8.1.3 Appendices

8.2 Regulatory Requirements

The requirements of 10 CFR 71 applicable to the acceptance tests and maintenance program review of the packaging are as follows:

8.2.1 Acceptance Tests

- The applicant must identify the location, on the outermost receptacle (i.e., on the outside of the package), where the package has been plainly marked with a trefoil radiation symbol that is resistant to the effects of fire and water. [49 CFR 172.310(d)]
- The application must identify the established codes and standards used for the package design, fabrication, assembly, testing, maintenance, and use. In the absence of such codes, the application must describe the basis and rationale used to formulate the quality assurance program. [§71.31(c)]
- The applicant must describe the quality assurance program for the design, fabrication, assembly, testing, and use of the proposed package. [§71.37(a)]
- The applicant must identify any specific provisions of the quality assurance program that are applicable to the particular package design under consideration, including a description of the leak testing procedures. [§71.37(b)]
- Before first use, each packaging must be inspected for cracks, pinholes, uncontrolled voids, or other defects that could significantly reduce its effectiveness. [§71.85(a)]
- Before first use, if the maximum normal operating pressure of a package exceeds 35 kPa (5 psi) gauge, the containment system of each packaging must be tested at an internal pressure at least 50% higher than maximum normal operating pressure to verify its ability to maintain structural integrity at that pressure. [§71.85(b)]
- Before first use, each packaging must be conspicuously and durably marked with its model number, serial number, gross weight, and a package identification number. [§71.85(c)]
- Before first use, the fabrication of each packaging must be verified to be in accordance with the approved design (see details/notes in SARP drawings). [§71.85(c)]
- The applicant must perform any tests deemed appropriate by the certifying authority. [§71.93(b)]

8.2.2 Maintenance Program

- The applicant must identify the established codes and standards used for the package design, fabrication, assembly, testing, maintenance, and use. In the absence of such codes, the applicant must describe the basis and rationale used to formulate the quality assurance program. [§71.31(c)]
- The applicant must describe the quality assurance program for the testing, maintenance, repair, modification, and use of the proposed package. [§71.37(a)]

- The packaging must be maintained in unimpaired physical condition except for superficial defects such as marks or dents. [§71.87(b)]
- The presence of any moderator or neutron absorber, if required, in a fissile material package must be verified prior to each shipment. [§71.87(g)]
- The applicant must perform any tests deemed appropriate by the certifying authority. [§71.93(b)]
- Each type B(U) or Type B(M) package design must have on the outside of the outermost receptacle a fire resistance radiation symbol in accordance with 49 CFR 172.310(d).

8.3 Review Procedures

The packaging acceptance tests and maintenance program are acceptable if it can be shown that they are in compliance with the appropriate requirements set forth above.

8.3.1 Acceptance Tests

To ensure compliance with Subpart G of 10 CFR 71, prior to the first use of each packaging, the Purchasing organization must verify conformance of all design, fabrication, and quality assurance requirements summarized in Chapters 8, 9, and Drawings in Appendix 1.1. The required tests and inspections must be specified in the procurement documents for the packaging and are typically performed by the Supplier.

The Design Agency (DA) for the DOE Certificate Holder of the package is the SRNL's Packaging Transportation & Pressurized Systems Organization. The DA must verify that fabrication, testing, and inspections of packaging is acceptable prior to first use and in accordance with the current revisions of the SARP and DOE CoC. The DA must also verify, through review and approval, that the procurement QA documents are properly dispositioned (including nonconformance records) and controlled, and are retrievable by packaging serial number. The Acceptance Tests in Section 8.1 provide the packaging owner verification that the Supplier has fabricated the packaging in accordance with the SARP and CoC and that the fabrication meets the acceptance criteria of the Codes and Standards referenced in the SARP drawings.

If packaging is procured by an entity other than SRNL, the DA must review and approve acceptance test documentation prior to first use of the packaging.

