Safety Evaluation Report for the Model ES-3100 Package with Plutonium Oxide Content

Docket No. 10-57-9867

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SUMMARY

By a letter dated September 30, 2010, the National Nuclear Security Administration Office of Fissile Materials Disposition (NA-26) submitted to the U.S. Department of Energy (DOE) Packaging Certification Program (PCP), Office of Packaging and Transportation, an application requesting that the DOE issue a Certificate of Compliance (CoC) for the ES-3100 package with plutonium oxide content. A Safety Analysis Report for Packaging (SARP), identified as SRP-802006-0001, Rev. A, dated September 30, 2010, was also submitted with the intent to provide the necessary documentation that the design of the Model ES-3100 package with plutonium oxide content: (a) satisfies the relevant Department of Transportation (DOT) and Nuclear Regulatory Commission regulatory (NRC) safety requirements as specified in Title 49 of the Code of Federal Regulations (CFR) Part 173 and Title 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 Nuclear Regulatory Commission Regulatory Guides 7.9 and 7.10.

DOE PCP staff reviewed the Rev. A SARP and had 13 Q1 questions on the nine chapters in the SARP. During its confirmatory review, the PCP staff had 9 additional questions. The applicant responded to all 22 questions and provided revisions to the SARP. PCP staff also conducted independent confirmatory evaluation of the SARP. On the basis of the statements and representations in the SARP[1] and DOE PCP staff's confirmatory evaluation, as summarized in this Safety Evaluation Report (SER), the DOE PCP finds that the design and performance of the ES-3100 package is acceptable for the transport of plutonium oxide, 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.

It should be noted that even though the request was for a new ES-3100 content, which could be covered as an amendment under the existing CoC USA/9315/B(U)F-96 (DOE) for the HEU contents, a new CoC for the transport of plutonium oxide content in the ES-3100 packaging will be issued as USA/9867/B(U)F-96 (DOE).

DOE PCP has concluded that fourteen (14) conditions of approval will be placed in the DOE CoC USA/9867/B(U)F-96, Revision 0, as follows:

(1) The Model ES-3100 package with plutonium oxide content is for domestic use only.

(2) The vent holes on the outer steel drum shall be capped closed during transport and storage to preclude entry of rain water into the insulation cavity of the drum.

(3) 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 ES-3100 containment vessel (CV) is sealed.

(4) The package content includes either one or two 3013 container assemblies and associated packing materials (aluminum spacers and stainless steel scrubbers). For two 3013 container assemblies, a 5.25 inch-tall aluminum spacer shall be placed below each 3013

container assembly. For a single 3013 container assembly, an additional 10 inch-tall aluminum spacer shall be placed on top of the 5.25 inch-tall aluminum spacer. Stainless-steel scrubbers may be added on top of the upper 3013 container assembly or the 10 inch-tall aluminum spacer to minimize vertical movement of the 3013 container assemblies and aluminum spacers during transport.

(5) In addition to the radioactive material and impurity mass loading limits per 3013 container assembly (Tables 1.2 and 1.3 of this SER), the plutonium oxide in the ES-3100 package shall be limited to a total of 10 kg (22.05 lb) and the maximum amount of fissile material allowed in the package shall be 8.8 kg (19.4 lb).

(6) As prescribed in Table 1.3 of this SER, the mass of impurities in the plutonium oxide to be loaded into the ES-3100 package will be counted against the fissile mass loading limit. The plutonium oxide will not contain unevaluated moderating materials.

(7) The bulk density of the plutonium oxide shall be >2.31 g/cm^3 and <11.46 g/cm^3.

(8) The maximum allowable payload weight in the ES-3100 package (which includes 3013 container assemblies with plutonium oxide, aluminum spacers, and stainless steel scrubbers) may not exceed 40.82 kg (90 lb). The maximum allowable gross shipping weight is 190.5 kg (420 lb).

(9) The void space within the CV shall be backfilled with $\geq$80% by volume carbon dioxide gas prior to shipment.

(10) The maximum decay heat of the contents in the package shall be limited to a total of 30 W, with no more than 19 W per 3013 container assembly.

(11) Transport by air or water is not authorized.

(12) Shippers must have a methodology for assuring that the pressure in each of the 3013 cans does not exceed 50 psig at the time of loading and does not exceed 50 psig during transportation. This methodology must be approved in writing by the Headquarters Certification Official prior to shipment.

(13) All CV assemblies used to transport plutonium oxide in the ES-3100 package shall be hydrostatically pressure tested at 250 ± 5 psig.

(14) In addition to the requirements of Subparts G and H of 10 CFR Part 71, each package must be fabricated, acceptance tested, loaded, operated, and maintained in accordance with the Operating Procedures requirements of Chapter 7, the Acceptance Tests and Maintenance requirements of Chapter 8, and the packaging-specific Quality Assurance requirements of Chapter 9 of the SARP

1. GENERAL INFORMATION AND DRAWINGS

1.1 Packaging Description

The ES-3100 package consists of the packaging components and the plutonium oxide content that are placed within 3013 container assemblies.

Figure 1.1 is a schematic of the ES-3100 packaging (without the plutonium oxide content and the 3013 container assemblies). The packaging consists of a cylindrical container that is approximately 43.5 in. (110 cm) in overall height, including the cover and lid, with an approximate 19 in. (49 cm) overall diameter. It is composed of an outer drum assembly and an inner containment vessel (CV). The main functions of the packaging are to provide containment, shielding, and nuclear criticality safety. Table 2.6 of the SARP provides detailed material specifications for the packaging components.

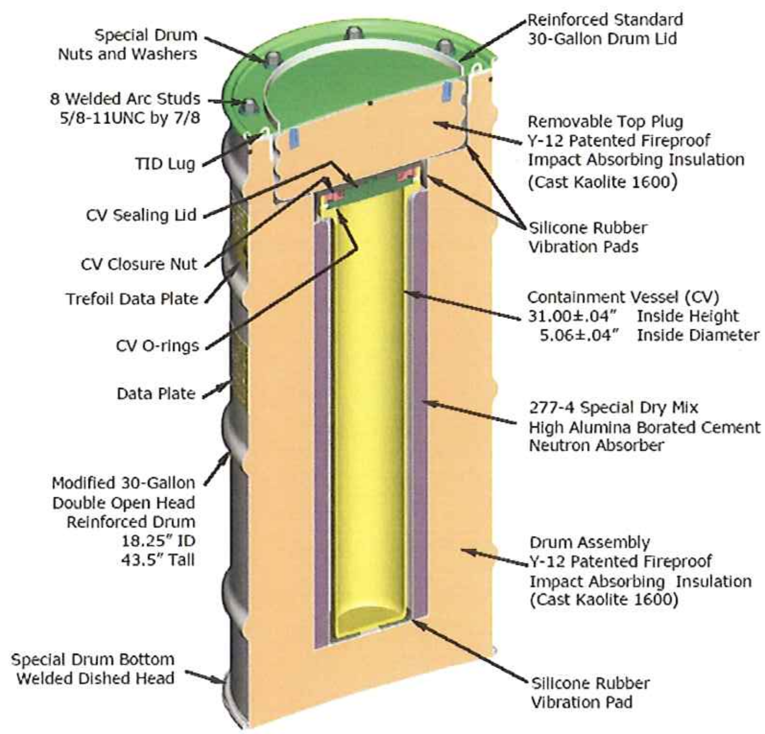


Figure 1.1. Schematic of the ES-3100 packaging

Figure 1.2 depicts a typical shipping configuration of the ES-3100 package, with plutonium oxide contained in two 3013 container assemblies: an aluminum spacer is at the bottom of the CV, the other aluminum spacer is between the two 3013 container assemblies, and stainless steel scrubbers are above the second 3013 container assembly.

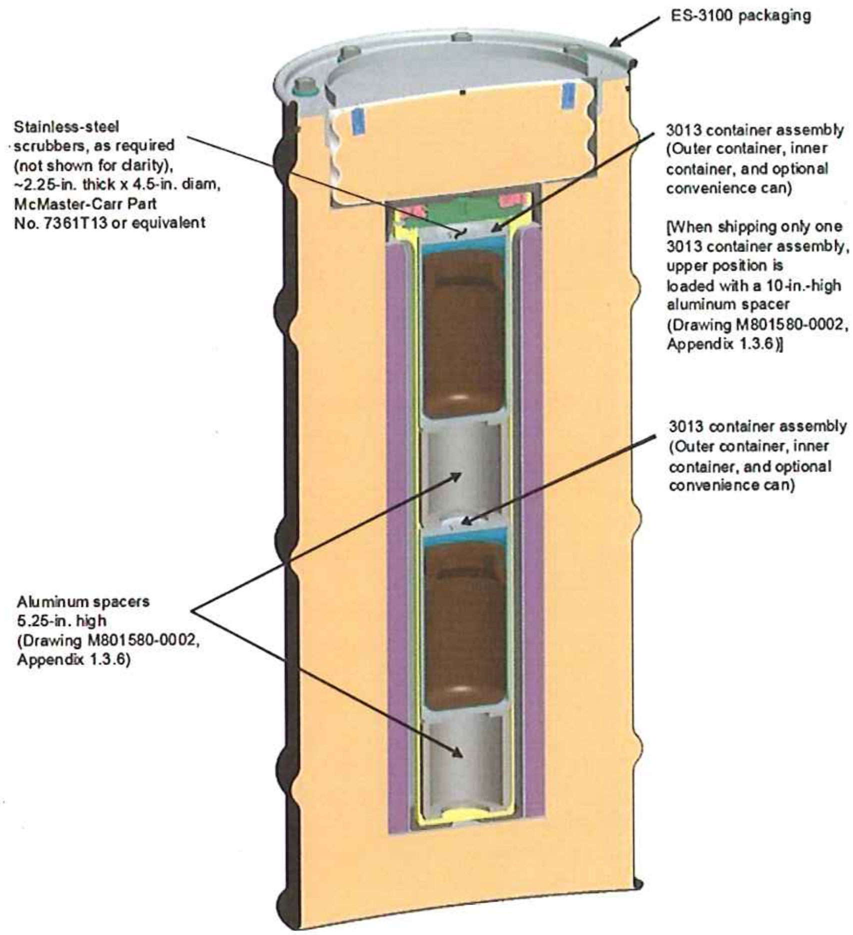


Figure 1.2. ES-3100 package with plutonium oxide content in two 3013 container assemblies

Outer Drum Assembly

The outer drum assembly consists of (a) a reinforced stainless steel, standard mil spec 30-gallon drum with an increased length, (b) a cylindrical layer of castable refractory material (Kaolite 1600™), which is composed of concrete and vermiculite, and which acts as both an impact-absorbing and thermal-insulating material, (c) a cylindrical layer of castable refractory (277-4 special dry mix) for neutron attenuation purposes, (d) an inner steel liner, and (e) a removable top plug that also has a layer of the castable refractory material (Kaolite 1600) for impact absorption and thermal insulation.

