Safety Evaluation Report for
Model 9979 Type AF-96
Safety Analysis Report for Packaging
S-SARP-G-00006, Revision 1
May 2010

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SUMMARY

By a letter dated March 10, 2009, the Savannah River National Laboratory (SRNL) submitted an application to the U.S. Department of Energy (DOE) Packaging Certification Program (PCP), Office of Packaging and Transportation (EM-45), requesting certification for the Model 9979 Type AF Shipping Package (henceforth the 9979 package). The application request included, a Safety Analysis Report for Packaging (SARP), identified as S-SARP-G-00006, Revision 0, dated February 27, 2009, was submitted with the intent to provide documentation that (a) the 9979 package design satisfied the U.S. Department of Transportation (DOT) and Nuclear Regulatory Commission (NRC) relevant regulatory safety requirements, as specified in Title 49 of the Code of Federal Regulations (CFR) Part 173 and Title 10 of the CFR Part 71, respectively; and (b) met the requirements of DOE Order 460.1B and in a format specified in the NRC Regulatory Guides 7.9 and 7.10.

The DOE PCP staff reviewed the Revision 0 SARP and generated 37 questions (Q1) on the nine chapters in the SARP. The applicant responded to all the questions and provided revisions to the SARP. The DOE PCP staff also conducted an independent confirmatory evaluation of the SARP. On the basis of the statements and representations in Revision 1 of the SARP and the 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 9979 package is acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173, and DOE Order 460.1B have been met.

Reference

Model 9979 Type AF Shipping Package, Safety Analysis Report for Packaging, prepared by Savannah River National Laboratory, Savannah River Nuclear Solutions, S-SARP-G-00006, Revision 1, May 2010.

1. GENERAL INFORMATION AND DRAWINGS

1.1 Packaging Description

The 9979 packaging replaces the UN1A2/DOT 7A specification drum identified in 49 CFR 173.417 (2004), which was formerly used by the DOE for packaging and shipment of Type A quantities of fissile materials over public highways. The 9979 package consists of a 30-gallon confinement drum nested inside an internally insulated 55-gallon overpack drum. The 30-gallon confinement drum secures the package payload, thereby providing the capability (a) to prevent loss or dispersal of its radioactive contents when the package is exposed to the Normal Conditions of Transport (NCT), and (b) to ensure that the fissile material contents would remain subcritical when the package is exposed to both the NCT and the Hypothetical Accident Conditions (HAC), as required by 10 CFR 71.

The 9979 package configuration is illustrated schematically in Figure 1.1 of this SER. Table 2.4 of the SARP provides detailed material specifications for the packaging components.

Two weights limits are applicable to the 9979 package. The gross weight of a fully loaded 9979 package shall not exceed 415 lb. The package contents, including radioactive material, dunnage, packing, and thermal insulating bag, if used, is limited to 200 lb.

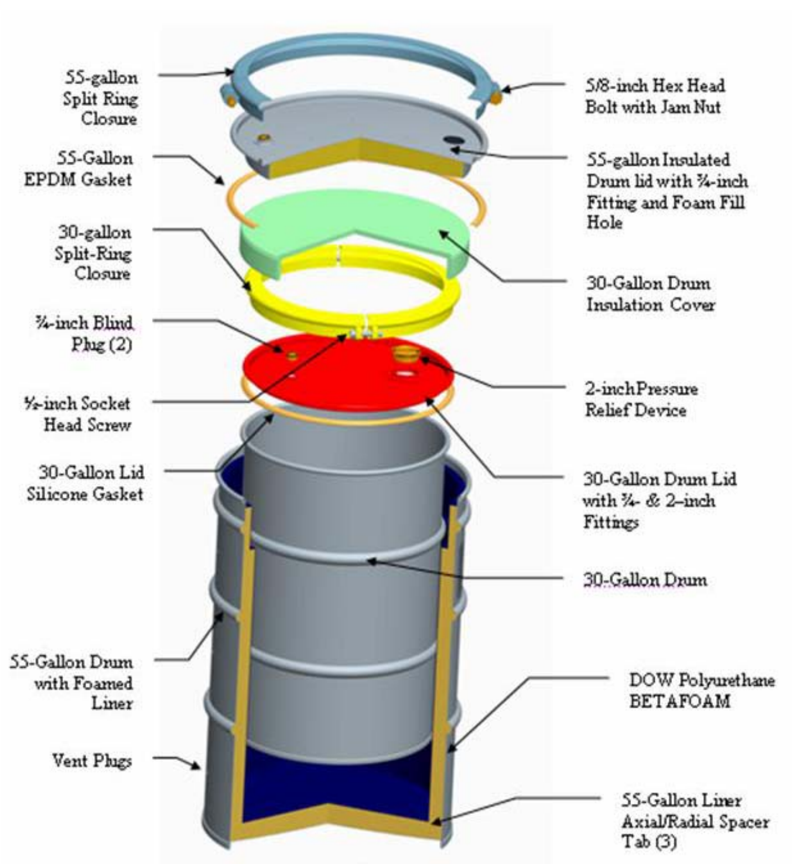

Figure 1.1. Schematic of the 9979 Package Configuration

55-gallon overpack drum

The 55-gallon overpack drum, which is nominally 23 in. in diameter and 34½ in. in height, is fabricated of 16-gauge sheet carbon steel and is painted externally with a water-based paint. It includes an internal welded liner fabricated of 18-gauge carbon steel on the cylinder and of 16-gauge carbon steel on the bottom. The lid of the 55-gallon drum, fabricated of 16-gauge carbon steel, also has a 16-gauge carbon steel top liner. The lid for the 55-gallon overpack drum, which incorporates a blind plug in the bung hole, is secured to the drum body with a reinforced split-ring device and is sealed with an ethylene propylene M-class (EPDM) gasket.

The space between the drum wall and the liner, as well as the space between the lid and its top liner, are filled with polyurethane foam. The foam material serves as a thermal barrier for the 30-gallon confinement drum and its contents during exposure of the package to a severe fire environment, such as the HAC fire described in 10 CFR 71.73. The foam and steel liner also provide structural support by positioning the 30-gallon confinement drum, both radially and axially, within the 55-gallon overpack liner. The 55-gallon overpack drum is also fitted with vent plugs that are sealed against NCT environments; however, it will allow venting of gases produced by the foam in the event of exposure to a severe fire environment. In addition, nondestructive methods, such as thermal imaging, ultrasonic evaluation, radiography, or other acceptable methods, shall be used to verify complete foam filling of each production drum and drum lid.

There are no external impact limiters or other energy-absorbing features, nor any engineered structural features for lifting or tie-down on the package.

Drawings

The drawings that pertain to the 9979 packaging are listed in Table 1.1 of this SER.

Table 1.1. List of Drawings Pertaining to the 9979 Packaging*

Drawing No.	Revision	Title
R-R5-G-00006	1	9979 Type AF Package Tree
R-R1-G-00026	1	9979 Type AF 30-Gallon Container Split-Ring Assembly (U)
R-R1-G-00027	1	9979 Type AF 55-Gallon Drum Lid Split-Ring Assembly (U)
R-R1-G-00028	1	9979 Type AF 30-Gallon Drum Assembly (U)
R-R1-G-00029	1	9979 Type AF 55-Gallon Drum Assembly (U)
R-R1-G-00030	1	9979 Type AF Packaging Assembly (U)
R-R2-G-00057	1	9979 Type AF 55-Gallon Drum Sub-Assembly and Weldment (U)
R-R2-G-00058	1	9979 Type AF 30-Gallon Drum (U)

R-R2-G-00059	1	9979 Type AF 55-Gallon Drum Lid Sub-Assembly and Weldment (U)
R-R2-G-00060	1	9979 Type AF 30-Gallon Drum Lid with Dual Bung Closures (U)
R-R4-G-00062	1	9979 Type AF 30-Gallon Drum Lid Gasket (U)
R-R4-G-00064	1	9979 Type AF Insulation Bag
R-R4-G-00065	1	9979 Type AF Insulation Cover Assembly for 30-Gallon Drum (U)

* Engineering drawings of the 9979 packaging design are the property of SRNS.

<u>30-gallon confinement drum</u>

The 30-gallon confinement drum, which is nominally 18.6 in. in diameter and 29 in. in height, is also fabricated with 16-gauge sheet carbon steel and is painted externally with a water-based paint. The lid for the 30-gallon confinement drum, which incorporates a pressure-relieving plug in the bung hole, is secured to the drum body with a reinforced split-ring device and is sealed with a silicone gasket.

