# Safety Evaluation Report for the Justification for Dual-3013 Contents, Addendum 7 to Safety Analysis Report for Packaging Model 9977

Docket Number: 11-41-9977

Prepared by: ______________________ Date: 7/30/12
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## SUMMARY

The National Nuclear Security Administration (NNSA), Nuclear Operations Division (NA-172), submitted an application by letter[1] dated June 7, 2011, to the U.S. Department of Energy (DOE) Packaging Certification Program (PCP), Office of Packaging and Transportation, requesting that the DOE issue a Certificate of Compliance (CoC) for the Model 9977 package with Dual-3013 containers as contents. Along with the application request, Addendum 7 to Revision 2 of the 9977 Safety Analysis Report for Packaging (SARP),[2] identified as S-SARA-G-00012, Revision 0, dated May 31, 2011, was submitted with the intent to provide the necessary documentation that the design of the 9977 package with Dual-3013 containers (a) satisfies the relevant Department of Transportation (DOT) and Nuclear Regulatory Commission (NRC) regulatory safety requirements as specified in Title 49 of the Code of Federal Regulations (CFR) Part 173 and 10 CFR Part 71, respectively; (b) satisfies the relevant DOT modal requirements for rail and road transport as specified in Title 49 CFR Parts 174 and 177, respectively; and (c) was prepared in accordance with DOE Order 460.1C and in the format specified in NRC Regulatory Guides 7.9 and 7.10.

DOE PCP staff reviewed Revisions 1 and 2 of Addendum 7[3,4] to the 9977 SARP and generated eighteen (18) Q1 questions on the nine (9) Chapters in Addendum 7. The applicant responded to all the questions and provided revisions to Addendum 7, which were accepted and incorporated in Revision 3 of Addendum 7[5]. DOE PCP staff also conducted independent confirmatory evaluations of Addendum 7.

On the basis of the statements and representations in Revision 3 of Addendum 7 and Revision 2 of the 9977 SARP and DOE PCP staff's confirmatory evaluation, as summarized in this Safety Evaluation Report (SER), DOE PCP finds that the design and performance of the 9977 package are acceptable for the transport of Dual-3013 containers and will provide reasonable assurance that the regulatory requirements of 49 CFR Part 173, 10 CFR Part 71, and DOE Order 460.1C have been met.

DOE PCP has concluded that thirteen (13) conditions of approval will be added to Revision 12 of the CoC pursuant to the approval of the application request, as follows:

(1) The contents shall have a maximum decay heat generation rate of:
- 19 Watts for all contents/configurations; unless otherwise restricted below,
- 19 Watts per 3013 Container and 38 watts total per Package in the Dual 3013 configuration,
- 15 Watts for a package identified with a greater than 1-year periodic maintenance,
- 6 Watts in the SGQ-SC1 configuration,
- 3 Watts in the SGQ-SC2 configuration, and
- 3.5 Watts in Training Sources Engineered Container configuration.

(2) The maximum weight of the payload (everything that goes into the 6CV, including radioactive contents, convenience cans, contamination control devices, packing materials, spacers, etc.) is not to exceed 100 lb except for the Dual 3013 configuration where the maximum weight of the payload shall not exceed 77.7 lbs. The maximum allowable gross shipping weight of the 9977 package is 350 lb.

(3) The Model 9977 Package must be shipped in a closed conveyance.

(4) Transport of fissile material by air is not authorized. In addition, for Dual 3013 configuration shipments shipment by water is not authorized.

(5) In addition to the requirements of Subparts G and H of 10 CFR Part 71, and except as specified in section 5(d) of this certificate, each package must be fabricated, acceptance tested, operated, and maintained in accordance with the Operating Procedures requirements of Chapter 7, Acceptance Tests and Maintenance Program requirements of Chapter 8, and packaging-specific Quality Assurance requirements of Chapter 9 of the SARP [See 5.(e)(1)] as supplemented by the Addendums [See 5.(e)(2), 5.(e)(4), 5.(e)(7), 5.(e)(11), 5.(e)(12), and 5(e)(13)] and the Applications [See 5.(e)(3), 5.(e)(8), and 5.(e)(9)].

(6) For the AGR-1 fuel compacts, the requirements specified in Section 1.2.2.2.2, and in Table A.1.2, of the Addendum [5(e)(4)], must be followed, along with the specific procedures outlined in Steps 1, 2, 6, 8, and 12 of Section 7.1.1.2 of the Addendum [5(e)(4)]. The documentation packages for the quality category (Q) items, numbered as 17–20, in Table A.App.8.2.1 of the Addendum [5(e)(4)], Dimensions/Materials Requiring Independent Verification Records, must be supplied by the Site directing fabrication to Savannah River National Laboratory as the Design Authority/Design Agency.

(7) If the option is chosen to attach a DOE ARG-US Radiofrequency Identification (RFID) tag to the 9977 packaging, the operating procedures must follow the additional steps per Chapter 7 in Addendum [See 5(e)(5)], and the guide to RFID monitoring system [See 5(e)(6)]. The RFID guide contains a copy of the Material/Product Safety Data Sheet for the batteries used in the DOE ARG-US RFID tag, which provides guidance on the safe use of the batteries.

(8) For the Type 4 (Sources) contents, the requirements specified in Section 1.2.2.2.1, and in Table A.1.2, of the Addendum [5(e)(4)], must be followed, along with the specific procedures of Section 7.1.1.2 of the Addendum [5(e)(4)]. The documentation packages for the Q items, numbered as 17–30, in Table A.App.8.2.1 of the Addendum [5(e)(4)], Dimensions/Materials Requiring Independent Verification Records must be supplied by the Site directing fabrication to Savannah River National Laboratory as the Design Authority/Design Agency.

(9) Verification of the pre-shipment containment integrity of the containment system, on both the O-ring seal and the Leak Test Port Plug, shall be accomplished using either the pressure rise method or the pressure drop method of testing as specified in ANSI N14.5-1997.

(10) The following conditions apply to the installation of a DOE ARG-US RFID tag on a 9977 packaging to allow for the extension of the maintenance interval:

(a) The maximum allowable radioactive decay heat rate for the 9977 package is 19 watts, except for extension of the packaging periodic maintenance interval, in which case the maximum allowable radioactive decay heat rate is limited to 15 watts.

(b) The user shall verify the installation of proper O-rings (i.e., GLT vs. GLT-S) and record the date of installation, e.g., 9977/GLT (or GLT-S)/xx/xx/201x, in the memory of the ARG-US RFID tag.

(c) During both use (loading, shipment, and unloading) and storage (loaded and empty) of the 9977 packaging, the containment vessel (CV) must remain sealed over the entire approved extended maintenance interval. In the event that operations require the CV to be opened, then the old O rings shall be replaced with new O-rings, all the requirements for the extended maintenance interval described in the SARP Addendum 4 shall be complied with for the new O-rings, and the sealing time shall be re-initialized to zero.

(d) The extension of the packaging periodic maintenance interval is to a maximum of five (5) years for the 9977 packaging using the Viton GLT O-rings; and to a maximum of two (2) years for the 9977 packaging using the Viton GLT-S O-rings as shown in Drawing R-R2-G-00042, Item 8. If the ongoing O-ring fixture long-term leak performance testing shows any GLT and GLT-S O-ring failures at 200°F, notify the Headquarters Certifying Official within 72 hours.

(e) The user of this CoC for extension of packaging periodic maintenance interval shall complete the prescribed training to become qualified and to be certified for operation of the RFID temperature monitoring system. The training course will be administered by Argonne National Laboratory on behalf of the Headquarters Certifying Official.

(f) When a temperature-sensing DOE ARG-US RFID tag is attached to a 9977 packaging, it shall be verified to be functional in accordance with the Operating Procedures requirements of Addendum 4 [See 5(e)(12)]. If a failure of the RFID tag or the temperature recording system results in a loss of temperature data for a duration ≥72 hours, then the packaging shall have a Nonconformance Report issued against it and be tagged and segregated until the disposition of the Nonconformance Report has been approved by both the 9977 Design Authority and Headquarters Certifying Official.

(11) The following conditions apply for Dual 3013 shipments in the 9977 packaging:

(a) The 3013 Container (consisting of the outer can, the inner can, and the convenience can) shall be inerted with helium or nitrogen such that oxygen content in all void spaces is no greater than 5% by volume at the time the outer 3013 Container is sealed (welded close).

(b) In addition to the radioactive material and impurity mass loading limits per 3013 container assembly (Table 7), the $PuO_2$ in the 9977 package shall be limited to a total of 10kg (22.05 lb) and the maximum amount of fissile material allowed in the package shall be 8.8 kg (19.4 lb).

(c) The Heat Dissipation Sleeve and the annular 3013 Spacer must be used for the 9977 package with Dual-3013 containers. Verify that the Heat Dissipation Sleeve and the annular 3013 Spacer have been properly installed.

(d) The bulk density of the $PuO_2$ shall be $>2 g/cm^3$ and $< 7 g/cm^3$.

(e) Seal time must be 12 months or less, where seal time is defined as the length of time that the shipment must be complete after the 9977 CV is sealed.

(f) The void space within the CV shall be backfilled with ≥ 75% by volume carbon dioxide gas prior to shipment.

(g) If the measured Transport Index is greater than 10, the package must be transported by "Exclusive Use" shipment, and/or additional; 3013 container mass loading restrictions or impurity control measures may be used to reduce the dose rates.

(12) The ARG-US RFID may be used as a Tamper-Indicating Device Seal [See 5(e)(14)].

(13) Previous revisions of this DOE Certificate of Compliance maybe used until July 31, 2013.

References


1. Letter from Paul T. Mann, Defense Programs Packaging Manager of Nuclear Operations Division (NA-172) of National Nuclear Security Administration, to Jim Shuler, Manager of Packaging Certification Program, Office of Packaging and Transportation of Department of Energy, "*Application for Contents Amendment 7, Revision 0 for Model 9977 Packaging,*" June 7, 2011.

2. Safety Analysis Report for Packaging Model 9977 B(M)F-96, S-SARP-G-00001, Revision 2, August 2007.

3. *Justification for Dual-3013 Contents*, Addendum 7 to Safety Analysis Report for Packaging Model 9977, S-SARA-G-00012, Revision 1, March 14, 2012 (updated shielding analysis).

4. *Justification for Dual-3013 Contents*, Addendum 7 to Safety Analysis Report for Packaging Model 9977, S-SARA-G-00012, Revision 2, July 02, 2012.

5. *Justification for Dual-3013 Contents*, Addendum 7 to Safety Analysis Report for Packaging Model 9977, S-SARA-G-00012, Revision 3, July 11, 2012.

6. DOE Standard, *Stabilization, Packaging, and Storage of Plutonium-bearing Materials*, DOE-3013-STD-2012, March 2012.

7. *Safety Analysis Report for Packaging Model 9977, Addendum 7, Justification for Dual 3013 Contents*, S-SARA-G-00012, Revision 3, July 2012.

8. *DOE Packaging Certification Program Qualification/Accreditation of ARG-US Tag as a TID Seal*, July 30, 2012.