All personnel performing acceptance tests and inspections must be certified/qualified in accordance with requirements described in the applicable sections of the ASME B&PV Code, the AWS structural welding codes or AWS recommended practices, or American Society For Nondestructive Testing ® (ASNT), *Recommended Practice No. SNT-TC-1A*.^[8-3]

8.3.1.1 Visual Inspections and Measurement

Throughout the fabrication process, visual inspections, tests, and measurements are performed by the Supplier to verify compliance with all packaging design requirements. The required inspections, tests, and measurements are detailed in Drawings (Appendix 1.1), Section 8.1 and

Appendix 8.1, *Acceptance Tests for Dow BETAFOAM 87100/87124 in the 9981 Packaging*, in accordance with applicable QA requirements in Chapter 9.

8.3.1.2 Weld Examinations

All weld examinations must be performed by qualified inspectors. A welding inspector must be certified to examine specific welds in accordance with the Supplier's written practice. Inspection methods, weld procedures, personnel qualifications, and weld examination reports must be in accordance with requirements of the ASME B&PVC, applicable Sections III,^[8-4] and V,^[8-5] and/or VIII.^[8-6] and/or SRNL Welding Data Sheets (Chapter 2 References 38-42, as applicable). Welding examinations include verification of weld location, type, and size and include nondestructive examination as specified on the Drawings (Appendix 1.1).

Inspector qualification must be in accordance to the employer's written practice and as required in the AWS D1.1 Structural Welding Code – Steel [2015], Clause 6, Section 6.1.4. Visual weld inspections must meet acceptance criteria, as applicable, of the following codes/specifications:

- AWS D1.1:2015, Structural Welding Code – Steel, Clause 7, Section 7.4, Paragraph 7.4.7, Acceptance Criteria^[8-7]
- AWS D1.3:2018, Structural Welding Code – Sheet Steel, Clause 8, Part A, Section 8.1, Production Weld Acceptance Criteria^[8-8]
- AWS C1.4:2017, Specification for Resistance Welding of Carbon and Low-Alloy Steels, Clause 7, Section 7.2, paragraph 7.2.1, Visual Examination.^[8-9]

Materials, workmanship, welding procedure specification, welder performance qualification, weld acceptance criteria, and weld documentation must meet the requirements of the following codes/specifications:

- AWS D1.1:2015, Structural Welding Code – Steel, Clause 7.
- AWS D1.3:2018, Structural Welding Code -Sheet Metal.
- AWS C1.4:2017, Specification for Resistance Welding of Carbon and Low-Alloy Steels, Clause 7, Section 7.2, paragraph 7.2.1, Visual Examination.

Personnel performing nondestructive examination (NDE) must, at a minimum, be certified to Level II in the NDE methods used, to the requirements of ASNT SNT-TC-1A.

8.3.1.3 Structural and Pressure Tests

Structural and pressure tests are conducted by the drum fabricator in accordance with commercial standards for the specified drums; unique requirements are specified in the SARP Drawings and in the paragraphs below.

8.3.1.3.1 Pressure Tests

The drum fabricator performs hydrostatic pressure tests per 49 CFR 178.605 for the 30-gallon drum. The drum fabricator tests a minimum of three samples from each drum lot at 150 kPa (22.5 psig) for five minutes. Closure-lid vents are sealed during the tests. Acceptance is conditional on no visible water leakage from the drum.

Typically, the hydrostatic pressure test is only specified for packaging design types intended to contain liquids; liquids contents are prohibited in this package. The hydrostatic test requirement ensures additional integrity and robustness of the 30-gallon drum.

8.3.1.3.2 Structural Tests

The 30-gallon and 55-gallon drums requires structural batch lot testing as Packing Group I (PG I) for solids and Packing Group II for liquids per §§ 173.465(b), (c), (d) and (e), 173.401(f) and 173.24(a)(5).

8.3.1.4 Leakage Tests

The 30- and 55-gallon drums and the 55-gallon drum liner are subjected to a leakproofness test in accordance 49 CFR 178.604 and 49 CFR 178 Appendix B, Method 3. This test requires the items to be pressurized with a gas medium to at least 30 kPa (4 psig) and show no leakage of air from the seams or bottom chime using a bubble test.