The 30-gallon drum is manufactured from 16-gauge type 304 or 304L stainless steel. The fabrication is accomplished according to requirements specified in NUREG/CR-3854 (specifically, it is in accordance with the dimensional requirements of MIL-D-6054F, as modified according to Drawing M2E801580A004). The inner liner is also manufactured from type 304 or type 304L stainless steel.

Containment Vessel

The CV is placed inside the outer drum assembly, surrounded by the neutron-attenuating material (277-4) and impact-absorbing and thermal-insulating material (Kaolite 1600). It is approximately 32 in. (82 cm) in overall height and 5 in. (13 cm) in overall diameter, and is constructed of 304L stainless steel. The CV lid assembly consists of a sealing lid, a closure nut, an external retaining ring that holds the assembly and closure nut together, and double ethylene-propylene elastomer O-rings. The double O-rings in the top flange of the CV permit leak testing of the CV. The containment boundary consists of the 0.1 in. (0.254 cm)-thick CV body, the CV sealing lid assembly, and the inner ethylene-propylene elastomer O-ring.

Drawings

The drawings that pertain to the ES-3100 package are listed in Table 1.1.

Table 1.1. List of Drawings Pertaining to the ES-3100 Package

Drawing No.	Revision	Title
M2E801580A001	C	Drum Assembly
M2E801580A002	B	Body Weldment
M2E801580A003	B	Inner Liner Weldment (2 sheets)
M2E801580A004	B	Double Open Head Reinforced Drum
M2E801580A005	D	Misc. Details
M2E801580A006	B	Drum Lid Weldment
M2E801580A007	B	18.25" Diameter Drum Lid
M2E801580A008	B	Top Plug Weldment
M2E801580A009	C	Pad Details
M2E801580A010	F	Data Plate Details
M2E801580A013	C	Containment Vessel O-ring Details
M801580-0001	A	Main Assembly
M801580-0002	A	5.25 & 10.00 in. Spacers Detail
M801580-0003	0	Containment Vessel Assembly
M801580-0004	0	Containment Vessel Body Assembly (2 sheets)
M801580-0005	0	Containment Vessel Lid Assembly
M801580-0006	0	Containment Vessel Sealing Lid
M801580-0007	0	Containment Vessel Closure Nut
M801580-0009	0	Containment Vessel Leak Test Assemblies
T2E801827A008	A	Leak Check Flange Assembly

1.2 Contents

The contents to be shipped in the Model ES-3100 package shall consist of not more than 10 kg (22.05 lb) of plutonium oxide. The plutonium oxide is placed in one or two 3013 container assemblies, with not more than 5 kg (11.02 lb) per 3013 container assembly.[2] The amount of fissile material allowed in the ES-3100 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.

The maximum weight of all materials in the CV, including the 3013 containers, aluminum spacers, and other packing materials, shall not exceed 40.82 kg (90 lb). The maximum mass and concentration of radioactive isotopes permitted in the ES-3100 content are listed in Table 1.2. In addition to the isotopes shown in Table 1.2, various impurities may be present in the content, as shown in Table 1.3.

Weights and Contents Descriptions

The maximum allowable gross shipping weight for the ES-3100 package is 190.5 kg (420 lb); the largest nominal gross shipping weight of the ES-3100 package with plutonium oxide content is 171.77 kg (378.69 lb). The maximum weight of plutonium oxide allowed in the ES-3100 package is 10 kg (22.05 lb). The maximum allowable payload weight, including 3013 container assemblies with their content, aluminum spacers, and stainless-steel scrubbers, is 40.82 kg (90 lb).

The fissile material content shall be in solid form. All plutonium oxide contents shall be packed in accordance with DOE-STD-3013 inside a 3013 container assembly.

The maximum decay heat of the plutonium oxide content is 30 W per package and 19 W per 3013 container assembly.

Table 1.2. Radioactive material mass limits per 3013 container assembly [a, b]

Radionuclide [c]	Concentration basis	Bounding mass limit (g)
	Plutonium	
^{236}Pu	1 ppb Pu	0.0000044
^{238}Pu	0.05 wt % Pu	2.2
^{239}Pu	100 wt % Pu	4400.0
^{240}Pu	9 wt % Pu	396.0
^{241}Pu	1 wt % Pu	44.0
^{242}Pu	0.1 wt % Pu	4.4
	Uranium	
^{232}U	12 ppb U	0.0000528
^{233}U	0.5 wt % of total mass [a]	25.0
^{234}U	2 wt % U	88.0
^{235}U	100 wt % U	4400.0
^{236}U	40 wt % U	1760.0
^{238}U	100 wt % U	4400.0
	Other radionuclides	
^{241}Am	7000 µg/g Pu	30.8
^{237}Np	1000 µg/g Pu	4.4
^{232}Th	300 µg/g Pu	1.32

[a] Material loading limits and safety-related requirements for the 3013 container assembly are stipulated in DOE-STD-3013 (Stabilization, Packaging, and Storage of Plutonium-Bearing Materials, DOE-STD-3013-2004, U.S. DOE, April 2004), which include the following criteria:

1) Plutonium-bearing materials stabilized and packaged to meet earlier versions of DOE-STD-3013 are acceptable without further evaluation as to whether they meet the 2004 version. (DOE-STD-3013, "Foreword")
2) The mass of plutonium plus uranium shall be ≥30 wt % of the total material mass. (DOE-STD-3013, Sect. 1, "Scope")
3) The mass of ^{233}U shall be ≤0.5 wt % of the total material mass. (DOE-STD-3013, Sect. 1, "Scope")
4) Oxide materials shall be stabilized in accordance with DOE-STD-3013, Sect. 6.1.2, "Oxides."
5) The moisture content of the oxide materials shall be <0.5 wt % of the total material mass. (DOE-STD-3013, Sect. 6.1.2, "Oxides," and Sect. 6.1.4, "Storage after Stabilization-Deferred Packaging")
6) The mass of plutonium and other fissile species shall not exceed 4.40 kg (9.70 lb), and the total mass of contained materials shall not exceed 5.00 kg (11.02 lb). (DOE-STD-3013, Sect. 6.3.2, "Mass of Contained Materials")
7) The mass of contained materials shall be limited to ensure that the maximum decay heat will not exceed 19 W at any time during storage or transportation. (DOE-STD-3013, Sect. 6.3.2, "Mass of Contained Materials")
8) Contained materials shall not corrode or otherwise adversely affect the structural integrity of the 3013 inner or outer container. (DOE-STD-3013, Sect. 6.3.3, "Packaging Process")

[b] The bulk density of the oxide materials shall be >2.31 g/cm^3 and <11.46 g/cm^3.

[c] Except as stated in Table 1.1, actinides, fission products, decay products, and neutron activation products are permitted at concentrations <1000 ppm each. Assessment of these impurities may be based on process knowledge. The ^{232}U and ^{236}Pu concentrations are understood to be below normally available detection capability and are not measured; however, they are assumed present for conservatism in the appropriate SARP evaluations.

Table 1.3. Impurity mass limits per 3013 container assembly [a]

Element [b]	Bounding mass limit (g)
Aluminum (Al)	66.0
Barium (Ba)	44.0
Beryllium (Be)	22.0
Boron (B)	13.2
Calcium (Ca)	528.0
Carbon (C)	44.0
Chlorine (Cl)	1452.0
Chromium (Cr)	35.2
Cobalt (Co)	44.0
Copper (Cu)	13.2
Fluorine (F)	30.8
Gallium (Ga)	83.6
Hydrogen (H)	— [c]
Indium (In)	11.0
Iron (Fe)	79.2
Lanthanum (La)	22.0
Lead (Pb)	22.0
Lithium (Li)	44.0
Magnesium (Mg)	308.0
Manganese (Mn)	8.8
Molybdenum (Mo)	(Mo + Zr) ≤ 22.0
Nickel (Ni)	66.0
Niobium (Nb)	15.4
Nitrogen (N)	22.0
Oxygen (O)	— [d]
Phosphorus (P)	(P + S) ≤ 50.0
Potassium (K)	968.0
Rubidium (Rb)	22.0
Silicon (Si)	72.6
Silver (Ag)	44.0
Sodium (Na)	572.0
Strontium (Sr)	44.0
Sulfur (S)	(P + S) ≤ 50.0
Tantalum (Ta)	44.0
Tin (Sb)	44.0
Titanium (Ti)	13.2
Tungsten (W)	44.0
Vanadium (V)	30.8
Yttrium (Y)	44.0
Zinc (Zn)	44.0
Zirconium (Zr)	(Mo + Zr) ≤ 22.0

[a] Total impurity mass shall be ≤3.5 kg. The total impurity mass is calculated by subtracting the total mass of plutonium and uranium from the total material mass and counting the remaining mass as impurities. After stabilization in accordance with DOE-STD-3013, Sect. 6.1.2 ("Stabilization, Packaging, and Storage of Plutonium-Bearing Materials," DOE-STD-3013-2004, U.S. DOE, April 2004), the dominant impurity phases consist of binary and compound metal oxides in addition to binary chloride salts (i.e., NaCl, KCl, $CaCl_2$, and $MgCl_2$).