The 30-gallon drum is positioned, both radially and axially, within the 55-gallon drum by the close fit of the liner. An insulating cover is placed over the lid of the 30-gallon confinement drum before closure of the 55-gallon overpack drum.

1.2 Contents

The contents to be shipped in the 9979 package consist of all radioactive (fissile and non-fissile) and non-radioactive materials confined within the 30-gallon drum. The package contents, including radioactive material, dunnage, packing, and thermal insulating bag, if used, is limited to 200 lb. Table 1.2 of this SER provides a general description of the content payloads for the 9979 package for each material category.

Table 1.2. Radioactive Categories, Material Forms, and Content Descriptions

Payload Categories	Material Forms	General Descriptions
Combustible materials	Filters	Roughing, sock, demister, HEPA, and other uranium filters
	Rubber, plastics, cellulose products	Clothing, gaskets, bottles, filter frames, paper, wood, mop heads, etc.
	Floor sweepings	Miscellaneous materials collected from cleaning activities
	Process solids	Furnace residues (pan filter cloth and scrapings, wipes/sponges, etc.)
Non-combustible materials	Graphite/carbon	Carbon and graphite scrap molds
	Slag and liner	Residue that contains magnesium oxide, calcium fluoride, and/or lithium fluoride
	Ceramics/glass	Crucibles, glassware, and borosilicate rings
	Borax pellets	Borax pellets from analytical X-ray operations
	Reduction sand	Granular magnesium oxide (MgO)
	Asbestos/firebrick	Insulation, floor tiles, etc.
	Solid compounds	Uranyl fluoride, UO_4, ammonium diuranate, and residues and solid mixtures
	Standards and sources	Encapsulated calibration standards

Description of radioactive contents

The radioactive contents for the 9979 package are grouped broadly into two payload categories, as follows:

- Non-combustible materials, and
- Combustible materials.

The radioactive material and related payload mass limits are specified in Table 1.3 of this SER.

Description of non-radioactive contents

Non-radioactive contents include all secondary containers, wrapping, shoring, convenience cans, plastic bagging, polyurethane foam, and other dunnage material.

Additional payload limits and restrictions

The following additional limits apply to the contents of the 9979 package:

- Payload decay heat is limited to a maximum of 3.5 W, and
- Moisture within the payload is limited to a maximum of 1 weight percent.

Table 1.3. Content Envelope Limits

Feature	Material	Mass (g)			
Radioisotopes	Tc-99	1,430			
	Th-232	90,000			
	U-232	5.00E-05			
	U-233	16.7			
	U-234	26.1			
	U-235	350			
	U-236	2,500			
	U-238	90,000			
	Np-237	76.9			
	Pu-238	1.59E-03			
	Pu-239	0.435			
	Pu-240	0.119			
	Pu-241	1.58E-02			
	Am-241	7.69E-03			
Impurities	Carbon	1,000[d]	Unlimited[b, e]	1,000[d]	90,000[c, e]
	Beryllium		0		0
	Hydrocarbons[f]	1,000	1,000	Unlimited[e]	1,000
Total mass[a]	Fissile material [U-235 (eq)]*	350	350	300	150
	Radioactive material	90,000			
	Package payload	90,000			
Note: With the exception of U-235 and U-232, the mass of each isotope listed is based on a single A_2 or 90,000 grams.					

a Package contents are limited to a specified mass of U-235 (eq) and to a maximum composite A_2 of one.
b Fissile material must be fixed on graphite pieces.
c Fissile material is not fixed on graphite pieces.
d This limit applies to the sum of beryllium and carbon in the payload.
e This is subject to the payload limit.
f These materials contain predominantly hydrogen and carbon (i.e., molecular formula involving C_xH_y…), such as plastics, polyethylene, and oil.
* U-235(eq) = U-235 + [4.1 × U-233] + [4.1 × Pu]

The sum of U-233 and Pu must be ≤ 5 wt% total fissile mass. All other fissile isotopes are allowed only in trace quantities (i.e., <0.015 grams).

The following forms of materials are prohibited as contents of the 9979 package:

- Pyrophoric materials,
- Cryogenic liquids,
- Compressed gases,
- Visible liquids, and
- Chemically reactive materials.

All combustible contents are required to be packed in a thermal insulating bag that is placed inside the 30-gallon drum, as described in Section 1.2.4 of the SARP.

1.3 Criticality Safety Index

On the basis of the results of the criticality safety analysis presented in Chapter 6 of the SARP, the DOE PCP staff has confirmed, on the basis of the procedure in 10 CFR 71.59(b), that the Criticality Safety Index (CSI) is one (1.0). The packages may be shipped by commercial carrier under non-exclusive use.

1.4 Radiation Level and Transport Index

For the 9979 package, the dose rates calculated for NCT, as documented in the SARP and by the DOE PCP staff, are all significantly below the regulatory limits for non-exclusive use shipment. The dose rates calculated, as shown in the SARP and by the DOE PCP staff, are marginally different. This is because the source terms are calculated differently, and the shielding models used are different.

The calculated maximum radiation transport index (TI) in the SARP is 0.6, versus the 0.8 calculated by the DOE PCP staff. Both are significantly lower than 10, which is the TI limit in 10 CFR 71.47(a) for non-exclusive use shipment. The actual TI of the 9979 package will also be determined by measurement prior to shipment.

1.5 Conclusion

On the basis of the statements and representations in the SARP and the DOE PCP staff's confirmatory evaluation, DOE PCP finds the general information (and drawings) presented in Chapter 1 of the SARP to be acceptable. Evaluations of the 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 given in the remaining sections of this SER.

2. STRUCTURAL

2.1 Discussion

The DOE PCP staff reviewed the structural design and performance of the 9979 Type AF package, as described in Chapter 2 of the SARP. The DOE PCP staff also performed finite-element analysis to independently confirm the structural performance of the 9979 package during the HAC. The review and analyses focused on the conditions of the certification tests, mechanical properties of materials, and verification of the technical basis of the structural design and performance described in the SARP.

2.2 Structural Evaluation

Physical tests of five full-scale prototypes of the 9979 packagings, SN-01 to SN-05, were performed to demonstrate that the design of the 9979 package complies with the safety requirements under the HAC described in 10 CFR 71.73. The acceptable structural performance criteria during the HAC include: (1) confinement of the payload within the 30-gallon drum, (2) retention of the 30-gallon drum within the 55-gallon drum, and (3) minimum deformation of the 30-gallon drum during and after the HAC tests. The basis for these acceptance criteria is criticality safety derived from 10 CFR 71.55(e) and 71.59(a)(2).

The SARP concludes that the 9979 packaging experienced significant damage during the crush test, but only superficial damage during the drop and puncture tests. The conclusion was based on visual inspection of the external surface of the 55-gallon drum overpack. The DOE PCP staff requested direct evidence for any damage to the 30-gallon drum by disassembly and inspection of the tested prototypes. The inspection results are provided in the report “Test Report M-TSM-A-00010,” dated 10/23/2009. Due to the damage to the 55-gallon overpack and the buckling of the inner liner, the 30-gallon drum was “locked” and could not be removed from the 55-gallon overpack. However, no contents had been lost, and the 30-gallon drum had maintained its confinement with some plastic deformation. The report thus concluded that no damage had occurred to the 30-gallon drum confinement.

The DOE PCP staff had concerns that the HAC structural tests may not have been conducted under the most damaging test conditions. Specifically:

- Side drop test without a payload (SN-01),
- Effects of a shifted center of gravity (CG) during the slapdown test,
- Puncture drop locations, and
- Cumulative damage from sequential HAC structural tests.

The DOE PCP staff evaluated these concerns by finite-element analysis (FEA), and the results are summarized below. The finite-element model of the 9979 package was developed by using ABAQUS. The model was first validated by comparing the FEA results with data obtained for the HAC structural tests in the SARP. For the 30-ft side drop test (SN-01), the FEA results show scuffing of the closure device and a slight flattening of the bottom chime of the overpack; similar damage has been reported in the SARP. In the sequential crush test, the FEA results show comparable ovalization of the drum bottom and warping of the split ring closure; the calculated lid buckling is 2.4 in., versus the measured local lid buckling of $\approx$1 to 2 in.