# 1. GENERAL INFORMATION AND DRAWINGS

## 1.1 Packaging Description

Figure 1.1 is a schematic of the 9977 packaging as described in Revision 2 of the 9977 SARP and the previously certified addenda. The packaging consists of a cylindrical container that is ≈36.1 inches in overall height, including the lid, and ≈18.35 inches in overall diameter. It is composed of a drum assembly and a containment vessel (CV). The main functions of the packaging are to provide containment, shielding, and nuclear criticality safety. Table 2.6 of the Revision 2 SARP provides material specifications for the packaging components.

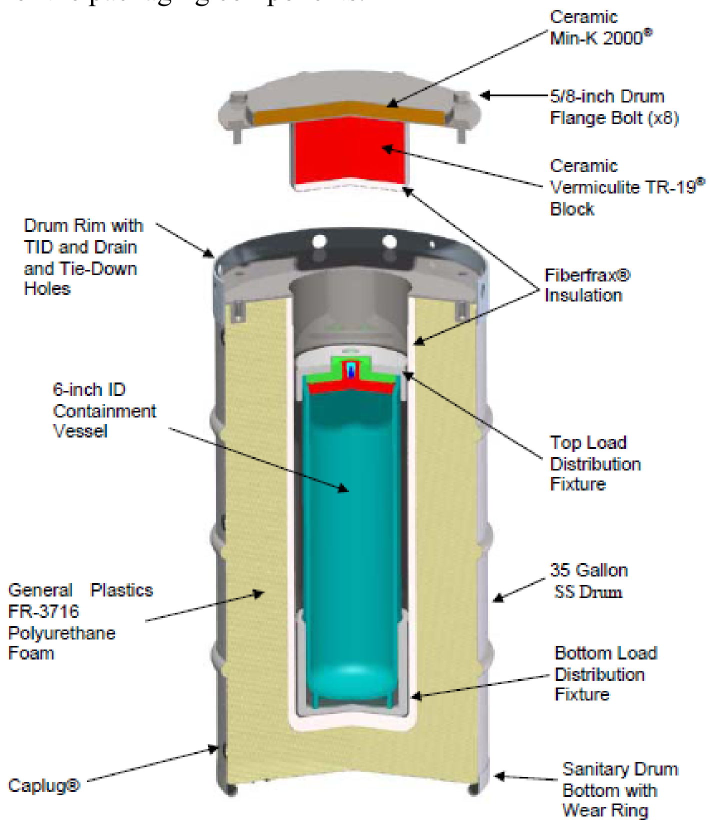



**Figure 1.1 – Three-dimensional Cutaway Illustration of the 9977 Packaging**

An aluminum Heat Dissipation Sleeve (HDS), shown in Figure 1.2, outside the CV has been added to enhance heat transfer from the package because of the increased decay heat load of the Dual-3013 contents. In addition, the CV is fitted with an aluminum 3013 Spacer to fill the space between 3013 container assemblies and the inner wall of the CV, as illustrated in Figure 1.3.

Drum Assembly

The drum design meets the performance requirements of 49 CFR 178 for an open-head drum, but is modified with a bolted-flange closure. The closure does not incorporate a gasket. The drum body is a closed unit consisting of a shell, top deck plate, reinforcing rim (vertical flange) and a liner assembly, with the volume between the liner assembly and drum shell filled with shock-absorbing and thermal insulating materials. The drum shell and liner are fabricated of 18-gauge (0.048-in.) Type 304L stainless steel (SS). Four (4) ¾-inch-diam vent holes are drilled at locations around the drum, approximately 90°

apart and at each of three elevations, for a total of 12 vent holes along the drum sidewall.  Five additional holes, two (2) 1-inch diameter fill holes and three (3) ¾-inch-diam vent holes, are located on the drum bottom.  All of the holes are covered with appropriately sized Caplug® fusible plastic plugs under Normal Conditions of Transport (NCT).  During a Hypothetical Accident Conditions (HAC) fire event, the plugs combust or melt, allowing the drum to vent gases generated by intumescing foam insulation.  The vent holes ensure that the drum will not be ruptured by gas pressure.

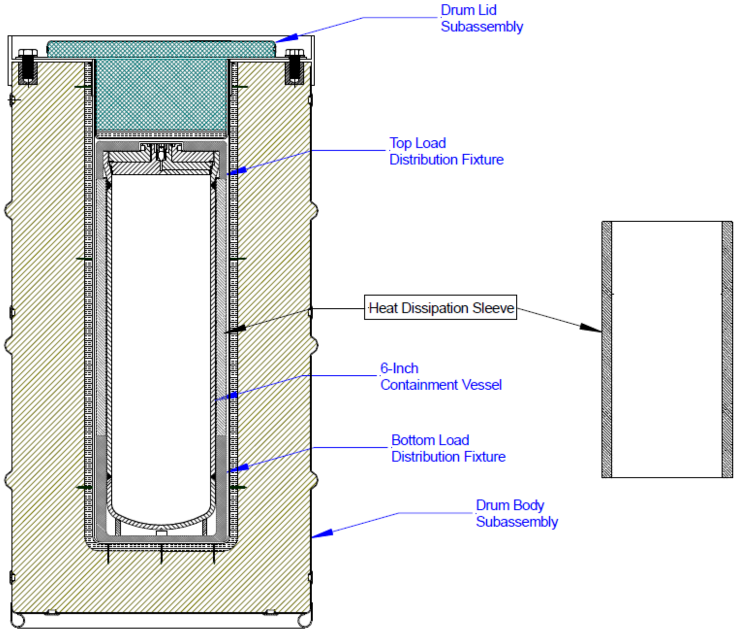



**Figure 1.2 – 9977 Package with Heat Dissipation Sleeve**

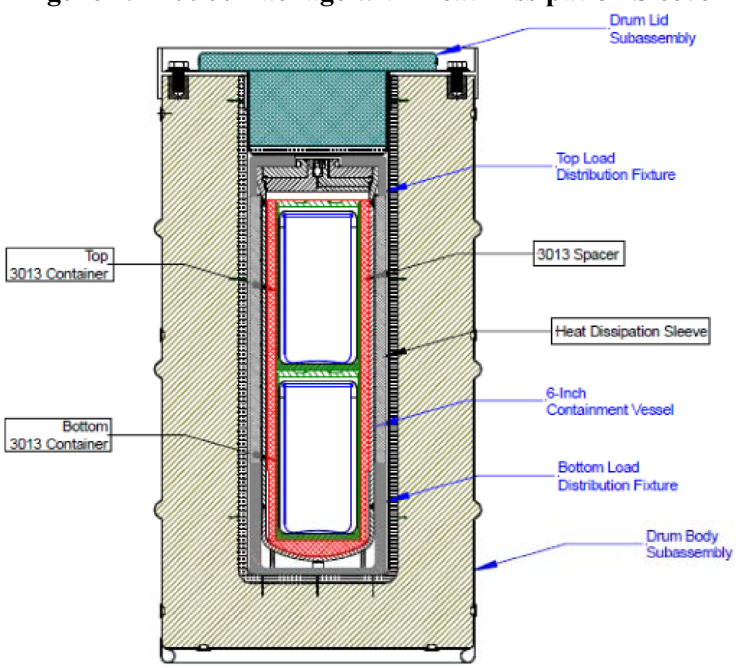



**Figure 1.3 – 9977 Package with $PuO_2$ Content in Dual-3013 Container Assemblies**

The drum closure lid is fabricated from ⅛-inch-thick Type 304L SS plate. Eight (8) ⅝-inch- by 1¼-inch-long heavy hex-head bolts with ⅝-inch plain, narrow Type B washers secure the lid to the top deck plate of the drum body. Four (4) ¼-inch-diam holes through the Lid Plate allow the Lid Top and Lid Bottom volumes to exchange gases and equilibrate pressure. The Lid Top chamber is vented by four (4) ¼-inch-diam holes, also covered with Caplug® fusible plastic plugs. The Caplugs® prevent water from entering the lid through the vent holes under NCT. In a HAC fire event, the plugs combust or melt, allowing the lid to vent heated air from the Lid Top and Lid Bottom chambers.

Two layers of insulation material fill the volume between the drum liner and shell. First, two (2) ½-inch-thick blankets of Fiberfrax® insulation are wrapped around and attached to the sides and bottom of the liner. The Fiberfrax® is backed on both sides with fiberglass cloth held in place by fiberglass thread stitched longitudinally at 4-in. intervals. The fiberglass cloth gives the Fiberfrax® composite both mechanical strength and wear resistance and helps retard gas flow during the HAC fire event. The remaining volume between the Fiberfrax® and the drum wall is filled with General Plastics FR-3716 polyurethane (PU) foam (also known as Last-A-Foam®) poured through fill holes in the drum bottom and foamed in place. The combined thickness of the two insulators is approximately 4.95 inches radially (i.e., between the liner and the drum shell) and approximately 4.52 inches axially (i.e., between the liner bottom and drum bottom).

The closure lid incorporates two chambers of insulation. The Lid Top chamber contains a 1-inch-thick, 14-inch-diam disk of Thermal Ceramics Min-K 2000® insulation. The Lid Bottom chamber contains a rigid disk of Thermal Ceramics TR-19® Block insulation, 4.3 inches thick by 8 inches in diam. When installed, the TR-19® disk compresses two (2) 8-inch-diam by ½-inch-thick blankets of Fiberfrax® insulation to a total thickness of ½ inch. The total axial thickness of both the insulators is approximately 5.75 inches.

Containment Vessel

The 9977 CV is designed with a nominal internal diameter of 6 inches (6CV). The 6CV is designed and fabricated from 6-inch Schedule 40 seamless Type 304L SS pipe (0.280-inch nominal wall thickness), in accordance with Section III, Subsection NB of the ASME Code, with design conditions of 800 psig at 300°F. A stayed head is machined from a 7½-inches-diam by 2¼-inches-long Type 304L SS bar and welded to the open end of the pipe segment, completing the vessel body weldment. The head is machined to include 6½-12UNS-2B internal threads and an internal cone-seal surface with a 32-μin. finish. Both vessel body joints are Category B full-penetration circumferential welds. A support skirt to stand the 6CV vertically is formed from a short segment of 5-in. Schedule 40 Type 304L SS pipe welded to the convex side of the cap. Two rectangular notches milled into the bottom edge of the skirt (180° apart) can engage a rectangular key to prevent vessel rotation during removal and installation of the closure assembly.

The 6CV Closure Assembly consists of a Type 304L SS Cone-Seal Plug shaped in part like a truncated cone and a threaded Cone-Seal Nut made from Nitronic 60 SS. The two Closure Assembly components rotate freely relative to one another and are coupled by a snap-ring that also ensures unseating of the closure seal during disassembly. As the Cone-Seal Nut is threaded into the stayed head of the vessel, the Cone-Seal Plug is thrust axially against the corresponding cone-seal surface of the vessel. Both internal and external sealing surfaces are machined to the same angles and surface finishes, and with matching diameters, so that they mate with essentially zero clearance. To minimize the potential for thread galling, the Cone-Seal Nut and the Containment Vessel body are made from dissimilar materials. Two O-ring grooves (outer and inner) are machined in the face of the external Cone-Seal Plug. Viton® GLT/GLT-S O-rings fit into these grooves to complete the leaktight closure assembly.