[b] Except as stated in Table 1.2, other impurities are permitted at concentrations <1,000 ppm each. Assessment of these impurities may be based on process knowledge.

[c] Hydrogen due to adsorbed water, which is limited in accordance with the DOE-STD-3013 moisture criterion (i.e., <0.5 wt % of the total material mass).

[d] Oxygen due to binary and compound oxides formed during the stabilization process plus the contribution from the adsorbed water.

Either one or two 3013 container assemblies will be shipped inside the ES-3100 CV. If two 3013 container assemblies are shipped, a 5.25 inch-tall cylindrical aluminum spacer (Part M801580-0002-1) shall be placed below each 3013 container assembly. If only one 3013 container assembly is shipped in the ES-3100 CV, a 5.25 inch-tall aluminum spacer (Part M801580-0002-1) shall be placed both below and above the 3013 container assembly and a 10-in.-tall cylindrical aluminum spacer (Part M801580-0002-2) shall be placed above the upper 5.25 inch-tall aluminum spacer. In both cases, stainless steel scrubbers may be added on top of the uppermost aluminum spacer to minimize vertical movement of the 3013 container assembly and aluminum spacers during transport.

Contents Radioactive Constituents

The maximum number of A_2 quantities allowed in an ES-3100 package with plutonium oxide content is 44,390 (at 40 years).

The maximum activity allowed in an ES-3100 package with plutonium oxide content is 369.90 TBq (at initial fabrication).

1.3 Criticality Safety Index (CSI)

Properly configured Model ES-3100 packages with plutonium oxide content must 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 ES-3100 packages meet the requirements of 10 CFR 71.55 and 10 CFR 71.59 for a package, with a Criticalty Safety Index of zero (CSI = 0).

1.4 Radiation Level and Transport Index

The maximum dose rates calculated in the SARP and confirmed by DOE PCP staff are all significantly below the regulatory limits for a nonexclusive-use shipment. The transport index calculated by the PCP staff is 2.4 (See Section 5 of this SER).

1.5 Conclusion

On the basis of the statements and representations in the SARP and DOE PCP staff's confirmatory evaluation, the staff finds the general information (and drawings) presented in Chapter 1 of the Model ES-3100 package with plutonium oxide content acceptable.

DOE PCP has concluded that eleven (11) conditions of approval need to be added to the DOE CoC USA/9867/B(U)F-96, Revision 0, as follows:

- The Model ES-3100 package with plutonium oxide content is for domestic use only. (Page 1-1 of the SARP)
- The vent holes on the outer steel drum shall be capped closed during transport and storage to preclude entry of rain water into the insulation cavity of the drum. (Page 1-5 of the SARP)

- 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 ES-3100 CV is sealed. (Page 1-11 of the SARP)

- The package content includes either one or two 3013 container assemblies and associated packing materials (aluminum spacers and stainless steel scrubbers). For two 3013 container assemblies, a 5.25 inch-tall aluminum spacer shall be placed below each 3013 container assembly. For a single 3013 container assembly, an additional 10 inch-tall aluminum spacer shall be placed on top of the 5.25 inch-tall aluminum spacer. Stainless-steel scrubbers may be added on top of the upper 3013 container assembly or the 10 inch-tall aluminum spacer to minimize vertical movement of the 3013 container assemblies and aluminum spacers during transport. (Page 1-13 of the SARP)

- In addition to the radioactive material and impurity mass loading limits per 3013 container assembly (Tables 1.2 and 1.3 of this SER), the plutonium oxide in the ES-3100 package shall be limited to a total of 10 kg (22.05 lb) and the maximum amount of fissile material allowed in the package shall be 8.8 kg (19.4 lb). (Page 1-16 of the SARP)

- As prescribed in Table 1.3 of this SER, the mass of impurities in the plutonium oxide to be loaded into the ES-3100 package will be counted against the fissile mass loading limit. The plutonium oxide will not contain unevaluated moderating materials. (Page 1-12 of the SARP)

- The bulk density of the plutonium oxide shall be >2.31 g/cm^3 and <11.46 g/cm^3. (Page 1-16 of the SARP)

- The maximum allowable payload weight in the ES-3100 package (which includes 3013 container assemblies with plutonium oxide, aluminum spacers, and stainless steel scrubbers) may not exceed 40.82 kg (90 lb). The maximum allowable gross shipping weight is 190.5 kg (420 lb). (Page 1-16 of the SARP)

- The void space within the CV shall be backfilled with $\geq$80% by volume CO_2 gas prior to shipment. (Page 1-16 of the SARP)

- The maximum decay heat of the contents in the package shall be limited to a total of 30 W, with no more than 19 W per 3013 container assembly. (Page 1-16 of the SARP)

- Transport by air or water is not authorized. (Page 1-16 of the SARP)

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

2. STRUCTURAL

2.1 Discussion

DOE PCP staff reviewed the structural design and performance of the ES-3100 package with plutonium oxide content described in Chapter 2 of the SARP. DOE PCP staff also performed finite element analysis to independently evaluate the design and performance of the package. The review and analysis were focused on the structural performance of the ES-3100 package with plutonium oxide content, the geometric stability of the aluminum spacers under Hypothetical Accident Conditions (HAC), material compatibility between the CV and the shipping contents, and the potential impact of hydrogen deflagration and detonation.

2.2 Structural Evaluation

Structural performance of the ES-3100 package with Pu oxide content

The major structural components of the ES-3100 packaging are the drum assembly, CV, 3013 container assemblies and aluminum spacers. The drum assembly provides confinement and protection to the CV and the shipping contents. All plutonium oxide contents will be packed in 3013 container assemblies in accordance with DOE-STD-3013. Either one or two 3013 container assemblies will be shipped in each ES-3100 CV. If two 3013 container assemblies are shipped, a 5.25 inch-tall hollow cylindrical aluminum spacer will be placed below each 3013 container assembly. If only one 3013 container assembly is shipped, the 5.25 inch-tall spacer will be placed both below and above the 3013 container assembly and a 10 inch-tall hollow cylindrical aluminum spacer will be placed above the upper 5.25 inch-tall spacer. Stainless steel scrubbers may be added on top of the upper 3013 container assembly or the taller spacer to minimize vertical movement of both the 3013 container assemblies and the aluminum spacers during transport.

The SARP structural evaluation was a combination of physical testing and finite element analysis using computer code LS-DYNA. For both the structural test and analysis, three steel cylinders were used as the surrogate payload. The surrogate payload had high stiffness to introduce damage to the CV at least as severe as that caused by impacts of the 3013 containers and the aluminum spacers. The highest nominal and maximum allowable gross shipping weights of the ES-3100 package with plutonium oxide content are 171.77 kg (378.69 lb) and 190.5 kg (420 lb), respectively, which are less than the maximum weight of the tested ES-3100 prototypes of 203.66 kg (449 lb). Therefore, the structural evaluation of the drum assembly and the CV based on field testing and analysis remains valid for the ES-3100 package with plutonium oxide content.

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-foot free drop of the 3013 assembly with the payload, and the inner container remained leaktight after a 4-foot free drop of the inner container with the payload.[3] Both the 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. The results of drop simulations using finite element code LS-DYNA, as documented in DAC-M801580-0001 of the SARP, showed that a 3013 container assembly maintains its structural integrity under both Normal Conditions of Transport (NCT) and HAC. However, the 3013 inner and outer containers are conservatively assumed not to maintain their structural integrity; they are only assumed to be adequate to maintain confinement of the plutonium oxide content under both NCT and HAC.

Geometric stability of aluminum spacers

The SARP contained LS-DYNA analysis results to demonstrate the structural performance of the spacers under the HAC drops, and concluded that there was no plastic deformation of the aluminum spacers. However, the critical load for dynamic buckling of the hollow aluminum spacers has not been evaluated. DOE PCP staff used Abaqus code to evaluate the buckling of the aluminum spacers during the bottom-down 30-ft drop, the orientation at which the largest buckling force is expected. The maximum dynamic load applied within a very short duration during HAC drops can far exceed the static buckling load of the aluminum spacers.[4] PCP staff calculated an impact load of approximately 9,000 lbf on the aluminum spacers during the 30-ft bottom-down drop, which is much lower than the static critical load of buckling of $P_{cr} = \pi^2 EI/4l^2 = 1.11 \times 10^7$ lbf for the 5.25 inch-tall spacers. The analysis results also showed no plastic deformation of the spacers during the 30-ft drop. Therefore, the aluminum spacers will not buckle or yield, and the spacing between the loaded 3013 containers will not change during NCT and HAC.

Material compatibility

There is no material compatibility issue between the 3013 container assemblies, scrubbers and CV, because they are all fabricated from stainless steel and are galvanically similar. The aluminum spacers are made of 6061 aluminum alloy, which is covered by an outer oxide layer at the surface. This oxide layer is passive and does not react with any other metallic components in the CV. Although 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 plutonium oxide contents will be confined within the multibarrier 3013 container assemblies, and corrosion of the CV caused by the plutonium oxide is unlikely.