For the top-down, 30-ft CG-over-corner (CGOC) drop test (SN-03), the FEA results show that the corner of the 55-gallon drum displaces inward ≈1.8 in., whereas the measured displacement is ≈2 in. For the side puncture test (SN-04), the puncture pin causes a dent of ≈ 0.1 in. at the mid-height of the overpack, versus a calculated dent of 0.27 in. The comparison of the FEA results with the test data shows that the finite element model generally produces conservative results for the structural damage of the prototype 9979 packagings.

All the DOE PCP staff's confirmatory analyses were performed at -20 ^{o}F, employing the corresponding low-temperature materials properties. The failure strain of the carbon steel drum material is conservatively assumed to be 0.38 in./in.

Side drop test (SN-01)

The 30-ft side drop test (SN-01) was performed without payload (200 lb) in order to maximize the damage from the crush test that follows the drop test. However, less damage is produced without payload during the 30-ft drop test because of the lower initial potential energy. The side drop test without payload thus produces a reduced damaged condition of the packaging that could affect the cumulative damage in the sequential crush test.

In the DOE PCP staff's confirmatory analysis, a 9979 package with a 200-lb payload was subjected to the 30-ft side drop, followed by a side crush. As expected, after the side drop, the 55-gallon drum overpack showed a flattening deformation at the bottom chime of 0.95 in. — higher than the 0.83 in. without payload. The maximum equivalent plastic strain, 0.35 in./in., in the 30-gallon drum is also larger than 0.28 in./in. calculated without payload. Both strains are less than the failure strain of 0.38 in./in. Therefore, the 30-gallon confinement drum should remain intact during the 30-ft side drop, with or without payload. The closure devices for both the 30- and 55-gallon drums should also remain intact, as indicated by the calculated maximum plastic strains in these components.

The sequential crush test of the 9979 package with payload produces similar deformation in the 55-gallon drum, but with higher equivalent plastic strain; the maximum equivalent plastic strain is larger than the failure strain of 0.38 in./in. However, the calculated breaching damage is highly localized in the regions adjacent to the lugs and at the bottom chime, the impact sites on the drum, whereas the 55-gallon overpack maintains its overall integrity. In addition, the closure device of the 55-gallon drum remains intact based on the calculated strains. Therefore, the 55-gallon drum overpack should retain the 30-gallon confinement drum during the sequential crush test, with or without the 200-lb payload. The calculated maximum plastic strain at the lower rolling hoop of the 30-gallon drum exceeds the failure strain of 0.38 in./in. However, the damage is local, and the 30-gallon drum maintains confinement of its contents.

Effects of shifted CG during the slapdown test

In shallow-angle (e.g., 15-degree) slapdown tests, the impact velocity is higher during the secondary impact than during the primary one. Therefore, if the slapdown tests were performed with the bottom end down, the closure lid would be expected to experience more damage during the secondary impact. Another feature in the shallow-angle slapdown test is that the CG of the payload may shift in both axial and lateral directions. Therefore, the DOE PCP staff analyzed two slapdown configurations.

For the first slapdown configuration, the CG of the 9979 package is kept fixed, located on the longitudinal axis and 17.7 in. away from the bottom of the package. The secondary impact occurring at the closure bolt and the lugs of the overpack drives the bolts and the lugs into the drum wall, breaching the skin of the 55-gallon drum, but does not fail the closure device. The 30-gallon drum shows more plastic deformation at the lid end than at the bottom end, and the maximum plastic strain is 0.29 in./in., which is less than the failure strain of 0.38 in./in.

For the second slapdown configuration, the payload of the 9979 package is conservatively modeled as eight steel cubes with a total weight of 200 lb that can move freely inside the 30-gallon drum. These steel cubes are stacked up and, due to the high density of steel, only fill the bottom corner of the 30-gallon drum. Though the calculated flattening deformation at the bottom chime of the 55-gallon overpack is larger, the secondary impact causes even less damage to the lid end of the overpack than that caused by the fixed-CG slapdown configuration. The secondary impact does not loosen the closure device of the overpack. The 30-gallon drum shows more plastic deformation at the bottom end than at the lid end, and the maximum plastic strain is 0.28 in./in., which is less than the failure strain of 0.38 in./in.

In summary, the FEA results of shallow-angle slapdown tests show that the tests cause slightly more damage to the 55-gallon drum at the drum skin below the split-ring adjacent to the lugs and at the bottom chime. However, the damage caused by the slapdown tests to the 30-gallon drum is considerably less than that by the side drop in terms of the maximum local plastic strains at the two rolling hoops.

<u>Puncture drop locations</u>

The side puncture tests for SN-01 and SN-04 were both performed with impact targeted at the mid-height of the 55-gallon overpack. However, puncture tests targeted at the split-ring closure and vertically at the drum lid could cause more damage to the 16-gauge drum shell, resulting in a closure failure. Additionally, there was no payload in the SN-01 test, and the SN-04 was tested at ambient temperature; neither SN-01 nor SN-04 represents the worst test conditions.

The DOE PCP staff analyzed three puncture tests of fully loaded, virgin 9979 packages at -20 ^{o}F — targeted at the mid-height in a side drop, at the closure bolts in a top-down CGOC drop, and at the center of the lid of the overpack in a top-down drop.

The FEA results confirmed that the puncture tests do not significantly challenge the foam-filled steel-drum-type packages, and that the puncture test targeted at the mid-height of the overpack is the most damaging. The calculated maximum equivalent plastic strain for the 30-gallon drum is less than 0.12 in./in., which is much smaller than those caused by 30-ft drop and crush tests. The plastic deformation of the 30-gallon drum calculated for the side puncture is localized at the two rolling hoops that are in contact with the inner liner of the 55-gallon drum. The maximum equivalent plastic strain in the 55-gallon drum is 0.1 in./in. in the side puncture and the top-down puncture, which is less than the failure strain of 0.38 in./in. The top-down CGOC puncture drop does not cause failure to the split ring, the closure bolt, and the lug of the 55-gallon overpack, though the localized plastic strain at the curl edge of the lid exceeds the failure strain due to the concentrated load of the impact.

<u>Cumulative damage from sequential HAC structural tests</u>

10 CFR 71.73 requires sequential application of the HAC tests to determine their cumulative effect on the package. Table 2.1 of this SER provides a summary of the cumulative damage in terms of the calculated maximum plastic strain in key components in three sequential HAC structural tests.

Table 2.1. Cumulative Damage and Maximum Plastic Strains in Key Components of the 9979 Package*

Components	Maximum Plastic Strain, in./in.									
	55-gallon drum					30-gallon drum				
	Body	Lid	Split ring	Lugs	Bolts	Body	Lid	Split ring	Lugs	Bolts
Side drop + crush, no-load	>0.38	>0.38	0.32	0.32	0.13	0.36	0.19	0.07	0.002	0
Side drop + crush, with payload	>0.38	>0.38	0.31	0.32	0.12	>0.38	0.25	0.10	0.003	0
Top-down CGOC drop + crush	>0.38	>0.38	>0.38	0.18	0.05	>0.38	>0.38	0.19	0.02	0

* The puncture drop was analyzed for virgin packages only. (See the preceding section: Puncture drop locations.)

Although the calculated maximum plastic strains in some components are larger than the failure strain of 0.38 in./in., the damage is highly localized and does not cause loss of confinement for the 55-gallon drum overpack or the 30-gallon drum in any of the sequential HAC structural tests.

The cumulative damage of HAC structural tests of the 9979 package is shown to satisfy the structural performance criteria outlined in this section for the criticality safety evaluation detailed in Section 6 of this SER.

2.3 Conclusion

Based on the statements and the representations in the SARP and the DOE PCP staff's confirmatory evaluation, DOE PCP finds that the structural design and performance of the 9979 Type AF package presented in Chapter 2 of the 9979 SARP are acceptable and provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

3. THERMAL

3.1 Discussion

The DOE PCP staff reviewed the thermal design and performance of the 9979 Type AF package, as described in Chapter 3 of the SARP. The DOE PCP staff also performed confirmatory analyses to independently confirm the thermal performance of the 9979 package during NCT and HAC. The review and analyses were focused on properties of the materials and their temperature limits, the maximum temperatures and the maximum thermal stresses of the package components, the maximum normal operating pressure during NCT, and the maximum pressure during HAC.