For operational safety, a 0.094-in.-diam vent hole is located in the stayed head between the threads and the internal sealing surface. The vent hole is clocked 90° from the notches in the vessel support skirt. Unscrewing the Cone-Seal Nut a few turns will unseat the Cone-Seal Plug from the internal cone-seal surface and route any pressurized gases from the CV through the vent hole.

A leak-test port is incorporated into the Cone-Seal Plug and connected by a drilled radial passage to the annular volume between the two O-ring grooves in the Cone-Seal Plug. The leak-test port provides a means of verifying proper assembly of the vessel closure and is itself closed by the Leak-Test Port Plug. The vessel containment boundary is formed by the vessel body weldment, the Cone-Seal Plug, the Cone-Seal Port Plug, and the Outer O-ring.

Load Distribution Fixtures

The top and bottom Load Distribution Fixtures (LDFs) are made from 6061-T6 aluminum round bar and fit within the Drum Liner cavity, above and below the 6CV. The LDFs center the 6CV in the liner, stiffen the package in the radial direction, and distribute loads away from the 6CV.

Heat Dissipation Sleeve

The HDS is made from 6061-T6 aluminum, surrounds the outside of the 6CV within the Drum Liner cavity, and is located between the Top and Bottom Load Distribution Fixtures (see Figures 1.2 and 1.3). The HDS enhances the conduction of content decay heat out of the 6CV and produces a more uniform temperature distribution, eliminating "hot spots" within the package, particularly in the PU foam.

3013 Spacer

The 3013 Spacer Sleeve is fabricated from 6061-T6 seamless aluminum tubing. The Spacer Bottom, curved to match the inside bottom of the 6CV, is pinned to the vertical tube section. The Spacer Sleeve is 21.2 inches tall, with a 5.02-inch ID and an approximately 0.465-inch wall thickness.

Figure 1.3 depicts a typical shipping configuration of the 9977 package, with $PuO_2$ contained in Dual-3013 container assemblies. The aluminum HDS is outside the 6CV, between the top and bottom LDFS; Dual-3013 containers are fitted into the aluminum 3013 Spacer, one above the other.

Drawings

The drawings that pertain to the 9977 package are listed in Table 1.1.

**Table 1.1 List of Drawings Pertaining to the 9977 Package**

| Drawing No. | Revision | Title |
|---|---|---|
| R-R2-G-00017 | 1 | 9977-Drum and Liner Subassembly (U) |
| R-R2-G-00018 | 2 | 9977- Drum Lid Subassembly (U) |
| R-R2-G-00019 | 1 | 9977-Insulating Blanket Subassembly (U) |
| R-R1-G-00020 | 2 | 9977-Assembly with 6-inch Diameter Containment Vessel (U) |
| R-R4-G-00032 | 3 | 9977-Load Distribution Fixtures (U) |
| R-R2-G-00042 | 2 | 9977-Six Inch Diameter Containment Vessel Subassembly (U) |
| R-R4-G-00053 | 2 | 9977-Sleeve and Plug Details (U) |
| R-R4-G-00081 | 0 | 9977-3013 Spacer |

1.2 Contents

The package contents are identified in Table 1.2 and are in solid form as oxides. Contents in liquid form are not permitted. The total content mass listed in Table 1.2 applies to each 3013 container.

The following requirements are modified from Revision 2 of the 9977 SARP, for the 9977 package with Dual-3013 contents, and shall be maintained for the content found in Table 1.2 of this addendum.

- The maximum allowable radioactive decay heat rate is 19 W per 3013 container and 38 W in total per package.
- Except as stated in Table 1.2, small concentrations (<1000 ppm each) of other actinides, fission products, decay products, and neutron activation products are permitted. Assessment of these impurities may be based on process knowledge.
- Except as stated in Table 1.2, inorganic material impurity quantities of less than 100 ppm each are permitted as long as the total mass is less than 0.1 weight percent of the total content mass. Assessment of these impurities may be based on process knowledge.
- The maximum weight of the payload (everything that goes into the 6CV, including radioactive contents, the 3013 Spacer, convenience cans, contamination control devices, packing materials, spacers, etc.) is not to exceed 77.7 lb.

**Table 1.2 Content Envelopes (per 3013 Container)**

| | **Material[a,b,c]** | **Pu Oxide "Maximum Impurities"** |
|---|---|---|
| **Fissile Material (Maximum Weight %)** | $^{236}Pu$ | $1 \times 10^{-7}$ |
| | $^{238}Pu$ | 0.05 |
| | $^{239}Pu$[d] | 95 |
| | $^{240}Pu$[e] | 9 |
| | $^{241}Pu$[d] | 1 |
| | $^{242}Pu$ | 0.1 |
| | U[f] | 50 |
| | $^{241}Pu + ^{241}Am$ | 1 |
| | $^{237}Np$ | 0.05 |
| **Impurities (grams)** | Be | 0.44 |
| | Al | 0.66 |
| | Mg | 2.2 |
| | Na | 1.32 |
| | F | 1.1 |
| | B | 2.2 |
| | Li | 2.2 |
| **Total Mass (kg)** | Radioactive Materials | 4.4 |
| | Impurities | 0.082 |
| | All Contents | 5.0 |

[a] All contents shall be dry.
[b] Pu/U content bulk density shall be no greater than 7 g/cc and no less than 2.0 g/cc.
[c] Contents shall be stabilized in accordance with DOE-STD-3013, Section 6.1.1.
[d] Nuclide classified as "fissile" per DOE Good Practices Guide, Criticality Safety Good Practices Program, Guide For DOE Nonreactor Nuclear Facilities, DOE G 421.1-1, 3.79 Fissile Nuclide, 8-25-99.
[e] $^{240}Pu$ shall be greater than $^{241}Pu$.
[f] All isotopes except $^{232}U$, which is limited to $1 \times 10^{-7}$ weight percent

The contents to be shipped in the Model 9977 package shall consist of not more than 10 kg (22.05 lb) of $PuO_2$. The $PuO_2$ is placed in a single or Dual-3013 container assemblies, with not more than 5 kg (11.02 lb) per 3013 container assembly. The amount of fissile material allowed in the 9977 package is 4.4 kg (9.7 lb) per 3013 container assembly, for a total of 8.8 kg (19.4 lb) in the CV.

Weights and Contents Descriptions

The maximum gross weight of the 9977 package is 350 lb. The maximum packaging weight, including the incorporated HDS, is 272.3 lb. The maximum weight of $PuO_2$ allowed in the 9977 package is 22.05 lb. The maximum payload weight, including the 3013 container assemblies, the Pu oxide content, and the 3013 Spacer, is 77.7 lb.

The fissile material content shall be in solid form. All $PuO_2$ contents shall be packed in accordance with DOE-STD-3013[6] inside a 3013 container assembly.

The maximum decay heat of the $PuO_2$ content is 38 W per package and 19 W per 3013 container assembly.

Either a single or Dual-3013 container assemblies will be shipped inside the 9977 CV. If only one 3013 container assembly is shipped in the CV, aluminum foil or peanuts may be used as dunnage in place of a 3013 container.

## 1.3 Criticality Safety Index (CSI)

Properly configured Model 9977 packages with $PuO_2$ content satisfy the requirements of 10 CFR 71.55 and 71.59 for the surface-only mode of transport. DOE PCP staff has confirmed that the 9977 packages meet the requirements of 10 CFR 71.55 and 10 CFR 71.59 for a package, with a CSI = 1.0.

## 1.4 Radiation Level and Transport Index (TI)

The maximum dose rates calculated in the SARP and confirmed by DOE PCP staff are all significantly below the regulatory limits for nonexclusive-use shipment. The calculated TI is 3.4 (see Section 5 of this SER). If the measured TI is greater than 10, the drum must be transported by "Exclusive Use" shipment, and/or additional 3013 container mass loading restrictions or impurity control measures may be used to reduce the dose rates.

## 1.5 Conclusion

On the basis of the statements and representations in Addendum 7 and the Revision 2 9977 SARP and DOE PCP staff's confirmatory evaluation, DOE PCP finds the general information (and drawings) presented in Section 1 of Addendum 7 acceptable.

DOE PCP has concluded that thirteen (13) conditions of approval will be added to Revision 12 of the Certificate of Compliance (CoC):

(1) The contents shall have a maximum decay heat generation rate of:
- 19 Watts for all contents/configurations; unless otherwise restricted below,
- 19 Watts per 3013 Container and 38 watts total per Package in the Dual 3013 configuration,
- 15 Watts for a package identified with a greater than 1-year periodic maintenance,

- 6 Watts in the SGQ-SC1 configuration,
- 3 Watts in the SGQ-SC2 configuration, and
- 3.5 Watts in Training Sources Engineered Container configuration.

(2) The maximum weight of the payload (everything that goes into the 6CV, including radioactive contents, convenience cans, contamination control devices, packing materials, spacers, etc.) is not to exceed 100 lb except for the Dual 3013 configuration where the maximum weight of the payload shall not exceed 77.7 lbs. The maximum allowable gross shipping weight of the 9977 package is 350 lb.

(3) The Model 9977 Package must be shipped in a closed conveyance.

(4) Transport of fissile material by air is not authorized. In addition, for Dual 3013 configuration shipments shipment by water is not authorized.

(5) In addition to the requirements of Subparts G and H of 10 CFR Part 71, and except as specified in section 5(d) of this certificate, each package must be fabricated, acceptance tested, operated, and maintained in accordance with the Operating Procedures requirements of Chapter 7, Acceptance Tests and Maintenance Program requirements of Chapter 8, and packaging-specific Quality Assurance requirements of Chapter 9 of the SARP [See 5.(e)(1)] as supplemented by the Addendums [See 5.(e)(2), 5.(e)(4), 5.(e)(7), 5.(e)(11), 5.(e)(12), and 5(e)(13)] and the Applications [See 5.(e)(3), 5.(e)(8), and 5.(e)(9)].

(6) For the AGR-1 fuel compacts, the requirements specified in Section 1.2.2.2.2, and in Table A.1.2, of the Addendum [5(e)(4)], must be followed, along with the specific procedures outlined in Steps 1, 2, 6, 8, and 12 of Section 7.1.1.2 of the Addendum [5(e)(4)]. The documentation packages for the Q items, numbered as 17–20, in Table A.App.8.2.1 of the Addendum [5(e)(4)], Dimensions/Materials Requiring Independent Verification Records, must be supplied by the Site directing fabrication to Savannah River National Laboratory as the Design Authority/Design Agency.

(7) If the option is chosen to attach a DOE ARG-US RFID tag to the 9977 packaging, the operating procedures must follow the additional steps per Chapter 7 in Addendum [See 5(e)(5)], and the guide to RFID monitoring system [See 5(e)(6)]. The RFID guide contains a copy of the Material/Product Safety Data Sheet for the batteries used in the DOE ARG-US RFID tag, which provides guidance on the safe use of the batteries.

(8) For the Type 4 (Sources) contents, the requirements specified in Section 1.2.2.2.1, and in Table A.1.2, of the Addendum [5(e)(4)], must be followed, along with the specific procedures of Section 7.1.1.2 of the Addendum [5(e)(4)]. The documentation packages for the Q items, numbered as 17–30, in Table A.App.8.2.1 of the Addendum [5(e)(4)], Dimensions/Materials Requiring Independent Verification Records must be supplied by the Site directing fabrication to Savannah River National Laboratory as the Design Authority/Design Agency.