Potential impact of hydrogen deflagration/detonation

DOE PCP staff also evaluated the potential impact of hydrogen deflagration/detonation on the ES-3100 package with plutonium oxide content. The stabilized plutonium oxide contains moisture (not more than 0.5%), and radiolysis of water could generate hydrogen gas in the 3013 containers. To avoid hydrogen deflagration and detonation, the ES-3100 CV is inerted with carbon dioxide (CO_2) to a minimum volumetric efficiency of 80%, 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 additional details).

2.3 Conclusion

On the basis of the statements and the representations in the SARP, and DOE PCP staff's confirmatory evaluation, DOE PCP finds the structural design and performance of the ES-3100 package with plutonium oxide content presented in Chapter 2 of the SARP 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 ES-3100 package with plutonium oxide content described in Chapter 3 of the SARP. DOE PCP staff also performed confirmatory analyses to independently evaluate the thermal performance of the ES-3100 package during both NCT and HAC. The review and the analyses were focused on the materials' thermal properties, temperature limits, maximum temperatures and maximum thermal stresses of the packaging components, maximum normal operating pressure (MNOP), maximum HAC pressure, and potential hydrogen deflagration/detonation issue inside the CV.

3.2 Thermal Evaluation

The plutonium oxide content is shipped in either one or two 3013 container assemblies placed inside the CV. The shipping content has a maximum decay heat load of 30 W per ES-3100 package and 19 W per 3013 container assembly. The thermal-related design features of the ES-3100 package (e.g., thermal properties, temperature limits, maximum temperatures and pressures, and thermal stresses) are described in the SARP. The SARP used both tests and analyses to evaluate the packaging component temperatures under NCT and HAC. The following assumptions are made in the SARP to determine the MNOP and the maximum HAC pressure:

(1) The ES-3100 CV is sealed at standard temperature and pressure (77 °F and 14.7 psia), and is backfilled with CO_2 to a minimum of 80 vol.%.

(2) The 3013 container assembly is sealed at 14.7 psia, and inerted with helium so the oxygen is less than 5 vol.%.

(3) The free gas volume inside the 3013 container assembly is evaluated based on a theoretical density (maximum) of plutonium oxide at 0.414 $lb/in.^3$

(4) Prior to loading into the CV, the initial pressure in a 3013 container assembly is assumed to be 50 psig based on surveillance data.[5]

(5) After loading into the CV, the 3013 container assembly leaks and the gas is completely mixed with the air and CO_2 in the CV.

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

DOE PCP staff also performed confirmatory analysis to evaluate the thermal design and performance of the package. The thermal properties of materials for fabricating the packaging components have been provided in the SARP, which are in good agreement with the literature data.

3.2.1 Thermal Evaluation Under NCT

The SARP evaluated the NCT thermal performance using finite element code ANSYS with a two-dimensional axisymmetric model for the ES-3100 package. Details of the finite element model and the results are provided in references DAC-M801912-0003 and DAC-M801912-0006 of the SARP. The NCT analyses simulated a five-day period for the package emplaced at an ambient temperature of 100°F with cyclic insolation loading of 12-hours-on/12-hours-off. The 30-W decay heat load was applied as a uniform heat flux to the inner surface of the 3013 containers.

Maximum packaging component temperatures under NCT

Table 3.1 shows the calculated maximum temperatures for the packaging components in the SARP and by DOE PCP staff, which are all well below the corresponding allowable temperature limits for these components.

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

Components	SARP	DOE PCP Staff	Allowable
Drum body	233.16	225.79	1,600
Drum liner	227.40	225.36	1,600
Drum lid	247.97	243.22	1,600
Drum top plug	243.06	239.29	1,600
Kaolite 1600	243.06	239.29	1,600
Neutron poison (CAT 277-4)	227.40	225.36	302
Silicone rubber pads	243.09	242.97	450
Containment vessel	245.04	252.41	800
Ethylene propylene O-ring	243.41	242.74	302
3013 cans	271.20	263.40	800
Aluminum spacers	N/A	254.10	400

The maximum outer surface temperatures of the ES-3100 package, when it is in still air at 100°F without insolation, are 121.19 °F and 120.35 °F, as calculated in the SARP and by DOE PCP staff, respectively. 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).

Maximum normal operating pressure

Appendix 3.5.1 of the SARP contains details of the calculation of the MNOP. The ES-3100 CV is inerted with CO_2 to reduce the oxygen concentration to less than 5 vol.% in the gas mixture to avoid hydrogen deflagration and detonation. The SARP calculated maximum temperature inside the CV as 253.88 °F, with the corresponding CV internal pressure as 103.27 psia. The SARP conservatively assumed that hydrogen reacts with the leftover oxygen and all the generated heat is absorbed by the gas mixture adiabatically, resulting in a peak temperature inside the CV of 515.08 °F. The corresponding MNOP calculated in the SARP is 141.78 psia (127.08 psig), versus 101.58 psia (86.9 psig) calculated by DOE PCP staff based on the fact that the gas mixture in the CV is nonflammable.

DOE-STD-3013-2004 requires that the inner 3013 container allow for a nondestructive indication of a buildup of internal pressure of less than 100 psig, which is adequately indicative of unexpected pressurization. Based on an initial pressure of 100 psig for the 3013 container assembly, which is twice of the assumed initial pressure of 50 psig based on the surveillance data, the staff calculated the MNOP to be 128.10 psia (113.4 psig). As stipulated in 10 CFR 71.4, Type B packaging with an MNOP of more than 100 psig shall receive a designation of B(M), requiring multilateral approval of international shipments. According to the SARP, the ES-3100 package has been requested to be used with a B(U) designation; the ES-3100 package with Pu oxide content is approved for domestic use only (see condition of approval below).

Maximum thermal stresses

Since 3013 container assemblies, aluminum spacers, scrubbers, and the CV 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

Five prototypic units subjected to the structural tests were subsequently tested in a furnace to evaluate the thermal design and performance of the package under HAC. Finite element analyses were conducted using ANSYS code and used in the SARP to determine the effects of the internal decay heat, the application of insolation during cool down, and thermal capacitance difference between the mock-up payloads and the plutonium oxide shipping content. Adjustments of temperatures were made to obtain the peak temperatures inside the CV, which are used to calculate the maximum HAC pressure in the CV (see Table 3.3 of this SER).

Maximum packaging component temperatures under HAC

Table 3.2 shows the maximum temperatures of the packaging components calculated in the SARP and by DOE PCP staff, and the corresponding allowable temperatures under HAC. Both the SARP and PCP staff calculations show the maximum temperatures of the packaging components are well below the allowable temperatures.

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

Components	SARP	DOE PCP Staff	Allowable
Drum body	1,472.27	1,473.24	1,600
Drum liner	1,456.80	1,457.67	1,600
Drum lid	1,453.07	1,452.02	1,600
Drum top plug	1,359.03	1,376.39	1,600
Kaolite 1600	1,472.26	1,472.88	1,600
Neutron poison (CAT 277-4)	294.50	298.89	302
Containment vessel	274.04	284.19	800
Ethylene propylene O-ring*	279.03	280.81	302
3013 cans	297.82	294.35	800
Aluminum spacers	N/A	283.26	400

* Maximum O-ring seal life up to 150 °C (302 °F) for 1000 h of continuous service (Parker O-Ring Handbook).

Maximum CV internal pressure under HAC

Appendix 3.5.2 of the SARP contains the detailed calculations of the maximum HAC pressure inside the ES-3100 CV. Using the final peak temperatures shown in Table 3.3, the SARP calculated a volume-averaged temperature of the gas mixture of 310.98 °F, which is conservative compared with the temperatures calculated by DOE PCP staff. The corresponding maximum CV internal pressure under HAC is 203.59 psia (188.89 psig) in the SARP, which is significantly higher than the DOE PCP staff-calculated maximum HAC pressure of 112.1 psia (97.40 psig).

Table 3.3. Adjusted Peak Temperatures of the CV after HAC (°F)

Locations in the CV	Peak temperatures during test	Analytical temperature adjustments	Final peak temperatures	Peak temperatures calculated by staff
Lid, top, center	261	93.97	354.97	290.01
Flange at interface, inner	241	94.64	335.64	280.81
Shell, mid-height, inner	199	118.71	317.71	270.35
Bottom, center, inner	210	88.95	298.95	244.79

Based on an assumed initial internal pressure of 100 psig for the 3013 container assembly, DOE PCP staff calculated the maximum HAC pressure as 141.37 psia (126.67 psig), which is below the design pressure of 200 psig for the ES-3100 CV.

3.2.3 Potential Hydrogen Deflagration/Detonation

After the loading of 3013 containers, the ES-3100 CV will be backfilled with CO_2 to a minimum volumetric percent of 80%, making the volume percent of air 20% or lower. If the gas in the 3013 containers (hydrogen and helium) leaks into the CV, the volume percentage of air in the CV will be further reduced. DOE PCP staff calculated the upper flammability limits of the CO_2-hydrogen-helium-air mixture using LeChatelier's Law, based on an assumed initial pressure of 0 to 100 psig for the 3013 container, and a seal period of 0 to 12 months for the CV, and found the upper flammability limits were below 80% in all cases. DOE PCP staff concluded that the gas mixture in the ES-3100 CV is nonflammable, and hydrogen deflagration or detonation is unlikely.

3.3 Conclusion

On the basis of the statements and representations in the SARP and DOE PCP staff's confirmatory evaluation, DOE PCP finds the thermal design and performance of the Model ES-3100 package with plutonium oxide content presented in Chapter 3 of the SARP acceptable, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

DOE PCP has concluded that a condition of approval needs to be added to the DOE CoC USA/9867/B(U)F-96, Revision 0, as follows:

"The Model ES-3100 package with plutonium oxide content is for domestic use only."