3.2 Thermal Evaluation

The SARP used MSC.Patran/Thermal to perform 2-D finite-element analysis for the 9979 Type AF package. The packaging components include the following materials: (1) carbon steel ASTM A1008 for the drum bodies, closure lids, and closure devices; (2) BETAFOAM™ for foam insulation; (3) thermal insulation materials, including both the ceramic fiber blanket and the K-Shield BF insulation liner; (4) an EPDM gasket for the 55-gallon drum, and a silicone gasket for the 30-gallon drum; (5) low-density PU foam for packing materials within the 30-gallon drum; and (6) air in the cavities. The materials properties provided in the SARP agree with the values found in the published technical reports, standards, and handbooks.

The DOE PCP staff used ANSYS (Version 10.0) to perform a 3-D confirmatory analysis. Due to symmetry, only a quarter of the package was modeled.

3.2.1 Thermal Analysis under NCT

The NCT analyses were performed at an ambient temperature of 100 ^{0}F, with insolation applied as a step function of 12-hours-on/12-hours-off. The 3.5-W decay heat load was applied as a uniform heat flux at the inner surface of the ceramic insulating blanket.

<u>Maximum component temperatures</u>

The maximum temperatures of the packaging components calculated in the SARP and by the DOE PCP staff, as well as the allowable temperature limits under NCT with insolation, are shown in Table 3.1 of this SER. The calculated maximum temperatures for the components are in reasonable agreement. Both the SARP and DOE PCP staff values are well below the corresponding allowable temperature limits.

Table 3.1. Summary of Calculated Temperatures under NCT (with isolation)

Location	Max. Component Temp., ^oF (SARP)		Max. Component Temp., ^oF (Staff)[1]	Max. Component Temp., ^oF (Allowable)
	Non-combustible	Combustible		
Outer drum	154	154	160	300
Outer drum gasket	145	145	142	350
Overpack insulation (BETAFOAM™)	154	154	159	200
Outer drum liner	144	144	151	300
Inner drum	147	149	157	300
Inner drum gasket	143	143	155	400

[1] Based on 100 ^oF ambient temperature and 3.5-W decay heat load.

With the package in still air at 100 ^oF and in the shade without insolation, the SARP calculated a surface temperature of 105 °F for the non-combustible source configuration and 110 °F the for combustible configuration. The DOE PCP staff calculated a surface temperature of less than 101 °F. Therefore, no accessible surface of the package would exceed the temperature limit of 122 °F in a non-exclusive use shipment per 10 CFR 71.43(g).

Maximum normal operating pressure (MNOP)

Pressurization within the 9979 package during NCT is due to the expansion of the sealed air in the drum cavity, combined with the evaporation of moisture (less than 1% of payload weight) in the contents when the package is heated. The MNOP calculated in the 30-gallon drum is 21.16 psia (6.46 psig) in the SARP, based on an average temperature of 154 °F during NCT, which is lower than the design pressure limit of 36.4 psia (21.7 psig) for the drums.

Maximum thermal stresses

The drums of the 9979 package are thin-walled structures. Thus, the temperature drop across the drum wall is small, and the temperature gradients are unlikely to result in any significant thermal stresses.

3.2.2 Thermal Analysis under HAC

The HAC analyses used the same configuration and initial and boundary conditions as those used in the SARP. However, the BETAFOAM™ insulation was completely removed from the ANSYS model at the beginning of the fire simulation to bound the effects of foam burning, and this assumption was different from the "effective-heat-conduction" approach employed in the SARP. Within the cavity left by the burned foam, the heat transfer modes were assumed to be conduction through air and radiation with no convection. This assumption was reasonable, since radiation dominates thermal transport at high temperatures.

Maximum component temperatures

The maximum temperatures of the packaging components calculated in the SARP and by the DOE PCP staff, as well as the allowable temperature limits under HAC with insolation, are shown in Table 3.2 of this SER.

Table 3.2. Summary of Calculated Peak Temperatures under HAC

Location	Calculated Max. Component Temp., ^{0}F (SARP)		Calculated Max. Component Temp., ^{0}F (Staff)	Max. Component Temp., ^{0}F (Allowable)
	Non-combustible	Combustible[1]		
Outer drum	1,475	1,475	1,473	2,750
Outer drum gasket	-	-	N/A[2]	N/A
Overpack insulation (BETAFOAM™)	-	-	N/A[2]	N/A
Outer drum liner	1,450	1,450	1,294	2,750
Inner drum	538	517	355	800
Inner drum gasket	501	477	258	500
Ceramic blanket	N/A	-	276	1,800
Packing material	530	326	206	640/400[3]
Contents	211	326	206	400

[1] The ceramic fiber bag is used as a thermal barrier to protect contents that are temperature sensitive.
[2] The staff assumed these items were completely burned.
[3] The maximum allowable temperatures for non-combustible and combustible configuration, respectively.

The maximum temperatures for the components calculated in the SARP are significantly higher than the staff values. However, they are well below the corresponding allowable temperatures.

Maximum internal pressure under HAC

The SARP calculated a maximum internal pressure of 62.14 psia (47.44 psig) in the 30-gallon drum during HAC at an average content temperature of 270 °F. However, the pressure release plug of the 30-gallon drum limits the pressure to 18-20 psig (Rieke Packaging Systems, S-220-2, Rieke® VISEGRIP II® Pressure Relief Plug, 2-in., Vent Pressure 18-20 psig). Therefore, it is expected that there should not be significant pressure buildup in the 30-gallon drum. The vent holes on the 55-gallon drum wall and lid would release pressure from the decomposition of BETAFOAM™ during the HAC fire.

3.3 Conclusion

Based on the statements and representations in the SARP and the DOE PCP staff's confirmatory evaluation, DOE PCP finds that the thermal design and performance of the 9979 Type AF package presented in Chapter 3 of the 9979 SARP are acceptable and provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

4. CONTAINMENT

4.1 Discussion

The DOE PCP staff reviewed the containment design and performance of the 9979 Type AF package, as described in Chapter 4 of the SARP. The 9979 package is designed for transportation of contents that are not to exceed an A_2 quantity. For this package, 10 CFR 71.51, *Additional Requirements for Type B Packages*, is not applicable, as stated in the SARP. The package is designed for confinement of the radioactive contents, thereby satisfying the no "*loss or dispersal of radioactive contents*" requirement of 10 CFR 71.43(f) following exposure of the package to the NCT conditions and tests specified in 10 CFR 71.71(c). This confinement is provided by a 30-gallon drum fabricated as a DOT 7A Type A, with the split-ring closure device. The drum is rated for a pressure retention of 21.7 psig (150 kPa). In addition, the closure lid of the 30-gallon drum includes ¾-in. and 2-in. bung holes or ports. The 2-in. port is fitted with a pressure release device that remains sealed under NCT, but releases pressure at 18-20 psig (and resets automatically at about 10 psig) to vent gases under HAC. The ¾-in. port is fitted with a standard non-venting plug. This 30-gallon confinement drum is protected by the 55-gallon overpack.

4.2 Containment Evaluation

Containment under NCT

The results of the tests and analyses described in Chapters 2 and 3 of the SARP and the DOE PCP staff's confirmatory evaluations (Section 2 and 3 of this SER) show that the confinement boundary will not fail under NCT. The maximum pressure differential achievable under NCT is 17.6 psig; including MNOP and the effects of 10 CFR 71 reduced external pressure, which is below the drum's pressure rating of 21.7 psig.

As described in Section 2.6 of the SARP, the prototype 9979 packages demonstrated "no loss or dispersal of (simulated) radioactive contents" under the NCT tests.

Containment under HAC

The HAC analyses described in the SARP and the DOE PCP staff's confirmatory structural evaluation (see Section 2 of this SER) show that under HAC, the 9979 package maintains confinement of contents in the 30-gallon drum, retention of the 30-gallon drum within the 55-gallon drum overpack, and minimum deformation of the 30-gallon drum.

The SARP's thermal analysis under HAC and the DOE PCP staff's confirmatory evaluation (see Section 3 of this SER) show that the calculated temperature for the 30-gallon drum closure gasket is slightly above its temperature limit. However, this small temperature excursion should have no effect on drum confinement of the contents. The split-ring closure of the 55-gallon drum overpack will be unaffected by the HAC temperatures and will retain the 30-gallon confinement drum.