(9) Verification of the pre-shipment containment integrity of the containment system, on both the O-ring seal and the Leak Test Port Plug, shall be accomplished using either the pressure rise method or the pressure drop method of testing as specified in ANSI N14.5-1997.

(10) The following conditions apply to the installation of a DOE ARG-US RFID tag on a 9977 packaging to allow for the extension of the maintenance interval:

(a) The maximum allowable radioactive decay heat rate for the 9977 package is 19 watts, except for extension of the packaging periodic maintenance interval, in which case the maximum allowable radioactive decay heat rate is limited to 15 watts.

(b) The user shall verify the installation of proper O-rings (i.e., GLT vs. GLT-S) and record the date of installation, e.g., 9977/GLT (or GLT-S)/xx/xx/201x, in the memory of the ARG-US RFID tag.

(c) During both use (loading, shipment, and unloading) and storage (loaded and empty) of the 9977 packaging, the containment vessel (CV) must remain sealed over the entire approved extended maintenance interval. In the event that operations require the CV to be opened, then the old O rings shall be replaced with new O-rings, all the requirements for the extended maintenance interval described in the SARP Addendum 4 shall be complied with for the new O-rings, and the sealing time shall be re-initialized to zero.

(d) The extension of the packaging periodic maintenance interval is to a maximum of five (5) years for the 9977 packaging using the Viton GLT O-rings; and to a maximum of two (2) years for the 9977 packaging using the Viton GLT-S O-rings as shown in Drawing R-R2-G-00042, Item 8. If the ongoing O-ring fixture long-term leak performance testing shows any GLT and GLT-S O-ring failures at $200^{o}$F, notify the Headquarters Certifying Official within 72 hours.

(e) The user of this CoC for extension of packaging periodic maintenance interval shall complete the prescribed training to become qualified and to be certified for operation of the RFID temperature monitoring system. The training course will be administered by Argonne National Laboratory on behalf of the Headquarters Certifying Official.

(f) When a temperature-sensing DOE ARG-US RFID tag is attached to a 9977 packaging, it shall be verified to be functional in accordance with the Operating Procedures requirements of Addendum 4 [See 5(e)(12)]. If a failure of the RFID tag or the temperature recording system results in a loss of temperature data for a duration ≥72 hours, then the packaging shall have a Nonconformance Report issued against it and be tagged and segregated until the disposition of the Nonconformance Report has been approved by both the 9977 Design Authority and Headquarters Certifying Official.

(11) The following conditions apply for Dual 3013 shipments in the 9977 packaging:

(a) The 3013 Container (consisting of the outer can, the inner can, and the convenience can) shall be inerted with helium or nitrogen such that oxygen content in all void spaces is no greater than 5% by volume at the time the outer 3013 Container is sealed (welded close).

(b) In addition to the radioactive material and impurity mass loading limits per 3013 container assembly (Table 7), the $PuO_2$ in the 9977 package shall be limited to a total of 10kg (22.05 lb) and the maximum amount of fissile material allowed in the package shall be 8.8 kg (19.4 lb).

(c) The Heat Dissipation Sleeve and the annular 3013 Spacer must be used for the 9977 package with Dual-3013 containers. Verify that the Heat Dissipation Sleeve and the annular 3013 Spacer have been properly installed.

(d) The bulk density of the $PuO_2$ shall be $>2 g/cm^3$ and $< 7 g/cm^3$.

(e) Seal time must be 12 months or less, where seal time is defined as the length of time that the shipment must be complete after the 9977 CV is sealed.

(f) The void space within the CV shall be backfilled with $\geq$ 75% by volume carbon dioxide gas prior to shipment.

(g) If the measured Transport Index is greater than 10, the package must be transported by "Exclusive Use" shipment, and/or additional; 3013 container mass loading restrictions or impurity control measures may be used to reduce the dose rates.

(12) The ARG-US RFID may be used as a Tamper-Indicating Device Seal [See 5(e)(14)].

(13) Previous revisions of this DOE Certificate of Compliance maybe used until July 31, 2013.

Evaluations of design and performance of the package for safety and regulatory compliance in the areas of structural, thermal, containment, shielding, criticality safety, operating procedures, acceptance tests and maintenance, and quality assurance are given in the remaining sections of this SER.

## 2. STRUCTURAL

### 2.1 Discussion

DOE PCP staff reviewed the structural design and performance of the 9977 package with Dual-3013 contents, as described in Chapter 2 of Addendum 7 and Chapter 2 of the SARP. DOE PCP staff also performed confirmatory finite element analysis to independently evaluate the design and performance of the 9977 package. The review and analysis were focused on 1) the structural performance of the 9977 package with Dual-3013 contents; 2) the effect of the addition of the HDS on the packaging performance under NCT and HAC; 3) material compatibility between the HDS and the CV and other packaging components, and material compatibility between the contents and the CV; and 4) the potential impact of hydrogen deflagration and detonation.

### 2.2 Structural Evaluation

#### Structural Performance of the 9977 Package with Dual-3013 Contents

The major structural components of the 9977 packaging are the drum assembly, HDS, the 6CV, the 3013 Spacer, and the 3013 containers. The drum assembly provides confinement and protection to the CV and the shipping contents. All $PuO_2$ content will be packed in 3013 containers in accordance with DOE-STD-3013. Either a single or Dual-3013 containers will be shipped in each 6CV. If only one 3013 container is shipped, aluminum foil or peanuts may be used as dunnage in place of a 3013 container.

The SARP structural evaluation was a combination of physical testing and finite element analysis using the computer code ABAQUS. For both the structural test and analysis, a 13-in.-long steel slug weighing 100 lb was used as a surrogate. The maximum gross weight of the 9977 package is 350 lb, and the maximum 9977 packaging weight with the HDS is 272.3 lb. The maximum payload weight of the 9977 package, including the 3013 containers, the 3013 Spacer, Pu oxide, the food pack can, etc., is not to exceed 77.7 lb, so that the structural evaluation of the drum assembly and the CV based on prototype testing and analysis bounds the 9977 package with Dual-3013 contents.

The outer and inner containers of the 3013 container assembly were qualified by physical testing as required by the DOE-STD-3013 standard. The 3013 outer container remained leaktight after a 30-ft free drop of the 3013 assembly with simulated non-radioactive payload, and the inner container remained leaktight after a 4-ft free drop of the inner container with simulated non-radioactive payload. Both inner and outer containers of the 3013 container assembly were tested for leaktightness as defined in ANSI N14.5 at the time of their closure. However, the 3013 inner and outer containers are conservatively assumed to not maintain their structural integrity; they are only assumed to be adequate to maintain confinement of the $PuO_2$ content under both NCT and HAC.

Effect of the Addition of the Heat Dissipation Sleeve

In Revision 2 of the 9977 SARP, the structural performance of the 9977 packaging was evaluated without the HDS. Additional structural analysis was conducted in Addendum 7 to investigate the effect of the addition of the HDS on the structural performance of the 9977 packaging. Table A.2.2 of Addendum 7 shows that following the 30-ft free drop on the side of the package, the CV would experience less stress with the HDS in place. DOE PCP staff performed confirmatory analysis to evaluate the effects of the HDS under HAC for a 30-ft drop and sequential crush. DOE PCP staff-calculated results are given in Table 2.1, which shows that the maximum stress and deformation of the CV are less if the HDS is installed in the 9977 package.

**Table 2.1 DOE PCP Staff-calculated CV Stress and Deformation Following 30-ft Drop and Sequential Crush**

| | Without HDS | | With HDS | |
|---|---|---|---|---|
| | **Maximum Stress** | **Plastic Strain** | **Maximum Stress** | **Plastic Strain** |
| **Following 30-ft Drop** | 57.7 ksi | 2.67% | 49.1 ksi | 1.66% |
| **Following Sequential Crush** | 72.9 ksi | 13.65% | 69.6 ksi | 11.84% |

Material Compatibility

The HDS is made from 6061 T6 aluminum alloy, which is covered by an aluminum oxide layer on its outer surface; this aluminum oxide layer is passive and does not react with the surrounding metallic packaging components, i.e., the CV (SS), the drum liner (SS) and the load distribution fixtures (6061 T6 aluminum alloy). Similarly, there is no material incompatibility issue inside the CV between the SS 3013 containers, the aluminum dunnage, the aluminum 3013 Spacer and the CV. Though corrosion pits were observed in some of the innermost containers of the 3013 assemblies, no corrosion has been found on any of the 3013 outer containers. Therefore, the $PuO_2$ contents will be confined within the multi-barrier 3013 containers, and corrosion of the CV caused by $PuO_2$ is unlikely.

Potential Impact of Hydrogen Deflagration/Detonation

DOE PCP staff also evaluated the potential impact of hydrogen deflagration/detonation on the 9977 package with $PuO_2$ content. Stabilized $PuO_2$ contains moisture (not more than 0.5 wt.%), and radiolysis of water could release hydrogen gas into the 3013 containers and the CV. In order to avoid hydrogen deflagration and detonation, the 9977 CV is inerted with carbon dioxide ($CO_2$) to a minimum volumetric efficiency of 75%, reducing the oxygen concentration to less than 5%. Therefore, the gas mixture in the CV is not flammable (see Section 3 of this SER for detailed evaluation).

2.3 Conclusion

On the basis of the statements and the representations in Revision 3 of Addendum 7 and Revision 2 of the SARP, and DOE PCP staff's confirmatory evaluation, DOE PCP finds that the structural design and performance of the 9977 package with Dual-3013 contents presented in Chapter 2 of Addendum 7 and Chapter 2 of the SARP are acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

## 3. THERMAL

3.1 Discussion

DOE PCP staff reviewed the thermal design and performance of the 9977 package with Dual-3013 contents, as described in Chapter 3 of Addendum 7 and Chapter 3 of the SARP. DOE PCP staff also performed confirmatory analyses to evaluate the thermal performance of the 9977 package during both NCT and HAC. The review and the analyses were focused on the materials properties, the temperature limits, the maximum temperatures and the maximum thermal stresses of the packaging components, the maximum normal operating pressure (MNOP), the maximum HAC pressure, and the potential hydrogen deflagration/detonation issue inside the CV.

3.2 Thermal Evaluation

The thermal-related design features of the 9977 package (e.g., thermal properties, temperature limits, maximum temperatures and pressures, and thermal stresses) are described in Addendum 7, the SARP, and two appendices to Chapter 3 of Addendum 7 (M-CLC-A-00390 and M-CLC-A-00393). The 9977 package accommodates a payload of $PuO_2$ content that is nested in Dual-3013 containers. The details of the content are specified as Content Envelope in Table A.1.1 of Addendum 7.

The primary design features intended to protect the CV and O-rings of the 9977 package from overheating are as follows:

- Last-A-Foam® (or PU foam) overpack, confined in the SS drum, which acts as an impact limiter and provides insulation under HAC; and
- A cylindrical HDS around the 6CV, which enhances heat dissipation under NCT.

The outer Viton GLT/GLT-S O-ring between the Cone Seal Plug and the vessel body complete the containment boundary of the CV.