4. CONTAINMENT

4.1 Discussion

DOE PCP staff reviewed the containment design and performance of the ES-3100 package with plutonium oxide content described in Chapter 4 of the SARP. PCP staff also performed confirmatory analyses to independently evaluate the containment performance of the ES-3100 package during both NCT and HAC. The review and the analyses were focused on containment under NCT and HAC and inerting with CO_2.

4.2 Description of the Containment Boundary

The CV body, lid assembly, and inner O-ring define the containment boundary. The outer O-ring is provided to allow a post-assembly verification leak check. The CV O-rings are manufactured from an ethylene-propylene diene monomer elastomer in accordance with specifications for 70A Durometer preformed packing developed at Y-12. These O-rings are rated for continuous service as a static face seal in the temperature range of 40 to 150°C (40 to 302°F) [*Parker O-Ring Handbook*, 2001 edition, Fig. 2-24]. DOE PCP finds the description of the containment boundary and the O-rings acceptable.

4.3 Containment Under NCT and HAC

The CVs of test units 1 through 5 were helium tested after the 10 CFR 71.71 NCT and 71.73 HAC tests. The results in the report (ORNL/NTRC-013) state that the CVs are leaktight in accordance with ANSI N14.5-1997, and thus maintaining the containment boundary after NCT and HAC tests. DOE PCP staff reviewed the report and finds the test results acceptable.

4.4 Inerting with CO_2

Inerting (i.e., diluting) the ES-3100 CV with CO_2 such that the oxygen concentration is reduced to below 5 vol.% is adopted in the SARP as a mitigation measure against hydrogen deflagration and detonation. Adding CO_2 as a diluent to the hydrogen-helium-air environment in the ES-3100 CV will change the flammability range of the gas mixture. A maximum safe oxygen concentration for CO_2-hydrogen-helium-air mixture at 1 atm and room temperature is 5.9 vol.%.[6] The oxygen concentration in the ES-3100 CV is maintained by the CO_2 diluting to be less than 5%, and therefore below the maximum safe concentration of 5.9%.

DOE PCP staff also considered the dependence of the detonation cell width with temperature, pressure, and composition of the gas mixture, and concluded with reasonable assurance that the CO_2-hydrogen-helium-air mixture in ES-3100 CV, as maintained by the diluting procedure, is a mitigation measure against hydrogen deflagration and detonation.

4.4 Conclusion

On the basis of the statements and representations in the SARP and DOE PCP staff's confirmatory evaluation, PCP finds the containment design and performance of the Model ES-3100 package with plutonium oxide content presented in Chapter 4 of the SARP 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 ES-3100 package with plutonium oxide content described in Chapter 5 of the SARP. The shielding evaluation considered the shipment of up to 10 kg of plutonium oxide in the ES-3100 package. The plutonium oxide will be shipped in one or two 3013 container assemblies (DOE-STD-3013), each having a maximum of 5 kg of plutonium oxide. Typical shipping configuration for the Model ES-3100 package with plutonium oxide contents is shown in SARP Figure 1.4. The bounding shielding evaluation is based on the typical shipping configuration with two identical contents in 3013 container assemblies. The maximum dose rates calculated for 10 kg of plutonium oxide bounds all those shipping mass limits described in Table 1.1 and 1.2 of the SARP except the mass limit of beryllium impurity. The Model ES-3100 package with plutonium oxide content is to be shipped under nonexclusive use. For packages exceeding the nonexclusive dose-rate limits, additional 3013 container mass loading restrictions or impurity control measures may be used to reduce the dose rates; otherwise, exclusive-use radiation controls are required. Actual radiation levels will be maintained as low as reasonably achievable and within the allowable regulatory limits for either nonexclusive or exclusive use shipments.

5.2 Shielding Design

The Model ES-3100 package with plutonium oxide content does not contain material specifically designed for shielding, although the stainless steel of the drum and the CV, the Kaolite 1600 material, and the 277-4 material provide some radiation attenuation. Restricting the amount of source material of the content (both radioisotopes and impurities) and maintaining the geometry of the 3013 container assemblies and the spacers within the CV keep the calculated radiation dose rates below the regulatory limits.

5.3 Source Specification

For the Model ES-3100 package with plutonium oxide content, the bounding source of photons are produced from the decay of the plutonium, uranium, and other radioactive isotopes specified in Table 5.2 of the SARP. Specifically, the plutonium is enriched at 90 wt% ^{239}Pu 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 ^{236}Pu. The source is also assumed to contain 7,000 μg/g Pu of ^{241}Am, 1,000 μg/g Pu of ^{237}Np, and 300 μg/g Pu of ^{232}Th as radioactive impurities.

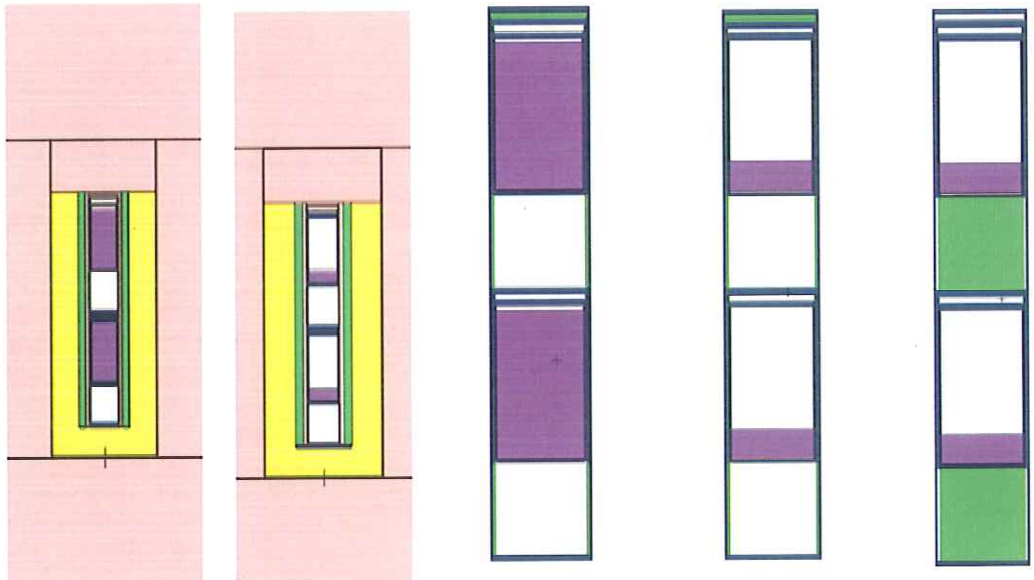
The presence of other nonradioactive impurities is also analyzed and discussed in SARP Section 5.3.1.3. The decay of ^{232}U isotope, a major photon dose contributor, was neglected in the SARP evaluation. The decay of ^{232}U leads to ^{208}Tl (thorium series), which produces high-energy gammas (~2.6 MeV). The concentration of ^{232}U is limited to 12 ppb of total uranium (See Table 1.1 in the SARP).

Table 5.3 of the SARP shows the bounding ORIGEN-S code-calculated photons per second per 100 grams of plutonium oxide that are decayed for 60 years. For the contents of the ES-3100 package, the source of neutrons comes from the combination of alpha-neutron (α, n) reaction, spontaneous fission, and neutron-induced fission. Table 5.4 of the SARP shows the bounding ORIGEN-S calculated neutrons per second per 100 grams of plutonium oxide that are decayed for 50 years. DOE PCP staff has confirmed these ORIGEN-S source terms in the SARP and added the photon contribution from 12 ppb ^{232}U in the confirmatory analyses. The neutrons from neutron-induced fissions and the secondary photons are not included in the ORIGEN-S source terms but included in the MCNP5 neutron transport calculations.

5.4 Shielding Model

The geometry of the shielding analysis model is a conservative representation of the package, as shown in SARP Figure 1.4. A single bounding content configuration has been investigated for the shielding analysis. No credit is taken for the 3013 containers. All materials interior to the CV except for the plutonium oxide content and the aluminum spacers are omitted for conservatism. The plutonium oxide material is in powder form and forms a cylindrical shape inside the 3013 container assembly. The presence of a convenience can, which is optional, is not modeled in the shielding evaluations. In NCT, the surface of the drum is considered to be the package surface with which the dose rates are calculated. In HAC, the SARP assumes total loss of all package components outside of the CV, but the CV and content remain intact. Thus, the surface of the CV is considered as the package surface in the HAC dose rate calculations. The staff have confirmed the dimension of the shielding models and verified the assumption used in the SARP for the dose rate calculations.

The bounding cases for the shielding calculations are determined by comparing radiation dose rates calculated from various models with different plutonium oxide content shapes and locations within the CV, as illustrated in Figure 5.1.



(a) NCT photon (b) NCT neutron (c) HAC photon (d) HAC photon (e) HAC neutron

Figure 5.1 Various NCT and HAC models are evaluated in the SARP and the staff's confirmatory analyses for the bounding dose rates summarized in Table 5.1. The plutonium oxide content is shown in purple and the aluminum spacers are either ignored as void, or included (shown in green), to maximize the calculated dose rates.

Photon dose rates are calculated at three densities: 11.46 g/cm^3 (the theoretical density of plutonium oxide), 7.0 g/cm^3 (the bulk density of plutonium oxide), and 2.308 g/cm^3 (calculated by dividing the mass by the volume of the 3013 container). In all SARP evaluations, the radius of the plutonium oxide cylinder is assumed to be 5.7 cm, and the height is adjusted for the density in each calculation to preserve the 5-kg plutonium oxide mass. However, for HAC side and top evaluations, the staff found that a shell model produces slightly higher dose rate for the side, and a much higher dose rates for the top when the two plutonium oxide contents are moved to the top of the 3013 inner containers (instead resting on the bottom, as in the SARP). Both aluminum spacers are modeled either as solid cylinders or as voids, with 6.0325-cm radii and 13.335-cm heights. The side photon dose rate is highest with the spacers modeled as voids and with 2.308-g/cm^3 density for plutonium oxide content; the bottom and top photon dose rates are highest with 11.46-g/cm^3 density for plutonium oxide content.

