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Shipment of Two DOE-STD-3013 Containers in a 9977 Type B Package

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ABSTRACT
The 9977 is a certified Type B Packaging authorized to ship uranium and plutonium in metal and oxide forms. Historically, the standard container for these materials has been the DOE-STD-3013 which was specifically designed for the long term storage of plutonium bearing materials. The Department of Energy has used the 9975 Packaging containing a single 3013 container for the transportation and storage of these materials. In order to reduce container, shipping, and storage costs, the 9977 Packaging is being certified for transportation and storage of two 3013 containers. The challenges and risks of this content and the 9977s ability to meet the Code of Federal Regulations for the transport of these materials are presented.

Background
The Department of Energy (DOE) established a design standard (the DOE-STD-3013, referred to as the 3013 Container) [Ref. 1] for a 50-year storage container for plutonium and uranium radioactive materials (RAM). The 3013 Standard permits contents with 4.4-kg of Pu/U metal (5.0-kg of oxide) and 19-watts of decay heat in a 4.95-inch diameter by 10-inch long stainless steel container. Shipping packages have been Certified (the Models 9975, 9977, 9978, etc) for shipment carrying one 3013 compliant container. The DOE has de-inventoried the Pu/U materials of several former weapons production sites to the Savannah River Site in 3013 Containers shipped in the 9975 Package. It has been typical for receiving sites to store their RAM materials in the same shipping package in which they were received. Recently, the need to reduce costs has led to the investigation of maximizing the contents of the shipping/storage packages. In this case it means transporting two (2) or more 3013 Containers in each package.

An Addendum was developed to document the review of the 9977 Safety Analysis Report for Packaging (SARP) [Ref. 2] for the addition of a new content consisting of plutonium and uranium oxides stabilized and packaged to the DOE-STD-3013 and shipped in a dual 3013 configuration. The 9977 package's maximum allowable radioactive decay heat rate (thermal) limit was also needed to be increased to 38 watts, to accommodate the two 3013s loaded to the DOE-STD-3013 limit.

The review of any new content and or configuration change to an existing package authorization basis consists of a comprehensive evaluation against the safety baseline established by the Certificate of Compliance (CoC) and each SARP chapter. The review also required additional analyses to evaluate the effects of the proposed change on the performance of the 9977 package as documented in the SARP. These actions are necessary to demonstrate how the proposed changes fit within the certified safety basis. The addendum supplements Revision 2 of the 9977 SARP and it's approved Addenda. The safety basis described addressed specific changes to the currently approved package contents and justification is made for shipping the additional content and new configuration under the Addendum.

DISCUSSION

An addendum was written that adds a new content consisting of DOE-STD-3013 stabilized plutonium and uranium oxide materials to the authorized 9977 contents. The proposed contents are not bounded by the current content envelope and a revision to the 9977 CoC is required. The Pu Oxide Content Envelope supports the NNSA shipment of materials between DOE facilities. Based on the findings presented in the Addendum, the new contents/configurations described below do not compromise the safety basis presented in the 9977 SARP Revision 2.

The SARP documents the performance of the Model 9977 shipping package in satisfying the regulatory safety requirements set forth in the Code of Federal Regulations (CFR) 10 CFR 71 [Ref. 3] and the International Atomic Energy Agency (IAEA) Safety Series No. TS-R-1, Regulations for the Safe Transport of Radioactive Material. [Ref. 4] The results of additional package analyses are documented in the Addendum. Results of the original package analysis and testing performed are presented in the 9977 SARP Revision 2, and it's Addenda

The performance evaluation documents the compliance of the package to the regulatory safety requirements for a Type B(M)F-96 package. The 9977 is designated as "B(M)" because the package design pressure and the Maximum Normal Operating Pressure (MNOP) for the new content envelope are greater than 100 psi (700 kPa) gauge, being 800 psig and 422 psig, respectively. Package contents include actinide metals and oxides in Type B quantities. Package contents can exceed 3,000 A_2s, as defined in 10 CFR 71.4, therefore, the 9977 is considered a Category I package.[A.1.8] Additional contents for the addendum include oxides in quantities larger than and having isotopic constituents in concentrations differing than those originally analyzed in the 9977 SARP Revision 2. The supporting analyses in the addendum confirm that the package remains capable of meeting the requirements found in the Code of Federal Regulations.

Limits on package contents are based on nuclear criticality, radiation shielding, and decay heat rate. The calculated nuclear Criticality Safety Index (CSI) for the package with the Plutonium Oxide Content envelope is 0.2. The Transport Index (TI) based on dose rate is calculated to be a maximum of 7.3, and shall be established for each package by measurement at the time of shipment. The package utilizes limits on contents decay heat rates and passive cooling to maintain internal temperatures below allowable limits.

Package Description

The 9977 is designed to ship radioactive contents in assemblies of Radioisotope Thermoelectric Generators, arrangements of nested food-pack cans, or engineered containers. These content configurations ensure product reliability, minimize contamination, simplify handling, and facilitate storage. Some containers are designed and tested to remain leaktight during transport, handling and storage; however, their ability to remain leaktight during transport in the 9977 is not credited.