8.3.1.5 Component and Material Tests

The packaging design incorporates a pressure-relieving device within the 30-gallon closure lid. The device is designed to release pressure between 12-15 psig and to reseal by 3 psig. The manufacturer must verify by test the minimum following critical characteristics for the device: relieving and resealing pressure. The test frequency must be in accordance with sampling as specified by ANSI/ASQ Z1.4-2008, *Sampling Procedures and Tables for Inspection by Attributes* for an Acceptance Quality Limit (AQL) not greater than 2.5, as defined in Table II-A and Table II-B for single sampling plans; reduced inspection not permitted.^[8-3]

The packaging incorporates a Dow Chemical rigid polyurethane foam as an energy impact absorber and thermal barrier. The material tests in Appendix 8.1 must be performed and documented on each batch of foam used in the construction of the packaging.

8.3.1.6 Shielding Tests

Not applicable: The packaging design does not include any shielding features.

8.3.1.7 Thermal Tests

Not applicable: The packaging design does not incorporate active heat transfer features. Passive heat transfer mechanisms are not significantly sensitive to normal variations in the materials of construction or fabrication methods.

8.3.1.8 Miscellaneous Tests

None.

8.3.2 Maintenance Program

The packaging design does not include components that require annual maintenance. The routine inspection steps in Chapter 7, for compliance §71.87, are performed prior to shipment of the package and are sufficient to ensure performance of the packaging has not been degraded.

Non-conforming packaging components may be repaired, refurbished, or replaced using procedures prepared and approved by the DA in accordance with the Section 9.15. All such repairs must be documented in accordance with the requirements of Section 9.6.

Records for packaging components repaired, refurbished, or replaced, must be retrievable by the packaging serial number.

8.3.2.1 Structural and Pressure Tests

Not applicable: the packaging design does not require periodic structural or pressure tests.

8.3.2.2 Leakage Tests

Not applicable: the packaging design does not require leakage tests. Non-conforming drum gaskets are replaced based on defects discovered during the routine visual inspections (Section 7.1.1) prior to each use of the packaging for shipment.

8.3.2.3 Component and Material Tests

Not applicable: The packaging design does not include materials or components that require routine annual maintenance.

8.3.2.4 Thermal Tests

Not applicable: The packaging design does not require annual thermal performance testing.

8.3.2.5 Miscellaneous Tests

None.

8.3.3 Appendices

Chapter 8 includes Appendix 8.1, *Acceptance Tests for Dow BETAFOAM 87100/87124 in the Model 9981 Type AF Packaging*.

8.4 Evaluation Findings

8.4.1 Findings

Based on review of the statements and representations in the SARP, PCP staff concludes that the acceptance tests for the packaging meet the requirements of 10 CFR 71, and that the maintenance program is adequate to assure packaging performance during its service life.

8.4.2 Conditions of Approval

PCP staff has concluded that no additional acceptance tests and maintenance-related conditions of approval are required in the CoC.

8.5 References

- [8-1] *Safety Analysis Report for Packaging*, Model 9981 Type AF Shipping Package, S-SARP-G-00020, Revision 0 (March 2019).
- [8-2] *Packaging and Transportation of Radioactive Material, Code of Federal Regulations*, Title 10, Part 71, Washington, DC (January 2017).
- [8-3] *Recommended Practice No. SNT-TC-1A - Non-Destructive Testing*, ASNT-SNT-TC-1A-2001, American Society for Nondestructive Testing (January 2001).
- [8-4] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (B&PVC), Section III, Subsection NF, *Component Supports*, American Society of Mechanical Engineers, New York, NY (2007).
- [8-5] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (B&PVC), Section V, *Nondestructive Examination*, American Society of Mechanical Engineers, New York, NY (2007).
- [8-6] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (B&PVC), Section VIII, Division 1, *Rules for Construction of Pressure Vessels*, American Society of Mechanical Engineers, New York, NY (2007).
- [8-7] *Structural Welding Code – Steel*, American Welding Society, D1.1:2015, Clause 7, Section 7.4, Paragraph 7.4.7 (2015)
- [8-8] *Structural Welding Code – Steel*, American Welding Society, AWS D1.3:2018, Clause 8, Part A, Section 8.1, Production Weld Acceptance Criteria (2018)
- [8-9] *Specification for the Resistance Welding of Carbon and Low-Alloy Steels*, American Welding Society, C1.4 (2017)

9. Quality Assurance Review

9.1 Areas of Review

This section of the SER documents PCP staff's review of Chapter 9, *Quality Assurance*.^[9-1] Staff review includes an evaluation of the SARP with respect to the requirements specified in 10 CFR 71.^[9-2]

The following elements of the *Quality Assurance* (QA) chapter were reviewed. Details of the review are provided below in SER Section 9.3.