The geometrical model for neutron dose rate calculations is identical to the model for photon dose rate calculations. The neutron dose rates are also calculated for three plutonium oxide densities: 11.46 g/cm^3, 7.0 g/cm^3, and 2.308 g/cm^3, with aluminum spacers modeled as either solid cylinders or voids. The side neutron dose rates are highest for the 11.46 g/cm^3 plutonium oxide density with solid aluminum spacers; the top and bottom neutron dose rates are the highest for the same density with spacers modeled as voids. The highest neutron dose rates are combined with the highest photon dose rates to obtain the bounding total dose rates shown in Table 5.1.

Dose rates calculated with the addition of the individual impurities are presented in SARP Table 5.8. As confirmed by DOE PCP staff confirmatory analyses, the dose rates for beryllium impurity with a mass limit of 22 g (5,000 μg/g Pu) exceeds the non-exclusive use regulatory limits. The dose rates for other impurities are much lower than the regulatory limits. With a beryllium impurity mass limit of 4.4 g (1,000 μg/g Pu), the dose rates on the drum surface and 1 m from the surface of the drum are within the regulatory limits for non-exclusive use. As shown in the SARP Table 5.9, and also confirmed by staff confirmatory analyses, for plutonium oxide content containing a mixture of all impurities that increase dose rates, the limiting amount of beryllium impurity must be reduced to 2.2 g (or 500 μg/g Pu) to meet the nonexclusive-use dose requirements. However, recent work at Lawrence Livermore National Laboratory shows that the calculated dose rates are much higher (by order of magnitude) than the measured dose rates when a significant amount of beryllium is present in the content. This is because the ORIGEN-S code modeled a mixture of plutonium oxide and beryllium oxide particles as a homogeneously mixed material at the atomic level instead of at the particulate level. As a result, the model over-predicts the production of neutrons through (α, n) reactions, and the calculated neutron dose rates are expected to be much higher than the measured dose rates.

5.5 Shielding Evaluation

The MCNP5 code was used for shielding evaluations in the SARP and by DOE PCP staff 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 personnel doses. Table 5.1 shows the calculated maximum dose rates for the ES-3100 package under NCT and HAC. The dose rates are calculated at the locations indicated for the package with no nonradioactive impurities.

Table 5.1. Maximum Dose Rates Calculated for the ES-3100 Package under NCT and HAC*

	Maximum Dose Location	**SARP** (mSv/h)	**DOE PCP Staff** (mSv/h)	**10 CFR 71 Limits** (mSv/h)
NCT	Side surface of the package	0.398 ± 0.6%	0.419 ± 0.9%	2
NCT	Top surface of the package	0.142 ± 1.3%	0.159 ± 1.3%	2
NCT	Bottom surface of the package	0.344 ± 2.3%	0.359 ± 2.2%	2
NCT	1 m from the side surface of the package	0.0219 ± 0.7%	0.0236 ± 0.2%	0.1
NCT	1 m from the top surface of the package	0.0096 ± 0.3%	0.0101 ± 0.3%	0.1
NCT	1 m from the bottom surface of the package	0.0123 ± 0.3%	0.0134 ± 0.3%	0.1
HAC	1 m from the side surface of the CV	0.0433 ± 0.1%	0.0479 ± 0.1%	10
HAC	1 m from the top surface of the CV	0.0086 ± 0.1%	0.0148 ± 0.1%	10
HAC	1 m from the bottom surface of the CV	0.0149 ± 0.1%	0.0158 ± 0.1%	10

* All dose rates were calculated for plutonium oxide contents without nonradioactive impurities using point detectors, and the statistical 1-σ uncertainties are generally well within ±2%.

As shown in Table 5.1, the maximum NCT dose rates from the SARP are about 10% lower than those obtained by DOE PCP staff; both sets of dose rates are well within the 10 CFR 71 regulatory limits of 2 and 0.1 mSv/h, respectively, at the surface and at 1 m away from the surface of the package. The difference between the SARP and DOE PCP staff calculations is caused by the inclusion of the 12 ppb ^{232}U in the confirmatory analyses. The maximum HAC side and bottom dose rates at 1 m away from the surface of the CV are about 10% lower in the SARP than those obtained by the staff; however, DOE PCP staff-calculated maximum HAC top dose rate at 1 m from the CV is about 75% higher than that in the SARP. This is due to the positioning of the two plutonium oxide contents at the top of the 3013 inner containers. Both sets of results are well within the 10 CFR 71 regulatory limit of 10 mSv/h at 1 m from the package.

Dose rates with the presence of nonradioactive impurities are presented in Tables 5.8 and 5.9 in the SARP; these rates were also confirmed by DOE PCP staff. The two tables show that the NCT dose rates, with the exception of beryllium, are below the nonexclusive-use regulatory limits. When all other impurities at their bounding mass limits in Table 1.2 of the SARP were considered, the evaluation concluded that the amount of beryllium impurity must be less than 2.2 g in 5.0 kg plutonium oxide content (or 500 μg/g plutonium) in each of the 3013 container assemblies. As shown by the dose rates in Tables 5.8 and 5.9 and the information in Section 5.3, the SARP shielding evaluation demonstrates that the package with plutonium oxide content with nonradioactive impurities at their bounding mass limits as shown in Table 1.2 in the SARP and a limited amount of beryllium meets the dose rate limits of NCT and HAC.

The maximum dose rates calculated in the SARP and confirmed by the staff are all significantly below the regulatory limits for nonexclusive-use shipment. The DOE PCP staff-calculated transport index (TI) is 2.4. During actual operations with the ES-3100 package, the maximum radiation level at the package surface is measured and the maximum radiation level at 1 m from the external surface shall be measured to establish the TI for the package, which is expected to be lower than the calculated TI.

5.6 Conclusion

On the basis of the statements and representations in the SARP and DOE PCP staff's confirmatory evaluation, PCP finds the shielding design and performance presented in Chapter 5 of the SARP acceptable, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

6. CRITICALITY

6.1 Discussion

DOE PCP staff reviewed the criticality safety design of the Model ES-3100 package with plutonium oxide content described in Chapter 6 of 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 ES-3100 package is 0.0.

6.2 Package Description

The design of the Model ES-3100 package with plutonium oxide content includes a stainless steel CV inside a 30-gallon outer drum (See Figure 1.1 of the SARP). The package includes an alumina borated concrete neutron absorber in a cavity surrounding the CV for criticality control. The drawings included in the SARP provide the dimensions of the relevant packaging components. Chapter 2 of the SARP provides material specifications for the packaging components.

Contents

The payload consists of one or two 3013 container assemblies with aluminum spacers (see Figure 1.4 of the SARP). The plutonium oxide in each 3013 container assembly may be confined in an optional convenience can inside the inner 3013 can. The radioactive material mass limits and impurity mass limits for each 3013 container in the CV are listed in Tables 1.1 and 1.2, respectively, in Chapter 1 of the SARP.

The 3013 container assemblies with plutonium oxide content are evaluated with respect to criticality safety in Chapter 6 of the SARP. Descriptions of the ES-3100 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 the SARP is complete and representative of the actual materials specified for the ES-3100 package. DOE PCP staff also confirmed that the models used in the criticality calculations are consistent with the drawings and the detailed package description given in the SARP.

6.3 Criticality Models

The KENO V.a code was used in the SARP for criticality analyses. The payload and the neutronically significant components of the Model ES-3100 package with plutonium oxide content were included in the KENO V.a models. Separate models were developed for single-package NCT and HAC analyses. Two single-package models, one consisting of a full ES-3100 package and the other consisting of just the CV, were used to calculate the effective neutron multiplication factors (k_{eff}) for the plutonium oxide contents under fully flooded and reflected conditions.

The NCT and HAC array calculations were based on detailed models of the ES-3100 package and payloads. Square arrays were modeled in the KENO V.a 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 V.a 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 array calculations for the plutonium oxide contents. The SARP 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 SARP determined the configurations of maximum reactivity with respect to moisture content within the CV and moisture contents of the neutron-absorber and impact-absorbing insulation.

The Standard Composition Library and the 238GROUPNDF5 nuclear data library in the SCALE code package were used for all KENO V.a calculations in the SARP and in the confirmatory analyses. Section 6.8 of the SARP summarizes the determination of the minimum k_{safe} value. The lowest k_{safe} value determined from the validation for the plutonium oxide contents is 0.902; therefore, any configuration of ES-3100 packages with $k_{eff} + 2\sigma < k_{safe}$ is deemed subcritical. All calculations incorporated sufficient neutron histories to ensure statistical uncertainty (σ) 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 ES-3100 package.

6.4 Summary of SARP Criticality Analysis and DOE PCP Staff's Confirmatory Evaluation

Single package under NCT and HAC

Chapter 6 of the SARP analyzed both a single package and a array of packages under NCT and HAC fully flooded and reflected package, and a fully flooded and reflected CV. Table 6.1 shows the maximum $k_{eff} + 2\sigma$ reactivity results listed in the SARP and the DOE PCP staff's confirmatory analyses for the Pu oxide content in the single package configuration. All single-package configurations resulted in acceptable $k_{eff} + 2\sigma$ values below the k_{safe} limit of 0.902. Therefore, the ES-3100 single package with the plutonium oxide contents and loading limits listed in Tables 1.1 and 1.2 of the SARP is subcritical and satisfies the requirements of 10 CFR 71.55(b) for a single package.