Addendum 7 used analyses to evaluate the packaging component temperatures under NCT and HAC. The temperature profiles that were obtained from the fire test are used to estimate the temperature rise during the fire. The following assumptions are made in Addendum 7 to conduct thermal analyses:

(1) The 9977 CV is sealed at standard temperature and pressure (77°F and 14.7 psia), and is backfilled with $CO_2$ to a minimum of 75 vol.% so the oxygen is less than 5 vol.%.

(2) The 3013 container assembly is sealed at 14.7 psia, and inerted with helium.

(3) The free gas volume inside the 3013 container assembly is evaluated on the basis of 50% $PuO_2$ density.

(4) The contents contain decay heat sources of 38 W uniformly distributed in Dual-3013 containers. The heat rate is limited to a maximum of 19 W in each container.

(5) The CV may be sealed up to one year after initial closure.

DOE PCP staff verified thermal-physical properties and temperature limits for each component of the 9977 packaging; the staff also performed confirmatory analysis to evaluate the thermal design and performance of the package, and the results are described below.

3.2.1 Thermal Evaluation under NCT

Addendum 7 evaluated the NCT thermal performance using finite element code MSC/PATRAN-THERMAL (M/PT), with a two-dimensional axi-symmetric model for the 9977 package. Details of the finite element model and the results are provided in M-CLC-A-00390 of Addendum 7. The thermal properties of the packaging materials, including insulating materials, aluminum internals, SS containers, and air, are listed in Sections 2.2 and 2.3 of M-CLC-A-00390. DOE PCP staff has concluded that 1) these properties are appropriate for the thermal analyses (except thermal radiation properties, which will be discussed in detail later) and 2) the expressions for the various modes of heat transport at the package boundaries are also appropriate. The NCT analyses simulated a period during which the package was placed at an ambient temperature of 100°F with cyclic insolation loading of 12-hours-on/12-hours-off. The 38-W decay heat load was applied, as a heat flux, uniformly to the inner surface of Dual-3013 containers.

a) Maximum packaging surface temperatures under NCT in shade

The maximum outer surface temperatures of the 9977 package in still air at 100°F without insolation is 122°F calculated in Addendum 7 vs. 110°F calculated by DOE PCP staff. Therefore, no accessible surface of the package would have a temperature exceeding 122°F in a nonexclusive-use shipment per 10 CFR 71.43(g).

b) Maximum packaging component temperatures under NCT

Table 3.1 shows the calculated maximum temperatures for the packaging components under NCT; all of the calculated temperatures are below the corresponding allowable temperature limits for these components.

**Table 3.1 Calculated Maximum Packaging Component Temperatures (°F) under NCT**

| Component | Staff | Addendum 7 | Allowable |
|---|---|---|---|
| Drum body | 169 | 189 | 800 |
| Drum lid, Min-k 2000 | 159 | / | N/A |
| Drum lid, TR19 | 200 | / | 2,500 |
| Drum lid, Fiberfrax | 207 | / | 3,200 |
| Fiberfrax blanket, near liner | 276 | / | 3,200 |
| Load distributor/top | 266 | / | 300 |
| Load distributor/bottom | 276 | / | 300 |
| Heat dissipation sleeve | 275 | / | 300 |
| Polyurethane (PU) foam | 266 | 291 | 300 |
| CV | 286 | 310 | 300*/800 |
| Viton O-ring | 269 | 299 | 400 |
| 3013 content/top | 484 | 559 | 800 |
| 3013 content/bottom | 480 | 555 | 800 |

*300°F is designated as the NCT temperature limit in Addendum 7.

Addendum 7 has used a partial heat flux of solar insolation to conduct thermal analysis for NCT with insolation, which is based on the fact that the drum is not a "black body." The sensitivity analyses are coupled to evaluate effects of absorptivity and emissivity on peak temperatures of the thermal-sensitive materials. It shows that those peak temperatures are not very sensitive to surface properties. DOE PCP staff has numerically evaluated the effect of surface absorption. The results indicate that the peak temperatures of the above-mentioned items are within the allowable limits even when the absorptivity is assumed to be 1.0.

c) Maximum Normal Operating Pressure (MNOP)

Addendum 7 calculated MNOP of 421.63 psig at a CV temperature of 369°F, assuming oxygen generated by radiolysis of moisture is completely absorbed by the $PuO_2$ content. DOE PCP staff has calculated the MNOP assuming no oxygen absorption by $PuO_2$ at the CV temperature of 369°F. The resulting MNOP is 613.38 psig, which is below the CV design pressure limit of 800 psig.

The DOE PCP staff has also calculated the MNOP using the gas mixture temperature of 302°F obtained from confirmatory calculation. The calculated MNOP is 386 psig and 577 psig, respectively, for complete oxygen absorption and no oxygen absorption. These values are lower than the CV design pressure limit of 800 psig.

d) Maximum thermal stresses

Since 3013 container assemblies, the CV, and the HDS are unrestrained, thermal stresses due to differences in thermal expansion are insignificant and they will have no effect on the ability of the CV to maintain containment.

3.2.2 Thermal Evaluation under HAC

Thermal evaluation of the 9977 package under HAC is conducted in Addendum 7 using the MSC/PATRAN-THERMAL(M/PT) code. Three cases were analyzed for the package with a layer of 0, 1, and 2.3 in. of foam remaining after the 30-min HAC fire. The calculated HAC temperatures are listed in Table 8 of reference A.3.1 of Addendum 7.

DOE PCP staff analyzed two cases, assuming a 0- and a 1-in. layer of foam, respectively, remaining after the 30-min HAC fire.

a) Maximum packaging component temperatures under HAC

Table 3.2 shows the maximum temperatures of the packaging components under HAC; all of the calculated maximum temperatures are below the allowable temperature limits.

**Table 3.2 Calculated Maximum Packaging Component Temperatures (°F) under HAC**

| Component | DOE PCP Staff | Addendum 7 | Allowable |
|---|---|---|---|
| Drum body | 1470 | 1475 | 2600 |
| Drum lid, Min-k 2000 | 1439 | / | N/A |
| Drum lid, TR19 | 729 | / | 2,500 |
| Drum lid, Fiberfrax | 426 | / | 3,200 |
| Fiberfrax blanket, near liner | 869 | / | 3,200 |
| Load distributor/top | 327 | / | 1,080[1] |
| Load distributor/bottom | 331 | / | 1,080 |
| Heat dissipation sleeve | 330 | / | 1,080 |
| CV | 339 | 395 | 500/800[2] |
| Viton O-ring | 328 | 385 | 400 |
| 3013 can/top | 535 | 588 | 800 |
| 3013 can/bottom | 530 | 588 | 800 |

[1] The limit is based on the ASM Material Data Sheet; see http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=MA6061T6 .
[2] 500°F is designated as the HAC temperature limit in Addendum 7.

For the case where a 1-in. layer of foam is left, the calculated PU foam temperature is below 400°F except briefly for a small region near the top of the drum.

b) Maximum CV internal pressure under HAC

Addendum 7 calculated maximum HAC pressure of 485.17 psig at a CV temperature of 431.83°F, assuming the oxygen generated by radiolysis of moisture is completely absorbed by $PuO_2$. DOE PCP staff calculated maximum HAC pressure of 703 psig at the CV temperature of 431.80°F, assuming no oxygen absorption by $PuO_2$. Both are below the CV design pressure limit of 800 psig.

DOE PCP staff has also calculated the maximum HAC pressure using the gas mixture temperature of 359°F, obtained from confirmatory calculation. The calculated maximum HAC pressure is 415.3 psig and 605.3 psig, respectively, for complete oxygen absorption and no oxygen absorption. These values are lower than the CV design pressure limit of 800 psig.

3.2.3 Potential Hydrogen Deflagration and Detonation

After loading 3013 containers into the CV, the CV is backfilled with $CO_2$ to 75 vol.% minimum, making the volume percent of air 25% maximum (or $O_2$ 5 vol.% maximum). If the gas (hydrogen and helium) in the 3013 containers leaks into the CV, the volume percent of oxygen in the CV will be further reduced. Limiting the oxygen concentration inside the CV to less than 5 vol.% precludes deflagration. Reference M-CLC-K-00755 calculated the detonation cell widths for the 9977 packages based on 24-W decay heat with an ambient temperature of 139.7°F at P-Area Vault (PAV). The 3013 containers are inerted with 75% He and the 6CV is inerted with 75% $CO_2$. The calculated detonation cell width is ≈550 mm at a CV temperature of 387 K. Addendum 7 conditions under NCT (38-W decay heat, 100°F ambient, and insolation) yield a CV temperature of 424 K. The detonation cell width is inversely proportional to temperature at a rate of ≈3 mm/K. Therefore, the detonation cell width calculated for the 9977 package under NCT is ≈440 mm (17.3 in.). Since there is no gap in the loaded 6CV that is larger than 17.3 in., the 75% $CO_2$ inerting of the CV precludes transition from deflagration to detonation.

3.3 Conclusion

On the basis of the statements and the representations in Revision 3 of Addendum 7 and Revision 2 of the SARP, and DOE PCP staff's confirmatory evaluation, DOE PCP finds that the thermal design and performance of the 9977 package with Dual-3013 contents presented in Chapter 3 of Addendum 7 and Chapter 3 of the SARP are acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

## 4. CONTAINMENT

4.1 Discussion

DOE PCP staff reviewed the containment design and performance of the 9977 package with Dual-3013 contents, as described in Chapter 4 of Addendum 7 and Chapter 4 of the SARP. DOE PCP staff also performed confirmatory evaluation of the containment design and performance of the 9977 package, and the results are provided below.

4.2 Containment Performance Evaluation

DOE PCP staff's confirmatory evaluation of the structural performance as described in Section 2 of this SER shows that the proposed addition of the $PuO_2$ in Dual-3013 containers to the 9977 package does not increase the impact loading on the CV. Section 3 of this SER shows that that the increase in temperature and pressure due to the increased content wattage are within the design limits for the CV. Therefore, the package containment performance (leak-tight in accordance with ANSI Standard N-14.5) documented in Rev. 2 of the 9977 SARP remains valid.

4.3 Conclusion

On the basis of the statements and the representations in Revision 3 of Addendum 7 and Revision 2 of the SARP, DOE PCP finds that the package containment design and performance presented in Chapter 4 of Addendum 7 and Chapter 4 of the SARP are acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

## 5. SHIELDING

5.1 Discussion

DOE PCP staff reviewed the shielding design and performance of the Model 9977 package with Dual-3013 containers, each having a maximum of 5 kg of $PuO_2$, in a configuration shown in Figure A.1.2 of Addendum 7. The bounding shielding evaluation is based on the Dual-3013 configuration. The maximum dose rates calculated for a package with 10 kg of $PuO_2$ and with the maximum Be impurity bound all those shipping mass limits described in Table A.1.1 of Addendum 7. The 9977 package with 10 kg of $PuO_2$ and with the maximum Be impurity level of 0.44 g may be shipped under non-exclusive use. DOE PCP staff confirmed a TI of 3.4 as calculated in Addendum 7 for the maximum Be impurity case. During actual operations with the 9977 package, the TI will be determined by measurement prior to shipment and all radiation levels must satisfy the 10 CFR 71, 49 CFR 173 dose rate requirements for the non-exclusive use shipment.