4.3 Conclusion

Based on the statements and representations in the SARP and the DOE PCP staff's confirmatory evaluation, DOE PCP finds that the containment design and performance of the 9979 package presented in Chapter 4 of the SARP are acceptable and provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

5. SHIELDING

5.1 Discussion

The DOE PCP staff reviewed the shielding design and performance of the 9979 Type AF package, as described in Chapter 5 of the SARP. The DOE PCP staff also performed Monte-Carlo analysis to independently confirm the shielding performance of the 9979 package. The review and evaluations focused on radiation source specifications, shielding models, and calculated dose rates. The 9979 package is to be shipped under non-exclusive use.

5.2 Shielding Evaluation

The 9979 package does not contain material specifically for shielding, although the carbon steel drum shells provide some radiation attenuation. Restricting the amount of source material and maintaining the distance between the contents and the package surface are the means for keeping the radiation dose rates below the regulatory limits.

The source terms and shielding analyses presented in Chapter 5 of the SARP provide bounding cases for contents of radioactive (mainly uranium) metals, oxides, and other solid compounds. The mass limits of the isotopes are listed in Table 5.3 of the SARP. The mass limits of all isotopes are below their A_2 values. The Monte Carlo Code (MCNP5) was used in the SARP, as well as by the DOE PCP staff, for shielding evaluation. The cross-section library used in the evaluations was based on the Evaluated Nuclear Data Formats-VI (ENDF-VI). ANSI/ANS-6.1.1-1977, *Neutron and Gamma-Ray Flux-to-Dose-Rate Factors*, was used to calculate the dose rates.

Source specification

For the contents of the 9979 package, the source of photons is due to a combination of the decay of uranium isotopes, fission, and the decay of fission products. Direct decay of the ^{232}U isotope is the major contributor to photon source terms. The decay of ^{232}U leads to ^{208}Tl (thorium series), which produces high-energy gammas (≈2.6 MeV). The mass of ^{232}U is limited to 5×10^{-5} g (see Table 5.3 of the SARP). In the photon source term calculations, the contents are decayed for 10 years to maximize the photon doses from the ^{232}U decay chain. Table 5.4 of the SARP shows the Radiation Source Term Analysis Code (RASTA)-calculated photons per second for the isotope mixtures listed in Table 5.3 of the SARP.

The source of neutrons for the contents of the 9979 package results from a combination of the Alpha-neutron (α, n) reaction, spontaneous fission, and neutron-induced fission. Impurities in the contents may introduce a significant amount of neutrons from (α, n) reactions. Thus, one weight percent of beryllium is assumed to be in the source term calculations to bound all other (α, n) targets in the impurities. Table 5.4 of the SARP shows the RASTA-calculated neutrons per second for the isotope mixtures listed in Table 5.3 of the SARP to be in non-fluoride forms. Because fluorine is also a significant (α, n) target, the non-fluoride neutron and secondary photon dose rates are multiplied by a factor of two to bound contents in fluoride forms.

The SARP used RASTA to calculate the photon and neutron source terms. The DOE PCP staff used ORIGEN-ARP 5.1.01 (Oak Ridge Isotope Generator–Automatic Rapid Processing 5.1.01) in the confirmatory evaluations. The neutrons from neutron-induced fissions and the secondary photons are not included in the ORIGEN-ARP source terms, but are included in the neutron transport calculations. The source terms calculated by the DOE PCP staff are slightly greater than those listed in the SARP.

Shielding model

A simple model was developed in the SARP for both NCT and HAC evaluations. The SARP model does not include radiation attenuation by any components of the packaging. The DOE PCP staff developed a more realistic model in the confirmatory analysis, which included the inner and outer drums of the packaging to account for such attenuations.

Shielding analysis

Table 5.1 of this SER shows the MCNP5 calculated maximum dose rates (in the SARP and by the DOE PCP staff) of the 9979 package under NCT and HAC.

Table 5.1. MCNP5 Calculated Maximum Dose Rates of the 9979 Type AF Package

	Maximum Dose Location	SARP (mSv/h)	Staff (mSv/h)	10 CFR 71 Limits (mSv/h)
NCT, on the package surface	Side surface of the package	1.729	1.63	2
NCT, 1 m from the package surface	1 m from the side surface of the package	0.0051	0.008	0.1
HAC	Not required			

The maximum dose rates under NCT calculated in the SARP and by DOE PCP staff are both below the regulatory limits for non-exclusive use shipment. The calculated dose rates are slightly different because of the differences in the source terms and the shielding model. The calculated maximum radiation TI in the SARP is 0.6; the TI calculated by the staff is 0.8. Both are lower than the regulatory limit of 10. The TI of the 9979 package will be measured prior to shipment.

5.3 Conclusion

Based on the statements and representations in the SARP and the DOE PCP staff's confirmatory evaluation, DOE PCP finds that the shielding design and performance of the 9979 Type AF package presented in Chapter 5 of the SARP are acceptable and provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 have been met.

6. CRITICALITY

6.1 Discussion

The DOE PCP staff reviewed the criticality safety design of the 9979 Type AF package, as described in Chapter 6 of the SARP. The 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 of the package is 1.0, and the packages may be shipped under non-exclusive use.

6.2 Package Description

The 9979 package is designed to ship radioactive uranium metals, oxides, and other solid compounds totaling less than one A_2. The material compositions used in the criticality analysis are representative of the materials specified for the 9979 package components. The 9979 package does not include any features intended for criticality control. No neutron absorbing (poison) materials are incorporated into the packaging design. Descriptions of the 9979 package design features and the models used in the criticality calculations are consistent with the drawings and the details of the package described in the SARP.

Contents

The radioactive contents can be grouped broadly into two categories: (1) non-combustible solids (oxides, sands and rubble) and (2) combustible solids (metals, plastics, and paper). Non-combustible materials are prepackaged within separate convenience containers (food-pack cans, etc.). Combustible materials (bricks, billets, etc.) are not prepackaged. The analysis in the SARP does not credit the performance of secondary containers or solid content geometries to maintain either subcriticality or payload confinement. The fissile content of the 9979 package is limited to a maximum of 350 g of U-235 equivalent mass. The uranium may be any enrichment and may be in any form. Carbon and/or beryllium may be present up to 1% of the total payload mass, except when the primary waste form consists of scrap carbon/graphite molds (in which case, carbon may exceed 1% of the total weight, but the mass of hydrocarbons is limited to 1 kg).

Based on the payload content mass limits on hydrocarbon, beryllium, carbon, and U-235, the SARP constructed four cases as the bounding envelopes in the criticality analysis. In the first two cases, the criticality evaluation considers only 350 g of U-235 as the limit, with water/or polyethylene as an internal moderator and with beryllium or carbon as a reflector surrounding the fissile mass inside the 30-gallon drum. In the third case, where hydrocarbon mass in the package is greater than 1 kg (up to the payload limit of 90 kg) and treated as polyethylene for an internal moderator, the U-235 mass limit is reduced to 300 g to meet the subcriticality requirement. In the fourth case, for scrap carbon/graphite molds, the criticality evaluation considers only 150 g of U-235 as the payload limit, with water as an internal moderator and with graphite (up to the payload limit of 90 kg) as a reflector surrounding the fissile mass inside the 30-gallon confinement drum.

U-233 and plutonium shall be accounted for in the total fissile mass of a package payload, according to the following equation defining the U-235 equivalent mass:

$$\text{U-235}_{\text{equivalent mass}} = \text{U-235}_{\text{mass}} + (4.1\times\text{U-233}_{\text{mass}}) + (4.1\times\text{Pu}_{\text{mass}}).$$

The equivalent mass ratios were determined to be 4.1 for U-233 and Pu-239, respectively, based on their subcritical mass limits in Table 6.6 of ANSI/ANS-8.1.

6.3 Criticality Models

The DOE PCP staff reviewed the packaging materials, their densities and compositions, and the fissile/fissionable material forms, masses, and isotopic compositions and found them to be adequate. Water was modeled as the moderator, since the package is not leak tight. The material inside the 30-gallon drum was modeled as a sphere of U-235 and water homogenized with dimensions corresponding to the H/X ratio. Both beryllium and carbon may be present in the package, and they were modeled as a reflector shell surrounding the fissile sphere. The criticality evaluation considered four cases of bounding payloads of U-235, with water (or polyethylene) as an internal moderator and with beryllium or carbon as a reflector surrounding the fissile mass inside the 30-gallon drum. The models in the SARP were constructed with the SCALE 5/KENO V.a code package, and calculations were conducted for various U-235 payloads, moderator and reflector combinations to assess whether the package remains subcritical for single package and array configurations under the most reactive conditions for both NCT and HAC. Section 6.9 of the SARP contains an appendix that documents the nuclear criticality safety evaluation (NCSE) of the 9979 package.