Table 6.1. SARP and Staff Confirmatory Criticality Analyses for the ES-3100 package with Plutonium Oxide Content

Case	Content	Case Name (Tables 6.5 and 6.6 of the SARP)	Maximum $k_{eff} + 2\sigma$[a] SARP	Maximum $k_{eff} + 2\sigma$[a] DOE PCP Staff
Single Package – Flooded CV or Package Reflected by Water				
S1	Two 3013 cans[b] – CV only	cvcr3013PuoxDt11_4_15_15	0.79910	0.79701
S2	Two 3013 cans[b] – NCT package	ncsr3013PuoxDt11_4_15_15	0.73941	0.73477
S3	Two 3013 cans[b] – HAC package	hcsr3013PuoxDt12_4_15_15	0.74194	0.73658
NCT Array – Infinite				
N1	Two 3013 cans[b] per package	ncia3013PuoxDt11_4_1_3	0.88263	0.88000
HAC Array – Infinite				
H1	Two 3013 cans[b] per package	hcia3013PuoxDt12_4_1_3	0.88240	0.87974

[a] Upper subcritical limit (USL) k_{safe} value is 0.902.

[b] Each 3013 can hold 4,400 g ^{239}Pu as plutonium oxide.

Undamaged package arrays (NCT)

The NCT undamaged package array model for the plutonium oxide contents consisted of an infinite array of packages. The analyses in Chapter 6 of the SARP show that maximum reactivity occurs in an array of ES-3100 packages when the CV is flooded and the packaging is dry, referring to a configuration in which (a) the neutron poison of the body weldment liner inner cavity and the impact-absorbing insulation are dry, (b) recesses of the package external to the CV do not contain any residual moisture, and (c) the interstitial space between packages in the array do not contain residual moisture. All of the NCT array configurations are based on a flooded CV and dry packaging to maximize the k_{eff} of the array.

Table 6.1 shows the maximum $k_{eff} + 2\sigma$ reactivity results listed in the SARP and DOE PCP staff's confirmatory analyses for the plutonium oxide contents for an infinite-array configuration. All NCT arrays analyzed in the SARP showed acceptable $k_{eff} + 2\sigma$ values that are below the k_{safe} limit of 0.902. Therefore, the ES-3100 package with the plutonium oxide content and loading limits listed in Tables 1.1 and 1.2 of the SARP satisfies the requirements of 10 CFR 71.59.

Damaged package arrays (HAC)

The HAC damaged package array model for the plutonium oxide contents consisted of an infinite array of packages, each with a flooded CV and dry packaging to maximize the k_{eff} of the array. Table 6.1 shows the maximum $k_{eff} + 2\sigma$ reactivity results listed in the SARP and DOE PCP staff's confirmatory analyses for the plutonium oxide content. All HAC arrays analyzed in the SARP showed acceptable $k_{eff} + 2\sigma$ values below the k_{safe} limit of 0.902. Therefore, the ES-3100 package with the plutonium oxide contents and loading limits listed in Tables 1.1 and 1.2 of the SARP satisfies the requirements of 10 CFR 71.59.

6.5 Criticality Safety Index

Based on the NCT/HAC infinite array analyses of the plutonium oxide contents, a CSI of 0.0 was determined and reported in Chapter 1 of the SARP. DOE PCP staff concurs that this CSI value of 0.0 is appropriate for the ES-3100 package with plutonium oxide content limits listed in Tables 1.1 and 1.2 of the SARP.

6.6 Conclusion

On the basis of the statements and representations in the SARP and DOE PCP staff's confirmatory evaluation, DOE PCP finds that the nuclear criticality safety design in Chapter 6 of the SARP 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 in loading, unloading, shipping, and receiving the Model ES-3100 packages with plutonium oxide content, preparation of empty ES-3100 packages for transport, and other operations as described in Chapter 7 of the SARP. The specific operational criteria for the ES-3100 package 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 of the SARP. Each user of an ES-3100 packaging shall register with the DOE Assistant Secretary for Environmental Management prior to first use of the packaging. Quality Assurance (QA) shall participate in package operations.

7.2 Package Loading

Section 7.1 of the SARP describes the package loading requirements for the Model ES-3100 package with plutonium oxide content. Before each shipment, the user must have site-specific procedures that comply with the requirements of the CoC, Chapter 7 of the SARP, and the requirements of 10 CFR 71.5. Before any packaging operations are started, the payloads to be shipped must be fully characterized with respect to the chemical and physical forms, the specific requirements of Section 1.2.2 of the SARP, and the requirements for content preparation described in Section 7.1.1.1of the SARP, including a demonstrated method to show that the 3013 inner container pressure is ≤50 psig. If the 3013 inner container pressure exceeds 50 psig, the 3013 container assembly cannot be shipped in the ES-3100 packaging.

Section 7.1.1.2 of the SARP describes the requirements related to packaging preparation. The user shall develop site-specific operating procedures to implement these requirements.

Section 7.1.2 of the SARP describes the loading of contents into the CV. The user shall develop site-specific operating procedures that indicate, at a minimum, that 1) the operating personnel ensure that the CV has been emptied of radioactive material, 2) the O-rings and grooves on the CV are protected during loading, and 3) the plutonium oxide content and packing materials are prepared and loaded in accordance with this section and Section 1.2.2.4 of the SARP. Per Section 1.2.2.6 of the SARP, the maximum allowable gross shipping weight of the ES-3100 package is 190.5 kg (420 lb).

Section 7.1.2.1 of the SARP describes the assembly and leak testing of the CV. Steps 1 through 7 address the assembly process, including inerting the CV with CO_2 according to step 5(b) of the SARP. Step 8 addresses the leak-testing process. The preshipment leak test meets the requirements of ANSI N14.5-1997. The leakage test shall demonstrate that there is no leakage between the O-rings at a sensitivity of 1×10^{-3} ref-cc/s of air.

Section 7.1.2.2 of the SARP describes the loading of the CV into the drum and closure. This section describes the steps that must be completed as a minimum. The CV is loaded into the drum, the drum lid is installed, and the drum-lid hex nuts are torqued to 30 ± 5 ft-lbs. This torqueing shall be done by hand and an impact wrench shall not be used. The tamper-indicating devices (TIDs) are attached, the radiation levels measured, and the appropriate labeling completed.

Section 7.1.3 of the SARP describes the preparation for transport, addressing package transfer or handling (Section 7.1.3.1), decontamination (Section 7.1.3.2), requirements prior to shipment (Section 7.1.3.3), and securing to the approved highway or rail conveyance. Transportation by air or water is not authorized.

7.3 Package Unloading

Section 7.2.1 of the SARP describes the steps involved in the receipt of the package from the carrier, provisions for reporting safety concerns, and the incidents requiring notifications. The user shall develop site-specific operating procedures to implement these steps as a minimum.

Section 7.2.2 of the SARP describes the steps involved in the removal of the contents from the package and disassembly of the CV. The user shall develop site-specific operating procedures to implement these steps as a minimum.

7.4 Preparation of Empty Package for Transport

Section 7.3 of the SARP describes the steps involved in the preparation of an empty package for transport. The user shall develop site-specific operating procedures to implement these steps as a minimum. The package will be prepared and shipped in accordance with 49 CFR 173.

7.5 Other Operations

Section 7.4 of the SARP addresses other operations. There are no special controls unique to this package.

7.6 Conclusion

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

DOE PCP has concluded that a condition of approval needs to be to the DOE CoC USA/9867/B(U)F-96, Revision 0, as follows:

> "Shippers must have a methodology for assuring that the pressure in each of the 3013 cans does not exceed 50 psig at the time of loading. This methodology must be approved in writing by the Headquarters Certification Official prior to shipment."

8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Discussion

DOE PCP staff reviewed the acceptance tests and maintenance program described in Chapter 8 of the SARP. The packaging acceptance testing and maintenance operations are consistent with maintaining occupational radiation exposures as low as reasonably achievable (ALARA). The fabrication requirements for the Model ES-3100 plutonium oxide packaging components are listed on the design drawings (Appendix 1.3.6) and the following appendices to the SARP: (a) the CV in Appendix 1.3.2, (b) the drum assembly in Appendix 1.3.1, (c) the casting of the Kaolite 1600 in Appendix 1.3.3, and (d) the 277-4 neutron absorber in Appendix 1.3.4. The CV is built to the ASME BPVC Section III, Division 1.

8.2 Acceptance Tests

Section 8.1 of the SARP describes acceptance tests. Before the first use of the packaging, the owner shall determine that the packaging has been fabricated in accordance with the approved design, including the preliminary determinations in 10 CFR 71.85, the quality requirements of 49 CFR 173.474 and 10 CFR 71 Subpart H, and the conditions of the CoC. The required inspections, tests, and measurements shall be in conformance with 10 CFR 71.85(a) and Tables 8.1–8.3 of the SARP. Table 8.1 describes the acceptance tests for the drum assembly, Table 8.2 the CV assembly, and Table 8.3 the packing materials. All welds and weld-repaired surfaces shall be visually examined by a qualified weld examiner for indications of inclusions, cracks, or porosity using approved written weld-examination procedures.

Section 8.1.3 of the SARP describes structural and pressure tests. The CV assembly is hydrostatically tested at 250 ± 5 psig. The CV MNOP is 127.08 psig, and the CV design pressure is 200.0 psig. 10 CFR 71.85(b) requires hydrostatic testing at 1.5 times operating pressure, and the ASME BPVC requires hydrostatic testing at 1.25 times design pressure. Therefore, doing the hydrostatic test of the CV at 250 psig satisfies both the regulatory and ASME code testing requirements. Two sample drums in each lot fabricated are to be pressure-tested to verify the integrity of the welded seams. The drums are pressurized with air to 10 psig, the air supply is closed, the initial pressure is recorded, and all joints are covered with a bubble-supporting film. After five minutes the pressure is recorded and the seams checked for evidence of bubble leakage. Any evidence of leakage, either pressure loss or bubbles, is cause for rejection.