5.2 Shielding Design

The 9977 package design does not include any specific features intended for shielding. The drum body and CV SS body weldment and closure provide some gamma attenuation. Neutron shielding is provided by the distance from the source, with minimal attenuation by the CV, Fiberfrax®, PU foam, and the drum. Restricting the amount of source material of the content (both radioisotopes and impurities) and maintaining package geometry keep the calculated radiation dose rates below the regulatory limits. Owing to the significant subcritical neutron source multiplication for the 9977 package, the geometry modeling for neutron shielding is the controlling factor in determining the maximum total dose rates.

## 5.3 Source Specification

For the contents of the 9977 package, the bounding source photons are produced from the decay of the plutonium, uranium and other radioactive isotopes listed in Table A.5.2 of Addendum 7. The plutonium is enriched to 89.9 wt% $^{239}Pu$ (note: different from Tables A.1.1 and A.5.2) and is assumed to contain 9 wt% $^{240}Pu$, 1 wt% $^{241}Pu$, 0.1 wt% $^{242}Pu$, 0.05 wt% $^{238}Pu$, and 1 ppb of $^{236}Pu$ and $^{232}U$. The bounding source terms were evaluated with all light-element impurities listed in Table A.1.1 of Addendum 7. Table A.5.3 of Addendum 7 shows the bounding RASTA-calculated photon source terms with $PuO_2$ decayed for 72 years.

Table 5.1 shows the calculated photon source terms in Addendum 7 vs. those calculated by DOE PCP staff using the ORIGEN-S code, which are found to be 30% lower than the RASTA results.

**Table 5.1 Calculated Photon Source Terms**

| Photon Group | Gamma Energy, MeV | | Addendum 7 RASTA (photons/sec) | DOE PCP Staff ORIGEN-S (photons/sec) |
|---|---|---|---|---|
| | Lower | Upper | | |
| **1** | 1.00E-08 | 1.00E-02 | 1.34E+11 | 4.12E+09 |
| **2** | 1.00E-02 | 2.00E-02 | 3.78E+12 | 2.62E+12 |
| **3** | 2.00E-02 | 3.00E-02 | 5.14E+11 | 3.67E+11 |
| **4** | 3.00E-02 | 4.00E-02 | 6.99E+09 | 7.53E+09 |
| **5** | 4.00E-02 | 5.00E-02 | 5.60E+09 | 5.59E+09 |
| **6** | 5.00E-02 | 5.90E-02 | 2.93E+09 | 3.67E+09 |
| **7** | 5.90E-02 | 6.00E-02 | 1.77E+12 | 1.78E+12 |
| **8** | 6.00E-02 | 8.00E-02 | 1.36E+09 | 4.80E+08 |
| **9** | 8.00E-02 | 1.00E-01 | 2.08E+09 | 5.21E+09 |
| **10** | 1.00E-01 | 2.00E-01 | 2.07E+09 | 2.26E+09 |
| **11** | 2.00E-01 | 4.00E-01 | 6.79E+08 | 3.89E+09 |
| **12** | 4.00E-01 | 6.00E-01 | 1.54E+08 | 3.45E+08 |
| **13** | 6.00E-01 | 7.00E-01 | 1.32E+07 | 3.23E+07 |
| **14** | 7.00E-01 | 8.00E-01 | 1.39E+07 | 3.07E+07 |
| **15** | 8.00E-01 | 1.00E+00 | 9.84E+05 | 9.92E+06 |
| **16** | 1.00E+00 | 1.50E+00 | 4.80E+05 | 2.05E+06 |
| **17** | 1.50E+00 | 2.00E+00 | 2.14E+05 | 3.40E+06 |
| **18** | 2.00E+00 | 3.00E+00 | 1.34E+06 | 6.96E+07 |
| **19** | 3.00E+00 | 4.00E+00 | 5.47E+04 | 5.86E+04 |
| **20** | 4.00E+00 | 5.00E+00 | 1.87E+05 | 1.95E+04 |
| **21** | 5.00E+00 | 6.00E+00 | 5.09E+03 | 6.50E+03 |
| **22** | 6.00E+00 | 7.00E+00 | 2.18E+03 | 2.17E+03 |
| **23** | 7.00E+00 | 8.00E+00 | 2.99E+04 | 7.27E+02 |
| **24** | 8.00E+00 | 1.00E+01 | 3.85E+02 | 3.16E+02 |
| **Total for 5 kg $PuO_2$ content** | | | **6.22E+12** | **4.81E+12** |

Table A.5.4 of Addendum 7 shows the bounding RASTA-calculated neutron source terms with $PuO_2$ decayed for 72 years. The source of neutrons originates from a combination of alpha-neutron (α, n) reaction with light elements, spontaneous fission, and neutron-induced fission.

The DOE PCP staff used the ORIGEN-S code package to calculate the neutron source terms for the maximum Be impurity case. The bounding source contribution in both Addendum 7 and the staff confirmatory analyses included small contributions from $^{232}U$, $^{237}Np$, and $^{241}Am$ impurities and all light elements in Table A.1.1.

Table 5.2 shows the calculated neutron source terms in Addendum 7 vs. those calculated by the DOE PCP staff using the ORIGEN-S code for the maximum Be impurity case, which are found to be 30% lower than the RASTA results.

The neutrons from neutron-induced fissions and the secondary photons are not included in the RASTA or ORIGEN-S source terms in Table 5.2 of this SER; however, they are included in the MCNP5 neutron transport calculations in Table 5.3. It is important to model the geometry of the Dual-$PuO_2$ content that maximizes subcritical neutron source multiplication to bound the total dose rates for the 9977 package.

**Table 5.2 Calculated Neutron Source Terms**

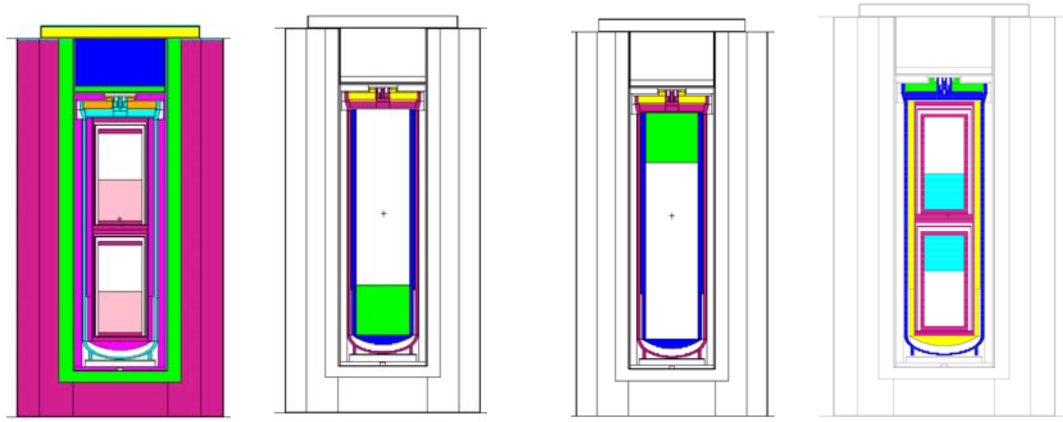
| Neutron Group | Neutron Energy, MeV | | Addendum 7 RASTA (neutrons/sec) | DOE PCP Staff ORIGEN-S (neutrons/sec) |
|---|---|---|---|---|
| | Lower | Upper | | |
| **1** | 1.00E-11 | 1.00E-07 | 1.04E-05 | 5.41E-06 |
| **2** | 1.00E-07 | 4.14E-07 | 7.55E-05 | 1.45E-04 |
| **3** | 4.14E-07 | 8.76E-07 | 1.91E-04 | 2.93E-04 |
| **4** | 8.76E-07 | 1.86E-06 | 6.07E-04 | 8.03E-04 |
| **5** | 1.86E-06 | 5.04E-06 | 3.05E-03 | 3.46E-03 |
| **6** | 5.04E-06 | 1.07E-05 | 8.21E-03 | 8.01E-03 |
| **7** | 1.07E-05 | 3.73E-05 | 6.71E-02 | 5.90E-02 |
| **8** | 3.73E-05 | 1.01E-04 | 2.74E-01 | 2.33E-01 |
| **9** | 1.01E-04 | 2.14E-04 | 7.36E-01 | 6.15E-01 |
| **10** | 2.14E-04 | 4.54E-04 | 2.28E+00 | 1.92E+00 |
| **11** | 4.54E-04 | 1.58E-03 | 1.85E+01 | 1.55E+01 |
| **12** | 1.58E-03 | 3.35E-03 | 4.61E+01 | 3.84E+01 |
| **13** | 3.35E-03 | 7.10E-03 | 1.44E+02 | 1.20E+02 |
| **14** | 7.10E-03 | 1.50E-02 | 4.52E+02 | 3.74E+02 |
| **15** | 1.50E-02 | 2.19E-02 | 5.23E+02 | 4.32E+02 |
| **16** | 2.19E-02 | 2.42E-02 | 1.97E+02 | 1.63E+02 |
| **17** | 2.42E-02 | 2.61E-02 | 1.70E+02 | 1.41E+02 |
| **18** | 2.61E-02 | 3.18E-02 | 5.49E+02 | 4.54E+02 |
| **19** | 3.18E-02 | 4.09E-02 | 9.86E+02 | 8.16E+02 |
| **20** | 4.09E-02 | 5.74E-02 | 2.09E+03 | 1.73E+03 |
| **21** | 5.74E-02 | 1.11E-01 | 8.73E+03 | 7.19E+03 |
| **22** | 1.11E-01 | 1.83E-01 | 1.49E+04 | 1.22E+04 |
| **23** | 1.83E-01 | 2.97E-01 | 2.76E+04 | 2.27E+04 |
| **24** | 2.97E-01 | 3.69E-01 | 1.93E+04 | 1.59E+04 |
| **25** | 3.69E-01 | 4.98E-01 | 3.76E+04 | 3.10E+04 |
| **26** | 4.98E-01 | 6.08E-01 | 3.35E+04 | 2.77E+04 |
| **27** | 6.08E-01 | 7.43E-01 | 4.25E+04 | 3.51E+04 |
| **28** | 7.43E-01 | 8.21E-01 | 2.52E+04 | 2.08E+04 |
| **29** | 8.21E-01 | 1.00E+00 | 5.81E+04 | 4.80E+04 |
| **30** | 1.00E+00 | 1.35E+00 | 1.11E+05 | 9.13E+04 |
| **31** | 1.35E+00 | 1.65E+00 | 9.54E+04 | 7.78E+04 |
| **32** | 1.65E+00 | 1.92E+00 | 9.30E+04 | 7.38E+04 |
| **33** | 1.92E+00 | 2.23E+00 | 1.24E+05 | 9.57E+04 |
| **34** | 2.23E+00 | 2.35E+00 | 5.30E+04 | 4.02E+04 |
| **35** | 2.35E+00 | 2.37E+00 | 9.05E+03 | 6.84E+03 |
| **36** | 2.37E+00 | 2.47E+00 | 4.58E+04 | 3.45E+04 |
| **37** | 2.47E+00 | 2.73E+00 | 1.22E+05 | 9.07E+04 |
| **38** | 2.73E+00 | 3.01E+00 | 1.26E+05 | 9.16E+04 |

| Neutron Group | Neutron Energy, MeV | | Addendum 7 RASTA (neutrons/sec) | DOE PCP Staff ORIGEN-S (neutrons/sec) |
|---|---|---|---|---|
| | Lower | Upper | | |
| **39** | 3.01E+00 | 3.68E+00 | 2.38E+05 | 1.70E+05 |
| **40** | 3.68E+00 | 4.97E+00 | 2.02E+05 | 1.42E+05 |
| **41** | 4.97E+00 | 6.07E+00 | 4.79E+04 | 3.42E+04 |
| **42** | 6.07E+00 | 7.41E+00 | 4.38E+04 | 3.12E+04 |
| **43** | 7.41E+00 | 8.61E+00 | 3.35E+04 | 2.31E+04 |
| **44** | 8.61E+00 | 1.00E+01 | 2.31E+04 | 1.53E+04 |
| **45** | 1.00E+01 | 1.22E+01 | 2.35E+03 | 1.50E+03 |
| **46** | 1.22E+01 | 1.42E+01 | 2.29E+01 | 2.33E+01 |
| **47** | 1.42E+01 | 1.73E+01 | 3.69E+00 | 3.75E+00 |
| **Total for 5.0 kg PuO2 content** | | | **1.64E+06** | **1.25E+06** |