9.1.1 Description of Applicant's QA Program

- Scope
- Program Documentation and Approval
- Summary of 18 Quality Criteria
- Cross-Referencing Matrix

9.1.2 Package-Specific QA Requirements

- Graded Approach for Structures, Systems, and Components Important to Safety
- Package-Specific Quality Criteria and Package Activities

9.1.3 Appendices

9.2 Regulatory Requirements

The requirements of 10 CFR 71 applicable to the QA review of the package are as follows:

- The application must describe the quality assurance program for the design, fabrication, assembly, testing, maintenance, repair, modification, and use of the package. [§71.31(a)(3), §71.37]
- The application must identify established codes and standards proposed for the package design, fabrication, assembly, testing, maintenance, and use. In the absence of any codes and standards, the application must describe the basis and rationale used to formulate the package quality assurance program. [§71.31(c)]
- Package activities must comply with the quality assurance requirements of Subpart H (§71.101–§71.137). A graded approach is acceptable. [§71.101(b)]
- Sufficient written records must be maintained to furnish evidence of the quality of the packaging. These records include results of the determinations required by §71.85: design, fabrication, and assembly records; results of reviews, inspections, tests, and audits; results of maintenance, modification, and repair activities; and other information identified in §71.91(d). Records must be retained for three years after the life of the packaging. [§71.91(b)]

- Records identified in §71.91(a) must be retained for three years after shipment of radioactive material. [§71.91(a)]
- Records must be available for inspection. Records are valid only if stamped, initialed, or signed and dated by authorized personnel or otherwise authenticated. [§71.91(c)]
- Any significant reduction in the effectiveness of a packaging during use must be reported to the certifying authority. [§71.95(a)(1)]
- Details of any defects with safety significance in a package after first use, with the means employed to repair the defects and prevent their reoccurrence, must be reported. [§71.95(a)(2), §71.95(c)(4)]
- Instances in which a shipment does not comply with the conditions of approval in the CoC must be reported to the certifying authority. [§71.95(a)(3)]

9.3 Review Procedures

This section details PCP staff's the review of the elements listed in SER Section 9.1.

9.3.1 Description of Applicant's QA Program

9.3.1.1 Scope

The Purpose and Scope of Chapter 9 were reviewed to confirm that Chapter 9 explicitly states that the applicant's QA Program complies with 10 CFR 71, Subpart H, and is applied to package-related activities, including procurement activities consistent with the applicable regulatory requirements.

Section 9.1 and Figure 9.1 describe and illustrate the applicant's QA organization, including the QA groups and their responsibilities relative to management and the implementation of the QA Program. The applicant documents that they purchase package fabrication services from suppliers that have been evaluated and approved to meet the applicable requirements of 10 CFR 71, Subpart H.

9.3.1.2 Program Documentation and Approval

The Savannah River Site (SRS) Management and Operator is currently Savannah River Nuclear Solutions (SRNS). The SRNS QA functional organization is described in Section 9.1 and illustrated in Figure 9.1. Section 9.2.1 describes the qualification requirements for personnel that perform QA functions, such as inspections, tests, and examinations.

Section 9.2.1 states that

The SRNS Management and Operations (M&O) Quality Assurance Program Document (QAPD) is the governing document for the SRNS Packaging and Transportation Program. The SRNS Quality Assurance Manual describes the procedures to be followed in implementing the QAPD. The SRNS Quality Assurance Manual QA Program complies with DOE Order 460.1C and 10 CFR 830, Subpart A. The QA program contains supplemental controls that maintain compliance with Subpart H of 10 CFR 71 and with NQA-1. The interrelationship among the SRNS QA Program documents, including implementing procedures, is depicted in Figure 9.2.