Two separate models were developed in the SARP for the NCT and HAC analyses. The KENO V.a models included only the 30-gallon confinement drum and the 55-gallon drum with the dimensions listed in Table 6.4 of the SARP. The drums were modeled as right circular cylinders. The material inside the 30-gallon confinement drum was modeled as a sphere of U-235 and water with dimensions corresponding to the H/X ratio. The sphere was positioned adjacent to the inside edge of the 30-gallon confinement drum to obtain the most reactive configurations for array analyses.

NCT Model: The NCT model includes an 8×8×8 rectangular-pitch array of packages with 2 ft of water reflection on all six sides. The model includes nominal dimensions of the 55-gallon drum and the 30-gallon drum, as shown in Table 6.4 of the SARP. Reducing the radius of the 55-gallon drum by 7% simulates a triangular-pitch array. The "Nuclear Criticality Safety Evaluation" for the 9979 package (NNCS-A-00014) showed the "2-cluster" configuration to be the most reactive arrangement. All NCT calculations used the "2-cluster" configuration. Figure 6.2 of the SARP depicts the package contents shifted to the left and right for maximum interaction with the adjacent package in a "2-cluster" configuration. Modeling the fissile material inside the 30-gallon confinement drum as an optimally moderated sphere of water and U-235 is conservative.

HAC Model: The SARP assumed complete radial crushing of the 55-gallon drum under HAC (i.e., the 55-gallon drum inner radius was set to the outer radius of the 30-gallon drum). Some HAC models credited the wall thickness of the 55-gallon drum. This is a very conservative assumption, representing closer spacing than possible with realistic drum damage. For the HAC array model, the 30-gallon confinement drum outer radius was reduced by 7% to simulate a close-packed triangular array. The HAC model used a 6×6×3 array of damaged 9979 packages, reflected by 60 cm of water along all sides of the array. The HAC calculations also used the "2-cluster" configuration, since it is the most reactive arrangement. Figures 6.3 and 6.4 of the SARP show a "2-cluster" configuration in which the package contents are shifted to the left or right and bottom or top for maximum interaction with adjacent packages.

Internal Reflectors: The Nevada Test Site Waste Acceptance Criteria limits carbon and beryllium to 1% of the total package mass (200-lb total mass). The SARP models assumed close reflection by 1 cm of carbon or beryllium around the fissile source. This is a conservative assumption for the1-kg mass limit of carbon or beryllium in the package. For the scrap carbon/graphite molds analysis, Cases N4 and H4 (as shown in Table 6.1 of this SER) assumed non-fixed fissile material with carbon placed as a reflector around the fissile solution. The carbon was modeled as a cylinder with a Height to Diameter (H/D) ratio of 1 as the most reactive configuration.

Internal Moderators: Water is modeled as the moderator for cases in which hydrocarbons are limited. Both beryllium and carbon may be present in the package, and they both are less reactive than water as moderator for uranium solutions. However, when hydrocarbons are not limited, polyethylene is modeled as the moderator because it is a better moderator than water. Cases N3 and H3 in Table 6.1 of this SER assumed polyethylene as the moderator and determined a U-235 mass limit of 300 grams, which is necessary to meet the subcriticality criterion.

The "Standard Composition Library" in SCALE was used for the compositions of all modeled materials. Uranium was conservatively considered as 100 wt. % U-235 metal with a density of 19.05 g/cc. Lower densities and oxide forms were not studied because the maximum theoretical density of metal provides bounding results. Neither plutonium nor U-233 was explicitly modeled. These are accounted for in terms of equivalent U-235. For most modeled configurations, water was treated as the moderating material, and optimum water moderation (H/X ratio) was determined for various configurations. The possible presence of carbon and beryllium was accounted for by modeling the uranium configuration completely reflected by 1 cm of carbon or beryllium. The possible presence of moderators more effective than water (e.g., hydrocarbons) was accounted for by repeating the calculations using polyethylene as the moderator (Cases N3 and H3 in Table 6.1 of this SER). The scrap carbon/graphite model considered "carbon" and "graphite" as reflectors around a water-moderated U-235 spherical configuration (Cases S4, S4a, N4, and H4 in Table 6.1 of this SER).

6.4 Summary of SARP Criticality Analyses and DOE PCP Staff Confirmatory Evaluation

Evaluation of a single package under NCT and HAC

The single package model does not require criticality analysis because the allowable fissile mass (350-g U-235) is below the ANSI/ANS-8.1 subcritical mass limit of 700 g. Furthermore, the single package case is bounded by the NCT and HAC analyses of arrays. Therefore, any single package is subcritical, and a fully loaded 9979 package satisfies the 10 CFR 71.55(b) requirements related to a flooded condition. The 9979 package design under NCT meets the additional requirements of 10 CFR 71.55(d)(2) through §71.55(d)(4). The staff's evaluation confirms the validity of the single package criticality analyses in the SARP.

Evaluation of undamaged-package arrays (NCT)

The NCT undamaged package array model considered an 8×8×8 square array of stacked packages with the content optimally moderated and offset to form a "2-cluster," the most reactive configuration. The array included 2 ft of water on all six sides. Beryllium reflection increased reactivity more than carbon. Therefore, the NCT model considered only beryllium as a reflector (1-cm thickness), surrounding the fissile configurations with an H/X ratio range of 600-

900 (the most reactive H/X range). Since interstitial water reduces reactivity, additional water was not included in the drum as a reflector. Table 6.1 of this SER presents the maximum reactivity results presented in the SARP and the DOE PCP staff's confirmatory analyses. All 8×8×8 NCT arrays resulted in acceptable k_{eff} + 2σ values that are below the k_{safe} limit of 0.931. Therefore, the 9979 package with contents consisting of a U-235 mass that corresponds to the mass limits and moderator and reflector conditions given in Table 6.1 of this SER satisfies the requirements of 10 CFR 71.55(d) and 10 CFR 71.59(a)(1).

<u>Evaluation of damaged-package arrays (HAC)</u>

The HAC model omitted the 55-gallon drum to represent the maximum crushing effect of the outer drum. The 30-gallon confinement drum radius was also reduced by 7% to simulate a triangular pitch array. As mentioned before, the "2-cluster" model was the most reactive configuration under HAC, which is also consistent with 10 CFR 71.55(e)(1). The most reactive configuration consists of a 6×6×3 square array of fully loaded packages with 2 ft of water reflection in all six sides, with no interstitial water moderation.

As shown in Table 6.1 of this SER, the 6×6×3 arrays resulted in calculated values of k_{eff} + 2σ below k_{safe}. Therefore, the 9979 package loaded with U-235 that corresponds to the mass limits and moderator and reflector conditions given in Table 6.1 of this SER satisfies the requirements of 10 CFR 71.55(e) and the HAC-related requirements of 10 CFR 71.59(a)(2). Since hydrocarbons may provide better moderation than water, analyses (Case H3 in Table 6.1 of this SER) were performed in the SARP and by the staff with polyethylene as the moderator (including 1 cm of beryllium reflection) and the U-235 mass was reduced to 300 g in order to have a calculated k_{eff} + 2σ value less than k_{safe} of 0.931.

Table 6.9 of the SARP summarizes the determination of k_{safe} values corresponding to each of the cited validation reports. The lowest k_{safe} value derived from the validations is 0.931 for a uranium metal system. Therefore, any configurations of 9979 packages showing $k_{eff} + 2\sigma < k_{safe}$ are deemed subcritical. All calculations incorporated sufficient neutron histories to ensure a statistical uncertainty (σ) less than 0.002 and convergence. The DOE PCP staff concurs that the benchmark experiments and corresponding bias value are conservative, as applied to the 9979 package.

6.5 Criticality Safety Index (CSI) for Nuclear Criticality Control

Based on the HAC 6×6×3 array analyses, a minimum CSI of 1.0 was determined and reported in Chapter 1 of the SARP. DOE PCP concurs that this CSI value is appropriate for the 9979 package, with the specified payload limits shown in Table 6.1 of this SER.

6.6 Conclusion

Based on the statements and representations in the SARP and the DOE PCP staff's confirmatory evaluation, DOE PCP finds that the nuclear criticality safety design presented in Chapter 6 of the SARP is acceptable and provides reasonable assurance that the regulatory requirements of 10 CFR Part 71 are met.