5.4 Shielding Model

The geometry of the shielding analysis model used in Addendum 7 is a homogeneously distributed, cylindrical representation of the $PuO_2$ content in the Dual-3013 configuration, as shown in Figure A.5.1 of Addendum 7. The configuration consists of 5.0 kg of $PuO_2$ powder compacted at 7 g/cm$^3$ within the convenience cans in cylindrical form in each of the Dual-3013 containers. In Addendum 7 shielding models, all materials inside the CV are modeled explicitly, including the 0.08-cm-thick convenience can, inner 3013 container, and outer 3013 container. In the NCT model, the surface of the drum is considered to be the package surface, where dose rates are calculated. In HAC models, Addendum 7 assumes a total loss of all package components outside of the CV, but the CV and content remaining intact. Thus, the surface of the 6CV is considered as the package surface in the HAC dose rate calculations. The Addendum 7 evaluation further assumed that the $PuO_2$ contents from the Dual-3013 containers are combined into one compact cylinder filling the CV bottom within the aluminum sleeve. This is a very conservative assumption, since it maximizes the neutron subcritical multiplication. DOE PCP staff has confirmed the dimension of the shielding geometry and verified that the model assumption used in Addendum 7 for the dose rate calculations is conservative.

The bounding cases for the shielding calculations must be determined by comparing radiation dose rates from various models with different $PuO_2$ content shapes and locations within the CV. Addendum 7 evaluated homogeneously distributed cylinder models initially and then only considered the compact cylinder models shown in Figure 5.1(a) and (b) of this SER. DOE PCP staff confirmatory analysis evaluated compact sphere, cylindrical shell, homogeneous cylinder and compact cylinder models, as shown in Figure 5.1. DOE PCP staff obtained the highest HAC dose rates for the compact cylinder models in configuration (c) (HAC Top – ANL), because the $PuO_2$ source material is near the top of the CV, and in configuration (d) (HAC Side – ANL), because the two $PuO_2$ source materials are adjacent and located at the middle of the CV.



(a) NCT Model (b) HAC Bottom (c) HAC Top – ANL (d) HAC Side – ANL

**Figure 5.1 – (a),(b) NCT and HAC Models Evaluated in Addendum 7; and (a)-(d) Confirmatory Analyses. The $PuO_2$ contents are shown in color.**

In the shielding evaluations, the content is represented by a compact cylinder of $PuO_2$ powder filling the interior of the convenience can within the 3013 inner container. Furthermore, DOE PCP staff found that a compact cylinder model produces the highest dose rates for the 9977 package when the two $PuO_2$ contents are resting on the bottom of the 3013 inner container under NCT. Dose rates are highest when modeled with 7.0 $g/cm^3$-density $PuO_2$ content as a compact cylinder with a radius of 4.92 cm and a height of 9.372 cm, dimensions that preserve the total mass of 5 kg of $PuO_2$. The geometrical configuration of the neutron dose rate calculation model is identical to the configuration of the photon dose rate calculation model.

5.5 Shielding Evaluation

The MCNP-5 Code was used for shielding evaluations in Addendum 7; DOE PCP staff also used MCNP-5 for confirmatory evaluation. The cross section library used in the evaluations was based on ENDF-VI (Evaluated Nuclear Data Formats-VI). ANSI/ANS-6.1.1-1977 Neutron and Gamma-Ray Flux-to-Dose-Rate Factors were used to calculate dose rates. The highest photon dose rates are combined with the highest neutron dose rates to obtain the bounding total dose rates as shown in Table 5.3 of this SER, along with the 10 CFR 71 dose rate limits.

Table 5.3 shows that the calculated maximum NCT dose rates in Addendum 7 are slightly higher (≈2%) than the DOE PCP staff results; both sets of results are below the 10 CFR 71 regulatory limits for non-exclusive use shipment. The calculated maximum HAC side and bottom dose rates in Addendum 7 are comparable (within ≈10%) to the results obtained by DOE PCP staff. However, the DOE PCP staff-calculated maximum dose rate at 1 meter from the top of the package surface is about three times higher than that of Addendum 7, because the location of the $PuO_2$ source is near the top [Figure 5.1(c)]. Both sets of results are below the 10 CFR 71 regulatory limits of 1000 mR/h for non-exclusive use shipment.

According to the Addendum 7 dose rates summarized in Table A.5.1 and confirmed by the DOE PCP staff evaluation, the maximum dose rates from the 9977 package design are always on the drum surface since the $PuO_2$ content inside the CV is closest to the side surface.

**Table 5.3 Maximum Dose Rates* of the 9977 Package for $PuO_2$ in Dual-3013 Configuration**

| | Maximum Dose Location | Addendum 7 (mR/h ) | Staff (mR/h ) | 10 CFR 71 Non-Exclusive-Use Limits (mR/h ) |
|---|---|---|---|---|
| NCT, on package surface | Side | 72.51 | 71.80 | 200 |
| | Bottom | 35.53 | 34.40 | 200 |
| | Top | 11.02 | 9.81 | 200 |
| NCT, 1 m from package surface | Side | 3.34 | 3.31 | 10 |
| | Bottom | 1.32 | 1.19 | 10 |
| | Top | 0.54 | 0.45 | 10 |
| HAC, 1 m from package surface | Side | 5.52 | 5.89 | 1000 |
| | Bottom | 6.24 | 5.32 | 1000 |
| | Top | 1.37 | 4.11 | 1000 |

*All dose rates are the mean values from the MCNP calculations plus three standard deviations. The maximum Be impurity is 0.44 g per 3013 container.

DOE PCP staff confirmed the Addendum-7-calculated TI of 3.4 for the maximum Be impurity case (see Table 5.3, "NCT 1 m from package surface" data). The radiation level at 1 m from the external surface shall be measured to establish the TI for the package, and compared to the regulatory limit in 10 CFR 71. If the measured TI is greater than 10, the drum must be transported by "Exclusive Use" shipment, and/or additional 3013 container mass loading restrictions or impurity control measures may be used to reduce the dose rates.

### 5.6 Conclusion

On the basis of the statements and the representations in Revision 3 of Addendum7 and Revision 2 of the SARP, and the DOE PCP staff's confirmatory evaluation, DOE PCP finds that the shielding design and performance of the 9977 package with Dual-3013 contents presented in Chapter 5 of Addendum 7 and Chapter 5 of the SARP are acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

DOE PCP has concluded that the following condition of approval will be added to Revision 12 of the DOE CoC 9977:

- If the measured Transport Index is greater than 10, the drum must be transported by "Exclusive Use" shipment, and/or additional 3013 container mass loading restrictions or impurity control measures may be used to reduce the dose rates.

## 6. CRITICALITY EVALUATION

### 6.1 Discussion

DOE PCP staff reviewed the criticality safety design of the Model 9977 package with Dual- 3013 container assemblies and $PuO_2$ content described in Chapter 6 of Addendum 7 to the SARP. DOE PCP staff also performed Monte Carlo analyses to independently confirm the criticality safety for a single package, as well as for an array of packages under the most reactive conditions during NCT and HAC. The CSI for the Model 9977 package with Dual- 3013 container assemblies is 1.0.

## 6.2 Package Description

The design of the Model 9977 package with Dual- 3013 container assemblies and $PuO_2$ content includes a SS CV inside a 35-gal outer drum (see Figures A.0.1, A.1.1 and A.1.2 of Addendum 7 to the SARP). The space between the CV and the inner surface of the drum contains an HDS, thermal insulation and foam, but there are no specific neutron absorbers for criticality control. The drawings included in the references in Addendum 7 provide the dimensions of the relevant packaging components. Chapter 6 of Addendum 7 to the SARP and the associated references provide material specifications for the packaging components.

### 6.2.1 Contents

The payload consists of a single or Dual-3013 container assemblies (see Figure A.1.2 of Addendum 7 to the SARP). The $PuO_2$ in each 3013 container assembly is confined in a convenience can inside the inner 3013 can. The radioactive material mass limits and impurity mass limits for each 3013 container assembly in the CV are listed in Table A.1.1 in Chapter 1 of Addendum 7 to the SARP.

The 3013 container assemblies with $PuO_2$ content are evaluated with respect to criticality safety in Chapter 6 of Addendum 7. Descriptions of the Model 9977 package design features include identification of packaging materials, densities and compositions of packaging materials, and the fissile/fissionable material forms, masses, and isotopic compositions of the payloads. DOE PCP staff confirmed that the criticality-related information in Addendum 7 is complete and representative of the actual materials specified for the Model 9977 package. DOE PCP staff also confirmed that the models used in the criticality calculations are consistent with the drawings included in the references in Addendum 7.

## 6.3 Criticality Models

The KENO-VI code was used for criticality analyses in Addendum 7 to the SARP. The payload and the neutronically significant components of the Model 9977 package with Dual-3013 container assemblies and $PuO_2$ content were included in the KENO-VI models. Separate models were developed for single-package NCT and HAC analyses.

The NCT and HAC array calculations were based on detailed models of the Model 9977 package and payload. Square arrays were modeled in the KENO-VI calculations. To simulate a triangular pitch in the array calculations, the outer radius of the package was reduced by 7% in the square lattice KENO-VI models and the compositions of the outer regions of the package were then adjusted to conserve mass.

The array size was assumed infinite in the NCT array calculations for the $PuO_2$ contents. For the corresponding HAC array calculations, the array size was $6 \times 6 \times 3$. The Addendum 7 criticality analysis did not take credit for watertight containment either in the single-package analyses or in the array analyses. Water was modeled as the moderator and reflector for single-package and array calculations. The Addendum 7 criticality analysis determined the configurations of maximum reactivity with respect to moisture content within the drum, CV and 3013 container assemblies.