Quality assurance activities for the packaging or package operate within the scope of the SRNS *Management and Operations (M&O) Quality Assurance Program document (QAPD)*^[9-3] and *Quality Assurance Manual, 1Q*.^[9-4] These documents are implemented through procedures that describe specific QA requirements.

As required by §71.31(a)(3) and §71.37, Sections 9.1.1 and 9.2 identify that the SRNS QAP complies with 10 CFR 71, Subpart H. SRNS purchases fabrication services from suppliers that have been evaluated and approved to meet the applicable requirements of 10 CFR 71, Subpart H. SRNS uses ASME NQA-1a-2009 as a quality management standard for meeting the requirements of 10 CFR 71, Subpart H.

Additional information on the hierarchy and relationship of requirements documents and the relevant SRNS QA program description documents is provided in Figure 9.2 and the Section 9.20, *References*.

9.3.1.3 Summary of 18 Quality Criteria

Table 9.1 lists and summarizes the SRNS QA Manual 1Q (also referred to as the 1Q Manual) sections that implement the 18 quality assurance requirements of 10 CFR 71 of Subpart H. Sections 9.1 through 9.18 describe how the applicant meets the 18 QA requirements of 10 CFR 71, Subpart H.

9.3.1.4 Cross-Referencing Matrix

Table 9.1 provides a cross-referencing matrix that links the SRNS QA Manual 1Q sections (i.e., implementing procedures) to the corresponding QA requirements in 10 CFR 71, Subpart H.

9.3.2 Package Specific QA Requirements

9.3.2.1 Graded Approach for Structures, Systems, and Components Important to Safety

Section 9.2.3 was reviewed to verify it describes the graded application of the SRNS Quality Assurance Program (QAP) to the packaging structures, systems, and components (SSCs), including software that are important to safety consistent with the requirements in §§71.81 and 71.101(b), and the guidance in NRC RG 7.10.^[9-5] Safety-related “Q” package components are categorized as Levels A, B, or C, with Level A items having the largest impact on safety (see Table 9.3, i.e., the “Q” list). The packaging SSCs and their QA levels are provided in Table 9.3. Table 9.2 correlates the SRNS QA Levels Safety Class, Safety Significant, Production Support, and General Services safety designations to the corresponding Q categories in NRC RG 7.10, and an additional category of “Non-Q.” Table 9.4, QA Element 3 summarizes the software quality assurance (SQA) requirements for Q categories A, B, and C package design activities. Section 9.3.2 states that all software is to be assessed for and receive the appropriate amount of QA per the graded approach described in Section 20.0 of SRNS 1Q Manual, which defines the QA requirements for software design, testing, validation, operation, maintenance, configuration control, and procurement.

Commercial grade hardware can be dedicated (i.e., qualified) for safety-related applications in accordance with the controls described in Section 9.7 and in SRNS 1Q Manual, Section 7.3.

9.3.2.2 Package-Specific Quality Criteria and Package Activities

Chapter 9 was reviewed to verify it adequately described the QA controls and their application consistent with the requirements in §71.31(a)(3) and §71.37. Chapter 9 describes how the QA controls in each section of the SRNS 1Q Manual (Table 9.1) are applied by SRNS to the design, procurement, fabrication, handling, shipping, storage, cleaning, assembly, welding, operation, inspection, testing, maintenance, repair, modification, and use of the package. Chapter 9 also includes SRNS's provisions for implementing additional QA requirements of 10 CFR 71 that are listed in Section 9.2 above.

The graded approach described in Section 9.3.2.1 above is used by SRNS to selectively apply the QA controls to package SSCs and software based on their importance to safety, as shown in Tables 9.3 and 9.4. Table 9.1 describes the applicable QA Manual 1Q sections and procedures that will be used by SRNS to implement the QA requirements of Subpart H.

Section 9.3 describes the graded design controls for software and hardware. Design modifications to the package will be submitted by the Design Agency. The Headquarters Certifying Official approves design changes that affect the requirements of the CoC.

Sections 9.4 and 9.7 collectively identify the graded controls for procurement documents and purchased materials and services including: package design, SARP preparation, and packaging fabrication. These provisions ensure that procured items and services affecting quality of the package to meet the appropriate design basis, and the technical and quality assurance requirements. Procurement documents and changes must be reviewed and approved prior to issue.