Table 6.1. Summary of the SARP Criticality Analyses and Staff Confirmatory Evaluation

Single Package							
Water surrounding package							
Case #	Hydro-carbon Mass	Carbon* and Beryllium Mass	Fissile Fixed on Graphite Pieces	U-235 Mass **	Internal Moderation H/X	Maximum $k_{eff} + 2\sigma^{\#\#}$	
						SARP	Staff Confirmatory
S1	≤ 1 kg	≤ 1 kg	No	350 g	Not analyzed; bounded by the NCT and HAC array cases		
S2	≤ 1 kg	No beryllium	Yes	350 g			
S3	> 1 kg	≤ 1 kg	No	300 g			
S4	≤ 1 kg	≤ 90 kg carbon	No	350 g	700	0.9283	0.93468
S4a	≤ 1 kg	≤ 90 kg carbon	No	150 g	600	-	0.75565
NCT Array							
512 packages (8×8×8); no interstitial moderation; water surrounding array							
Case #	Hydro-carbon Mass	Carbon* and Beryllium Mass	Fissile Fixed on Graphite Pieces	U-235 Mass **	Internal Moderation H/X	Maximum $k_{eff} + 2\sigma^{\#\#}$	
						SARP	Staff Confirmatory
N1	≤ 1 kg	≤ 1 kg	No	350 g	700	0.9083	0.91008
N2	≤ 1 kg	No beryllium	Yes	350 g	Bounded by the above case ***		
N3	> 1 kg	≤ 1 kg	No	300 g	700	0.9166	0.91859
N4	≤ 1 kg	≤ 90 kg carbon	No	150 g	500	0.7972	0.79832
HAC Array							
108 packages (6×6×3); no interstitial moderation; water surrounding array							
Case #	Hydro-carbon Mass	Carbon* and Beryllium Mass	Fissile Fixed on Graphite Pieces	U-235 Mass **	Internal Moderation H/X	Maximum $k_{eff} + 2\sigma^{\#\#}$	
						SARP	Staff Confirmatory
H1	≤ 1 kg	≤ 1 kg	No	350 g	600	0.9175	0.91706
H2	≤ 1 kg	No beryllium	Yes	350 g	Bounded by the above case ***		
H3	> 1 kg	≤ 1 kg	No	300 g	700	0.9253	0.92554
H4	≤ 1 kg	≤ 90 kg carbon	No	150 g	500	0.9305	0.93211

* Carbon from boron carbide not included.
** No limit on uranium enrichment.
*** Bounded by the above case, where fissile can be homogeneously mixed with water.
For subcriticality, the maximum $k_{eff} + 2\sigma$ must be less than the upper safety limit (USL) k_{safe} value of 0.931.

7. OPERATIONS

7.1 Discussion

The DOE PCP staff reviewed the requirements for general operating procedures for loading, unloading, preparing empty 9979 packaging for transport, and other operations, as described in Chapter 7 of the SARP. These requirements for general operating procedures shall be implemented to ensure that the package is used in accordance with the Certificate of Compliance (CoC) for the 9979 package. In addition, packaging-specific requirements are reviewed to ensure that the package operations are in accordance with the CoC and Chapter 7 of the SARP. Each user of 9979 packaging shall register with the DOE Assistant Secretary for Environmental Management (EM) prior to first use of the packaging. Quality Assurance (QA) shall participate in package operations.

Section 7.0.1 of the SARP addresses planning. It requires the preparation and use of site-specific operating procedures, as well as the use of the SARP, CoC, packaging hardware, technical specifications, and engineering drawings when preparing these procedures. The principles of "as low as reasonably achievable" (ALARA) shall also be followed. Section 7.0.2 requires all personnel to be qualified, as described in Section 9.2.1 of the SARP. Section 7.0.3 addresses the equipment and materials necessary for packaging operations, and it specifies that a list of necessary equipment shall be provided with each operating procedure. All items that require calibration and control shall be calibrated and controlled as specified in the user's QA Program. Section 7.0.4 covers QA as it relates to packaging operations. Each site-specific procedure shall document the revision numbers of the Certificate of Compliance (CoC) and SARP that are in effect when the package operation occurs. The packaging user shall document compliance with all procedural elements, and each procedure shall include instructions to be followed if a requirement cannot be met. Section 7.0.5 discusses the nomenclature used with the 9979 packaging. This nomenclature is depicted and defined in Figure 7.1 of the SARP.

7.2 Package Operations

Package loading

Packagings shall be loaded and closed in accordance with written operating procedures that include the procedural elements of Chapter 7 of the SARP, as well as the QA documentation required by Chapter 9 of the SARP.

Section 7.1.1 of the SARP discusses preparation for loading of the packaging. Section 7.1.1.1 contains 12 steps that address packaging preparation. These 12 steps cover packaging identification and verification, radioactivity surveys, and packaging condition. Section 7.1.1.2 addresses contents and payload preparation. The steps in this section cover confirmation that the radioactive contents comply with the CoC, thus verifying that the handling conveniences for the radioactive material are not degraded, and that the payload is configured as described in Section 1.2.2 of the SARP.

Section 7.1.2 of the SARP discusses procedures and steps for loading the radioactive contents into the 30-gallon confinement drum. This loading shall be done in accordance with the ALARA principles and by following the steps in Section 7.1.2 and Section 1.2.2 of the SARP. All combustible contents are required to be packed inside a thermal insulating bag, which is placed inside the 30-gallon drum, as described in Section 1.2.4 of the SARP. A tamper indicating device (TID) is installed on the 30-gallon confinement drum, if required by facility operations.

Section 7.1.3 of the SARP addresses preparation for transport. This section requires a radioactive contamination survey of a loaded 30-gallon confinement drum, and it covers the loading of the 30-gallon confinement drum into the 55-gallon drum overpack. A TID is then installed on the 55-gallon drum. The 55-gallon drum is then surveyed for surface contamination and radiation, in accordance with 10 CFR 835 and 10 CFR 71.4. The drum is then labeled and tagged per 10 CFR 172.

Package unloading

Some loaded 9979 packages will be disposed of directly as waste, and unloading procedures are not applicable. Packages that require unloading shall be unloaded in accordance with written operating procedures that include the procedural elements of Chapter 7 of the SARP, the ALARA principles, and the QA documentation required by Chapter 9 of the SARP.

Section 7.2.1 of the SARP addresses receipt of the package from the carrier. This section requires a radioactive survey of the package, verification that the TID on the 55-gallon drum overpack is unbroken, and verification that the package has not sustained any damage that may significantly reduce the packaging performance.

Section 7.2.2 of the SARP addresses removal of the contents from the 30-gallon confinement drum. This section contains 12 steps. These steps include the documentation of the removal of the TID on the 55-gallon drum; the opening and removal of the closure lid and insulation from the 55-gallon drum; the removal of the 30-gallon confinement drum;* the removal of the packing, dunnage, and contents from the 30-gallon confinement drum; and the completion of appropriate radiation surveys on all parts as they are removed and on the interior surface of the 30-gallon drum (when empty) to check for contamination. (**Note: The 30-gallon drum could be pressurized. By using the appropriate facility precautions, the ¾-in. blind plug should be backed out to relieve any internal pressure.*)

Preparation of empty package for transport

An empty 9979 package shall be shipped per 49 CFR 173.428. A package that is internally contaminated shall be prepared for transport per 49 CFR 173.421.

Section 7.3.1 of the SARP covers shipping of an empty package. The packaging shall be verified to be undamaged, and surface surveys must show that the internal contamination does not exceed the limits in 49 CFR 173.428(d). The radiation levels shall be verified to be within the limits in 10 CFR 173.421. The packaging must be closed in accordance with Section 7.1.3, with an "EMPTY" label affixed over the Packaging Identification Plate.

Section 7.3.2 of the SARP covers shipping of a non-empty package. A non-empty package is any packaging that cannot qualify as "EMPTY" per Section 7.3.1 of the SARP. The non-empty packaging shall be prepared for shipment per Section 7.1.1.1, and the package closure per Section 7.1.3.

Other operations

There are no special operational controls or restrictions for shipping the 9979 package, other than those discussed in Chapter 7 of the SARP.

Section 7.4.1 of SARP addresses packaging storage. The 9979 packaging shall be stored in a facility that provides protection from the effects of temperature extremes and humidity to prevent condensation. The facility must also protect against chemical vapors, accelerating forces, and physical damage and airborne contamination such as rain, snow, dust accumulation, dirt, salt spray, and fumes. Drum assemblies are to be stored with the vent hole plugs in place, the closure lid in place, and the split ring closure device installed.