Section 8.1.4 of the SARP describes leakage tests. Following hydrostatic testing, a fabrication leakage test of the containment boundary is performed with the inner O-ring installed in accordance with ANSI N14.5-1997, Subclause 7.3. The CV leakage rate testing shall be performed using certified equipment and written procedures. An integrated air leakage rate exceeding 1×10^{-7} ref-cm^3/s of air is cause for rejection. In addition, a leakage rate test is performed at initial fabrication on the fully assembled CV with both O-rings installed. This test demonstrates the functionality of the CV leak-test port and the sealing capability of the outer O-ring. The acceptance criterion is that the CV shall not have an air leakage rate greater than 1×10^{-4} ref-cm^3/s. Performing this test at fabrication, to this more stringent criterion of an air leakage rate of 1×10^{-4} ref-cm^3/s, provides increased assurance that the CV will pass the actual preshipment leakage test when tested to an air leakage rate of 1×10^{-3} ref-cm^3/s.

Section 8.1.5 of the SARP describes component and material tests. The CV O-rings are visually inspected for defects, and each O-ring is packaged separately and adequately identified to provide traceability and an identified expiration date. The identifications shall be adequate to trace the O-rings to their raw material master batch. The mechanical properties of hardness and elongation shall be determined for each lot of the O-ring material. The acceptance criterion for hardness is a SHORE A of 70 ± 5 durometer; for elongation, the acceptance criterion is 100% minimum.

8.3 Maintenance Program

Section 8.2 of the SARP describes the Model ES-3100 package with plutonium oxide content maintenance program. This maintenance program ensures that the packaging continues to meet the design requirements and the conditions of approval in the CoC. The periodic maintenance shall be performed on a 12-month basis.

Section 8.2.2 of the SARP describes leakage tests. This section contains a series of steps to measure performance in the ANSI 14.5-1997 maintenance leakage rate test (Subclause 7.4), or the periodic leakage rate test (Subclause 7.5), to demonstrate that the containment boundary is "leaktight" when using a leak-check flange assembly such as shown on Drawing T2E801827A008. An integrated air leakage rate exceeding 1×10^{-7} ref-cm^3/s of air is cause for rejection.

Section 8.2.3 of the SARP describes component and material tests. The inner and outer O-rings are replaced during periodic maintenance of the packaging. Certified O-rings are used for replacement, and visually inspected for defects prior to use. Replacement O-rings are stored in sealed containers and have an expiration date marked on the package. The Kaolite 1600 insulation and the Cat 277-4 neutron absorber material are encased in stainless steel. No damage or deterioration is expected; however, the drum parts are visually inspected. Additionally, the drum assembly and top plug are weighed prior to first use and during periodic maintenance to evaluate any density changes. Drum assembly weight changes of greater than 10 lb or top plug weight changes of greater than 2 lb are cause for rejection and evaluation for rework.

Section 8.2.5 of the SARP describes miscellaneous tests. The CV is removed from the drum assembly for periodic maintenance inspections and the interior and exterior CV surfaces are examined for signs of moisture, corrosion, or physical damage. Any CV exhibiting these conditions shall be tagged and separated until the cause is determined and corrected. All threaded parts are examined and evaluated. The threads are cleaned and any small nicks or burrs are removed. If installed, the O-rings are removed, and the CV flange grooves and the CV sealing lid are cleaned and inspected.

The ES-3100 packaging is stored indoors and corrosion is not expected. However, during periodic maintenance inspections, all accessible surfaces shall be visually inspected for corrosion, moisture, or damage. Any drum exhibiting these conditions shall be tagged and separated until the cause is determined and corrected. Worn or faded packaging markings are touched up as necessary, and the data plate and trefoil plate are examined for legibility and secure attachment. The drum lid fasteners, both studs and nuts, are inspected for damage. The threads are cleaned and any small nicks or burrs are removed. The drum closure nuts may be replaced with certified nuts as part of routine maintenance. The silicone rubber pads are inspected during periodic maintenance to verify that there are no signs of moisture, and that there are no gouges, cuts, tears, or nondesign voids in the pads.

8.4 Conclusion

On the basis of the statements and representations in the SARP and DOE PCP staff's confirmatory evaluation, DOE PCP finds the acceptance tests and maintenance program requirements presented in Chapter 8 of the SARP acceptable, and will provide reasonable assurance that the regulatory requirements of 49 CFR 173, Subpart I, and 10 CFR Part 71 have been met.

DOE PCP has concluded that a condition of approval needs to be added to the DOE CoC USA/9867/B(U)F-96, Revision 0, as follows:

> "All CV assemblies used to transport plutonium oxide in the ES-3100 package shall be hydrostatically pressure tested at 250 ± 5 psig."

9. QUALITY ASSURANCE REQUIREMENT

9.1 Discussion

DOE PCP staff reviewed the requirements for a QA Program described in Chapter 9 of the SARP. These QA requirements provide sufficient control over all items and quality-affecting activities that are important to safety as applied to the design, fabrication, assembly, inspection, testing, operation, maintenance, modification, and repair of the Model ES-3100 package with plutonium oxide content. The QA requirements are based on a graded approach, as described in 10 CFR 71.105.

9.2 QA Program

The QA Chapter of the SARP, along with the *Y-12 National Security Complex Packaging Engineering Quality Assurance Program Plan* (QAP-Y-91-273860-1) provides QA requirements and implementation procedures that demonstrate compliance with each of the 18 QA requirements in 10 CFR 71, Subpart H. Appendix B of QAP-Y-91-273860-1 provides a crosswalk matrix that documents the conformance of the Y-12 packaging QA program to the 18 QA requirements of 10 CFR 71, Subpart H. The crosswalk matrix also provides requirements for software QA and integrated safety management.

Graded Approach

The graded approach in the QA Chapter of the SARP includes an important-to-safety Q-list for each significant item and activity; each item is graded on the basis of its design function relative to the safety and performance requirements for the complete packaging. Table 9.2 of the SARP contains the quality categories for each component, based on 10 CFR 71.105 and NRC Regulatory Guide 7.10, Appendix A. The Q-list establishes three QA categories with associated definitions for each. The QA level of each important-to-safety item is based on specific criteria. The QA requirements ensure that the packaging components are designed, fabricated, tested, and operated in accordance with the drawings identified in the SARP. In addition, the QA Chapter requires the user to invoke the same level of QA requirements for the use, maintenance, and repair of the packaging components, as is required for the procurement, fabrication, and acceptance testing of the original packaging components.

Section 9.3.2 of the SARP contains definitions for each QA category for important-to-safety items and activities and nonsafety-related items:

(1) Category A – Components are those whose failure or malfunction will directly result in an unacceptable condition of containment, shielding, or nuclear criticality.

(2) Category B – Components are those whose failure or malfunction will indirectly result in an unacceptable condition of containment, shielding, or nuclear criticality (if the primary event occurred in conjunction with a secondary event, another failure, or an environmental event).

(3) Category C – Components are those whose failure or malfunction does not result in an unacceptable condition of containment, shielding, or nuclear criticality regardless of other failures in this category.

Level of QA Effort

After determining the applicable QA category, the appropriate level of QA effort for design, procurement, fabrication, testing, operations, maintenance, modification, and repair activities is determined from the 18 QA elements identified in 10 CFR Part 71, Subpart H. Table 9.1 of the SARP includes specific QA requirements (Level of QA Effort) from Subpart H of 10 CFR 71 relative to packaging activities and specific categories. The 18 requirements identified in the SARP are organization; quality assurance program; design control; procurement document control; instructions, procedures, and drawings; document control; control of purchased material, equipment, and services; identification and control of material, parts, and components; control of special processes; inspection control; test control; control of measuring and test equipment; handling, shipping, and storage control; inspection, test, and operating status; control of nonconforming materials, parts, or components; corrective action; QA records; and audits. Each of the 18 requirements has assigned QA requirements on the basis of Quality Category A, B, or C.

Independent Verification

The QA Chapter of the SARP includes independent verification of fabrication and operational activities considered to be critical in satisfying the regulatory requirements as identified in 10 CFR 71, Subpart H. Section 9.3.10 of the SARP requires independent verification of critical activities, including inspection criteria for acceptance of the fabricated ES-3100 packaging components, assembly operations, and package loading. Specific inspection criteria are contained in drawings and Chapters 7 and 8.

Records

Table 9.3 of the SARP specifies which documents are considered to be lifetime records (e.g., the SARP, design drawings, audit reports, and nonconformance reports and resolutions). The record retention program specifies that the design authority must retain records for three years beyond the date when the package was last used in a particular activity documented by the prescribed records.

9.3 Conclusion

On the basis of the statements and representations in the SARP and DOE PCP staff's confirmatory evaluation, DOE PCP finds the Quality Assurance Program and requirements in Chapter 9 of the SARP acceptable, and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

DOE PCP has concluded that a condition of approval needs to be added to the DOE CoC USA/9867/B(U)F-96, Revision 0, as follows:

> "In addition to the requirements of Subparts G and H of 10 CFR Part 71, each package must be fabricated, acceptance tested, loaded, operated, and maintained in accordance with the Operating Procedures requirements of Chapter 7, the Acceptance Tests and Maintenance requirements of Chapter 8, and the packaging-specific Quality Assurance requirements of Chapter 9 of the SARP.

References

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