A standard SCALE 238-group cross section library based on ENDF/B Version 5 nuclear data was used for all KENO-VI calculations in Addendum 7 to the SARP and the confirmatory analyses. Section 6.8 of Addendum 7 summarizes the determination of the minimum $k_{safe}$ value. The lowest $k_{safe}$ value determined from the validation for the $PuO_2$ content is 0.945; therefore, any configuration of Model 9977 packages with $k_{eff} + 2\sigma < k_{safe}$ is deemed subcritical. All calculations incorporated sufficient neutron histories to ensure statistical uncertainty ($\sigma$) less than 0.002 and adequate convergence. DOE PCP staff concurs that the benchmark experiments and corresponding bias value are applicable and conservative, as applied to the Model 9977 package with Dual-3013 container assemblies and $PuO_2$ content.

6.4 Summary of Criticality Evaluation

Single Package under NCT and HAC

Chapter 6 of Addendum 7 to the SARP analyzed both a single package and an array of packages under NCT and HAC. Several single-package models were analyzed to determine the most reactive single-package configuration under various flooding scenarios. Table 6.1 shows the maximum $k_{eff} + 2\sigma$ reactivity results listed in Addendum 7 to the SARP and DOE PCP staff's confirmatory analyses for the Model 9977 package with $PuO_2$ content in the single-package configuration. All single-package configurations resulted in acceptable $k_{eff} + 2\sigma$ values below the $k_{safe}$ limit of 0.945. Therefore, the Model 9977 single package with Dual-3013 container assemblies and $PuO_2$ content and with the loading limits listed in Table A.1.1 of Addendum 7 to the SARP is subcritical and satisfies the requirements of 10 CFR 71.55(b) for a single package.

**Table 6.1 Addendum 7 and Staff Confirmatory Criticality Analyses for the Model 9977 Package with Dual-3013 Container Assemblies and $PuO_2$ Content**

| Case | Content | Case Name (Tables A.6.12–A.6.16 of Addendum 7) | Maximum $k_{eff} + 2\sigma$[a] | |
|---|---|---|---|---|
| | | | Addendum 7 | Staff |
| *Single Package – Flooded CV or Package Reflected by Water* | | | | |
| S1 | Dual-3013 containers[b] | sp_oxide_wet_no3013_sphere | 0.8808 | 0.8807 |
| S2 | Dual-3013 containers[b] | sp_oxide_mix_no3013_03_in | 0.8210 | 0.8196 |
| S3 | Dual-3013 containers[b] | sp_oxide_bot_vdf.11 | 0.7138 | 0.7157 |
| *NCT Array – Infinite* | | | | |
| N1 | Dual-3013 containers[b] per package | nct_oxide_dry_inf | 0.7199 | 0.7213 |
| *HAC Array – 6 × 6 × 3* | | | | |
| H1 | Dual-3013 containers[b] per package | hac_oxide-wetx_6x6x3 | 0.9379 | 0.9393 |

[a] Upper subcritical limit (USL) $k_{safe}$ value is 0.945.
[b] Each 3013 can hold 4,400 g $^{239}Pu$ as plutonium oxide.

Undamaged Package Arrays (under NCT)

The NCT undamaged package array model for the Model 9977 package with Dual-3013 container assemblies and $PuO_2$ content consisted of an infinite array of packages. The analysis in Chapter 6 of Addendum 7 to the SARP examined various flooding scenarios for the NCT array and showed that maximum reactivity occurs in an NCT array of Model 9977 packages under dry conditions, i.e., in a configuration in which there is no water in the 3013 container assemblies, CV, or drum.

Table 6.1 shows the maximum $k_{eff} + 2\sigma$ reactivity results listed in Addendum 7 to the SARP and DOE PCP staff's confirmatory analysis for the Model 9977 package with Dual-3013 container assemblies and $PuO_2$ contents for an NCT infinite-array configuration. All NCT arrays analyzed in Addendum 7 showed acceptable $k_{eff} + 2\sigma$ values that are below the $k_{safe}$ limit of 0.945. Therefore, the Model 9977 package with Dual-3013 container assemblies and $PuO_2$ content and with the loading limits listed in Table A.1.1 of Addendum 7 to the SARP satisfies the requirements of 10 CFR 71.59.

Damaged Package Arrays (under HAC)

The HAC damaged package array model for the Model 9977 package with Dual-3013 containers and $PuO_2$ content consisted of a 6 × 6 × 3 array of packages. Various flooding scenarios were analyzed to ensure that the configuration of maximum reactivity had been analyzed. Table 6.1 shows the maximum $k_{eff} + 2\sigma$ reactivity results listed in Addendum 7 and the staff's confirmatory analyses for the Model 9977 package with Dual-3013 containers and $PuO_2$ content. All HAC arrays analyzed in Addendum 7 showed acceptable $k_{eff} + 2\sigma$ values below the $k_{safe}$ limit of 0.945. Therefore, the Model 9977 package with Dual-3013 container assemblies and $PuO_2$ content and with the loading limits listed in Table A.1.1 of Addendum 7 to the SARP satisfies the requirements of 10 CFR 71.59.

### 6.5 Criticality Safety Index

On the basis of the NCT infinite array analysis and the HAC 6 x 6 x 3 array analysis of the $PuO_2$ content, a CSI of 1.0 was determined and reported in Chapter 1 of Addendum 7 to the SARP. DOE PCP staff concurs that this CSI value of 1.0 is appropriate for the Model 9977 package with Dual-3013 container assemblies and with $PuO_2$ content limits listed in Table A.1.1 of Addendum 7 to the SARP.

### 6.6 Conclusion

On the basis of the statements and the representations in Revision 3 of Addendum 7 and Revision 2 of the SARP, and DOE PCP staff's confirmatory evaluation, DOE PCP finds that the criticality design and performance of the 9977 package with Dual-3013 contents presented in Chapter 6 of Addendum 7 and Chapter 6 of the SARP are acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

## 7. PACKAGE OPERATIONS

### 7.1 Discussion

DOE PCP staff reviewed the requirements for general operating procedures for loading, unloading, shipping, and receiving the Model 9977 packages with Dual-3013 containers containing $PuO_2$ content; preparation of empty Model 9977 packages for transport; and other operations as described in Chapter 7, Addendum 7 of the SARP. The specific operational criteria for the 9977 package with Dual-3013 containers are presented in Chapter 7, and shall be implemented by the package user. In addition, the package user shall develop specific written operating procedures to ensure that the package operations are conducted in accordance with the CoC and Chapter 7, Addendum 7 of the SARP. Each user of a Model 9977 packaging shall register with the DOE Headquarters Certifying Official prior to first use of the packaging. Quality Assurance (QA) personnel shall participate in package operations.

### 7.2 General Information

Section 7.0 in Addendum 7 of the SARP provides general information relating to package operations and discusses planning, personnel qualifications, equipment, quality assurance, and nomenclature. Before each shipment, the user must have site-specific procedures that comply with the requirements of the CoC, Chapter 7 of Addendum 7 of the SARP, and the requirements of 10 CFR 71.5.

### 7.3 Package Loading

Section 7.1 in Addendum 7 of the SARP describes the package loading requirements for the Model 9977 packages with Dual-3013 containers containing $PuO_2$ content. Before any packaging operations are begun, the payloads to be shipped must be fully characterized with respect to the chemical and physical forms, and the specific requirements of Section 1.2.2 in Addendum 7of the SARP. The main changes in Addendum 7 include the addition of an HDS (the HDS and the 3013 Spacer shall be verified as properly installed) to accommodate the higher heat load of 38 W that comes from the use of Dual-3013 containers, and a requirement to dilute the 6CV atmosphere to at least 75% $CO_2$ by volume.

7.4 Package Unloading

Section 7.2 in Addendum 7 of the SARP describes the package unloading requirements for the Model 9977 packages with Dual-3013 containers containing $PuO_2$ content. This section has two changes to the SARP for Addendum 7. These changes address the HDS and the 3013 Spacer, and allow them to remain in the drum and 6CV, respectively, when the package is being unloaded. Remove the HDS, the Bottom Load Distribution Fixture, and the 3013 Spacer if contaminated, and decontaminate them in accordance with approved procedures.

7.5 Preparation of Empty Package for Transport

Section 7.3 in Addendum 7 of the SARP describes the preparation of an empty package for transport of the Model 9977 packages with Dual-3013 containers.

7.6 Other Operations

Section 7.4 in Addendum 7 of the SARP describes other operations, e.g., storage of the Model 9977 packages with Dual-3013 containers.

7.7 Conclusion

On the basis of the statements and representations, in Chapter 7 of Addendum 7, to the 9977 SARP and DOE PCP staff's confirmatory evaluation, DOE PCP finds that the operating procedure requirements presented in Chapter 7 of Addendum 7 of the 9977 SARP are acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

DOE PCP has concluded that the following three (3) conditions of approval will be added to Revision 12 of the DOE CoC 9977t:

- Use Chapter 7 of Addendum 7 Revision 3 in its entirety.
- The Heat Dissipation Sleeve and the annular 3013 Spacer must be used for the 9977 package with Dual-3013 containers. Verify that the Heat Dissipation Sleeve and the annular 3013 Spacer have been properly installed.
- If the measured Transport Index is greater than 10, the drum must be transported by "Exclusive Use" shipment, and/or additional 3013 container mass loading restrictions or impurity control measures may be used to reduce the dose rates.

## 8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

### 8.1 Discussion

DOE PCP staff reviewed the requirements for Acceptance Tests and Maintenance that are in Chapter 8, Addendum 7 of the 9977 SARP.

### 8.2 Acceptance Tests and Maintenance Program Evaluation

The addition of the 3013 Spacer to the 9977 packaging for inclusion of the Dual-3013 containers results in a revision to Appendix 8.2, *Packaging Independent Verification Items*. Certain attributes of the 3013 Spacer require independent verification that dimensional, surface-feature and material requirements satisfy drawing requirements and have been documented. There have not been any other changes to Chapter 8, nor to four of the other five appendices in Chapter 8. Appendix 8.2, *Packaging Independent Verification*, is the only appendix that has been revised.

### 8.3 Conclusion

On the basis of the statements and representations in Chapter 8 of Addendum 7 to the SARP and DOE PCP staff's confirmatory evaluation of the changes to Appendix 8.2, DOE PCP finds that the acceptance tests and maintenance program presented in Addendum 7 for Chapter 8 are acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

## 9. QUALITY ASSURANCE

### 9.1 Discussion

DOE PCP staff reviewed the requirements for the QA program that are in Chapter 9, Addendum 7 of the 9977 SARP. The results of the QA review are discussed below.

### 9.2 QA Evaluation

The addition of the HDS and the 3013 Spacer components to the 9977 packaging for inclusion of Dual-3013 contents has been included in *Table A.9.1 – Safety Assessment of Packaging Features*. The HDS is a Q Category B while the 3013 Spacer is a Q Category A. The HDS's function is to increase thermal conductance while the function of the 3013 Spacer is to maintain geometry within the 6CV for criticality safety.

### 9.3 Conclusion

On the basis of the statements and representations in Chapter 9 of Addendum 7 to the SARP and DOE PCP staff's confirmatory evaluation, DOE PCP finds that the QA requirements identified in Chapter 9 of the SARP and Addendum 7 are acceptable and will provide reasonable assurance that the regulatory requirements in 10 CFR 71 have been met.