Section 7.4.2 of the SARP addresses records and reporting. The package loading record shall be prepared in accordance with the requirements of 10 CFR 71.91 and maintained in accordance with Section 9.17 of the SARP. At a minimum, the identification shall include the packaging model and serial number, verification that there are no significant defects in the packaging as shipped, the type and quantity of the licensed material shipped and the total quantity in each shipment, the date of shipment, any special controls used, the name and address of the transferee, the address to where the shipment was made, and compliance with 10 CFR 71.87 and the CoC. Records are only valid if signed, initialed, or stamped and dated by authorized personnel.

7.3 Conclusion

Based on the statements and representations in Chapter 7 of the SARP and the DOE PCP staff's confirmatory evaluation, DOE PCP concludes that the operating procedure requirements presented in Chapter 7 of the SARP are acceptable and provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 and 49 CFR Part 173 have been met.

8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Discussion

The DOE PCP staff reviewed the requirements for acceptance tests to be performed for each 9979 packaging prior to initial use, as described in Section 8.1 of the SARP. These tests include visual inspections, weld examinations, structural and pressure tests, leakage tests, and component and material tests. Shielding and thermal acceptance tests are not applicable to the 9979 packaging. The DOE PCP staff also reviewed the requirements for the maintenance program of the packaging, as described in Section 8.2 of the SARP. The owner shall verify that all fabrication and rework records required by Chapter 9, Table 9.5, of the SARP are controlled and retrievable by the packaging serial number. The results of the DOE PCP staff's evaluation of the acceptance tests and maintenance program are given below.

8.2 Acceptance Tests

Visual inspections and measurements are detailed in Section 8.1.1 of the SARP. Throughout the fabrication process, visual inspections, measurements, and tests are performed to ensure compliance with all requirements on the drawings. Non-destructive methods such as thermal imaging, ultrasonic evaluation, radiography, or other methods shall be used to verify the complete filling of each production drum and drum lid. The inspections, measurements, and tests described in the SARP ensure that any newly fabricated packaging is complete and operable upon receipt.

Section 8.1.2 of the SARP addresses weld inspections. It requires a weld examiner to be certified per SNT-TC-1A. Inspection methods, criteria, weld procedures, personnel qualifications, and weld reports shall meet the American Welding Society (AWS) D.1.3.

Section 8.1.3 of the SARP (per Section 8.1.3.1) addresses pressure tests. The 30-gallon confinement drum requires a hydrostatic pressure test per 49 CFR 178.605. The drum vendor must hydrostatically pressure test at least three samples from each drum lot at 150 kPa (21.7 psig) for five minutes with the closure-lid vents sealed. The acceptance criterion is no visible water leakage from the packaging. Shipment of free liquids within the 9979 package is prohibited. The hydrostatic test requirement for a liquid packaging is specified to ensure additional integrity and robustness of the 30-gallon drum.

The drums are leak and pressure tested in accordance with 49 CFR 178.604 and 178.605. In addition, drawing R-R2-G-0057 requires pressure testing of the drum liner.

Section 8.1.3.2 addresses structural tests. The 30-gallon drum must pass a drop test per 49 CFR 178.603(e), a stacking test per 49 CFR 178.606, and a vibration test per 49 CFR 178.608. The acceptance criterion is no indication of rupture or leakage.

Section 8.1.4 of the SARP addresses leakage tests. Each 30-gallon confinement drum is required to pass a leakproofness test per 49 CFR 178.604. This test requires the container to be pressurized with a gas to at least 4.3 psig (30 kPa) and show no leakage. Acceptance is verified by a 100% inspection of the longitudinal drum seam and bottom chime using a bubble test.

Section 8.1.5 of the SARP addresses component and material tests. The 9979 packaging incorporates a pressure relief device within the 30-gallon closure lid. The device relieves at a pressure of 18-20 psig and resets at approximately 10 psig. The manufacturer provides a component test report, so that each device will operate as specified. The 9979 packaging incorporates DOW Chemical rigid polyurethane foam as an energy impact absorber and thermal barrier. The material tests in Appendix 8.3.1 of the SARP shall be performed and documented on each batch of foam used in the construction of the 9979 packaging. In addition, nondestructive methods such as thermal imaging, ultrasonic evaluation, radiography, or other methods shall be used to verify complete filling of each production drum and drum lid.

Section 8.1.6 of the SARP addresses shielding tests. Because the 9979 packaging does not have any shielding features, no shielding tests are required.

Section 8.1.7 of the SARP addresses thermal tests. The 9979 packaging does not incorporate any active heat transfer features or unique passive heat transfer features. Therefore, acceptance of a newly fabricated packaging does not require testing for thermal integrity.

Section 8.1.8 of the SARP addresses miscellaneous tests. The 9979 packaging does not require any miscellaneous tests.

The DOE PCP staff finds all the requirements for the acceptance tests described in Section 8.1 of the SARP to be acceptable.

8.3 Maintenance Program

Section 8.2 of the SARP states that the 9979 packaging does not require annual maintenance. The inspections required for normal use, per Chapter 7 of the SARP, are sufficient to ensure that the performance of the packaging has not been degraded. The DOE PCP staff finds the maintenance program to be acceptable.

8.4 Conclusion

Based on the statements and representations in Chapter 8 of the SARP and the DOE PCP staff's confirmatory evaluation, DOE PCP concludes that the acceptance tests and maintenance program requirements presented in Chapter 8 of the SARP are acceptable and provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 and 49 CFR Part 178 have been met.

9. QUALITY ASSURANCE

9.1 Discussion

The DOE PCP staff reviewed the requirements for a QA Program, as 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 9979 packaging. The QA requirements are based on a graded approach, as described in 10 CFR 71.101.

9.2 QA Program

The QA Chapter of the SARP, along with the Savannah River Nuclear Solutions (SRNS) QA Manual (*1Q Quality Assurance Manual*), provides the QA requirements and implementing procedures that demonstrate compliance with each of the 18 QA requirements in 10 CFR 71, Subpart H. Table 9.1 of the SARP provides a cross-reference matrix that links each of the 18 QA requirements in 10 CFR 71, Subpart H, to the applicable procedure in the *1Q Quality Assurance Manual*.

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. It is graded on the basis of the design function of the item relative to the safety and performance requirements for the packaging. The quality categories for each component are listed in Table 9.3 of the SARP, with the relationship established for the quality categories between the SARP and NRC Regulatory Guide 7.10. The Q-list uses three QA categories, with associated definitions for each. The QA level of each important-to-safety item is based on specific criterion. 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 are required for the procurement, fabrication, and acceptance testing of the original packaging components.

The QA categories for important-to-safety items and activities and non-safety-related items are based on the following definitions in Section 9.2.3 of the SARP:

1. Category A: Items that are critical to safety operation. Category A items could be structures, components, and systems whose failure or malfunction could result directly in a condition adversely affecting the public health and safety. This includes such conditions as the loss of shielding, or an unsafe geometry compromising criticality control.
2. Category B: Items that have a major impact on safety. Category B items could be structures, components, and systems whose failure or malfunction could indirectly result in a condition adversely affecting public health and safety. An unsafe condition involving Category B type items could occur only if a primary failure occurs in conjunction with another failure. This would include such conditions as the loss of shielding, or an unsafe geometry compromising criticality control.

3. Category C: Items that have a minor impact on safety. Category C items could be components and systems whose failure would not significantly reduce packaging functional requirements and would not create a condition that would adversely affect public health and safety.

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. Specific QA requirements (Level of QA Effort) from Subpart H of 10 CFR 71 relative to packaging activities are categorized in Table 9.4 of the SARP. Each of the 18 elements has assigned QA requirements on the basis of the Quality Category.

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. Verification of critical activities is contained in Section 9.2.3 of the SARP, which includes inspection criteria for acceptance of the fabricated 9979 packaging components, assembly operations, and package loading.

Records

Table 9.5 of the SARP specifies which documents are considered to be lifetime records, such as 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 that is documented by the prescribed records.

9.3 Conclusion

Based on the statements and representations in the SARP and the DOE PCP staff's confirmatory evaluation, DOE PCP finds that the Quality Assurance Program and requirements presented in Chapter 9 of the SARP are acceptable and provide reasonable assurance that the regulatory requirements of 10 CFR Part 71 are met.