Section 9.6 identifies documents that are controlled to ensure that the correct documents, including instructions, procedures, and drawings (described in Section 9.5), are used, and that records control requirements (Section 9.17) are met. Controlled documents include operating procedures (Chapter 7), procurement documents (Section 9.4), and inspection, testing, and maintenance procedures (Chapter 8, and Sections 9.10 and 9.11).

Section 9.8 provides requirements for items that require identification (e.g., serial numbers) and protection to ensure these items are correct for their intended use, and to provide traceability. Packaging-related nonconforming items are segregated and labeled to prevent their inadvertent use until they have been appropriately dispositioned.

Section 9.9 describes the SRNS controls for special processes, such as welding, foaming, and nondestructive examination of the package during fabrication, use, and maintenance. SRNS 1Q Manual, Section 9.0, establishes the requirements for qualifying special process procedures, equipment, and personnel in accordance with applicable codes, standards, and specifications. Also cited are SRNL data sheets and qualification summaries (i.e., SRNL-L4410-2011-00025 for resistance welded ASTM A1008 samples). The above are to be included in manufacturing and inspection plans (MIPs) and the Statements of Work for suppliers.

Sections 9.10 and 9.11 establish requirements for inspection and test status, respectively. The control of measuring and test equipment (M&TE) is described in Section 9.12. Section 9.12 includes controls for calibration of M&TE, and for M&TE found to be out of calibration.

Sections 9.13 contains requirements for handling, storage, and shipping in accordance with §71.127.

Section 9.14 contains requirements for inspection, test, and operating status in accordance with §71.129.

Sections 9.15 and 9.16 collectively describe the controls for documenting, resolving, and preventing the recurrence of package-related non-conformances identified by package users or suppliers. Section 9.15 includes provisions for obtaining Design Agency and Design Authority approval of nonconformance dispositions, and reporting package defects that significantly reduce the safety performance of the package or depart from the requirements of the Certificate of Compliance (CoC), to the Headquarters Certifying Official in accordance with §71.95.

Section 9.17 summarizes the provisions for ensuring sufficient written records are maintained to furnish evidence of the quality of the package. The records and their retention requirements, identified in Section 9.17 and Table 9.5, are consistent with §71.91.

Section 9.18 describes the SRNS system for QA audits that is also described in Section 18.0 of the SRNS IQ Manual.

Table 9-5 summarizes the QA Record summary used in the design, fabrication, assembly, testing, maintenance, and use of the package, as required by §71.31(c). Codes and standards used for the package design are also described in other sections of the SARP.

Section 9.20 is the list of references.

9.19 Appendices

Appendix 9.1 *Commercial Grade Dedication Process for 9981 Packages*

9.4 Evaluation Findings

9.4.1 Findings

Based on the review of the statements and representations in the SARP, PCP staff concludes that the applicant's QA program has been adequately described and meets the requirements of 10 CFR 71 Subpart H. The applicant's QA program is adequate to assure that the package is designed, fabricated, assembled, tested, used, maintained, modified, and repaired in a manner consistent with its evaluation.

9.4.2 Conditions of Approval

PCP staff has concluded that no additional quality assurance-related conditions of approval are required in the CoC.

9.5 References

- [9-1] *Safety Analysis Report for Packaging, Model 9981 Type AF Shipping Package, S-SARP-G-00020, Revision 0 (March 2019).*
- [9-2] *Packaging and Transportation of Radioactive Material, Code of Federal Regulations, Title 10, Part 71, Washington, DC (January 2017).*
- [9-3] *Management and Operations (M&O) Quality Assurance Program Document (QAPD), SRNS-RP-2014-00880, Rev. 1, Savannah River Nuclear Solutions.*
- [9-4] *Quality Assurance Manual, Manual 1Q, Savannah River Nuclear Solutions, Aiken, S.C.*
- [9-5] *Establishing Quality Assurance Programs for Packaging Used in the Transport of Radioactive Material, Regulatory Guide 7.10, Rev. 2, U.S. Nuclear Regulatory Commission, Washing, DC (March 2005).*