The package assembly shown in Figure 1 (from the 9977 SARP Revision 2) was maintained for the contents evaluated in the addendum. To increase heat transfer out of the package from the increased decay heat rate of the dual 3013s in the configuration an aluminum Thermal Dissipation Sleeve (HDS) was added, shown in Figure 2.

Drum Assembly - The 9977 consists of a Drum and Lid Overpack assembly, a 6-inch inside diameter Containment Vessel (6CV), and Load Distribution Fixtures. The Drum Overpack is an open head drum modified with a bolted-flange closure. The drum body is a closed unit consisting of a shell, top deck plate, reinforcing rim, and a liner assembly, with the volume between the liner assembly and drum shell filled with shock-absorbing thermal-insulating materials. As applicable, the drum is designed, analyzed, and fabricated in accordance with Section III, Subsection NF of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code. The drum closure lid is fabricated from stainless steel plate. The closure lid incorporates chambers above and below the Lid Plate filled with shock-absorbing thermal-insulating materials.

6-inch Containment Vessel - The 6CV is a stainless steel pressure vessel designed, analyzed and fabricated in accordance with Section III, Subsection NB of the ASME Code, with design conditions of 800 psig at 300 °F. The 6CV Closure Assembly consists of a Cone-Seal Plug shaped like a truncated cone and a threaded Cone-Seal Nut. The vessel containment boundary is formed by the vessel body weldment, the Cone-Seal Plug, the Cone-Seal Port Plug, and the Outer O-ring. The internal volume of a closed 6CV is approximately 608 cubic inches. The usable cavity of the 6CV is a minimum of 20.25 inches deep with a minimum diameter of 5.95 inches.

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

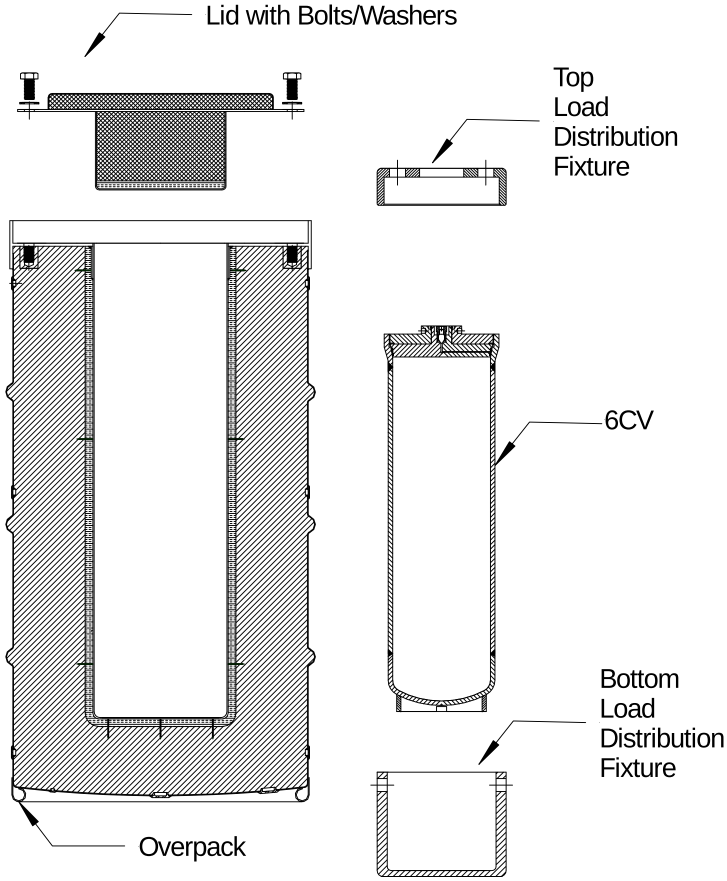

Figure 1 – General Components and Arrangement of the 9977 Packaging

Heat Dissipation Sleeve - The Heat Dissipation Sleeve (HDS) is made from 6061 T6 aluminum, surrounds the outside of the 6CV within the Drum Liner cavity, and is located between the Top and Bottom Load Distribution Fixtures (LDFs), see Figure 2. The HDS enhances the conduction of content decay heat out of the 6CV and produces a more uniform temperature distribution, eliminating "hot spots" within the package, particularly in the polyurethane foam.

3013 Sleeve - The 6CV is fitted with an aluminum sleeve to fill the space between 3013 Containers and the inner wall of the 6CV, as illustrated in Figure 3. The 3013 sleeve is fabricated from 6061-T6 seamless aluminum tubing. The Bottom, curved to match the inside bottom of the 6CV, is pinned to the vertical tube section to create an assembly. The sleeve is approximately 21 inches tall, has a 5 inch inside diameter and a 0.465 inch thick wall.

Contents and Configuration

The package contents are identified in Table 1, *Content Envelopes*, and are in solid form as oxides. Contents in liquid form are not permitted.

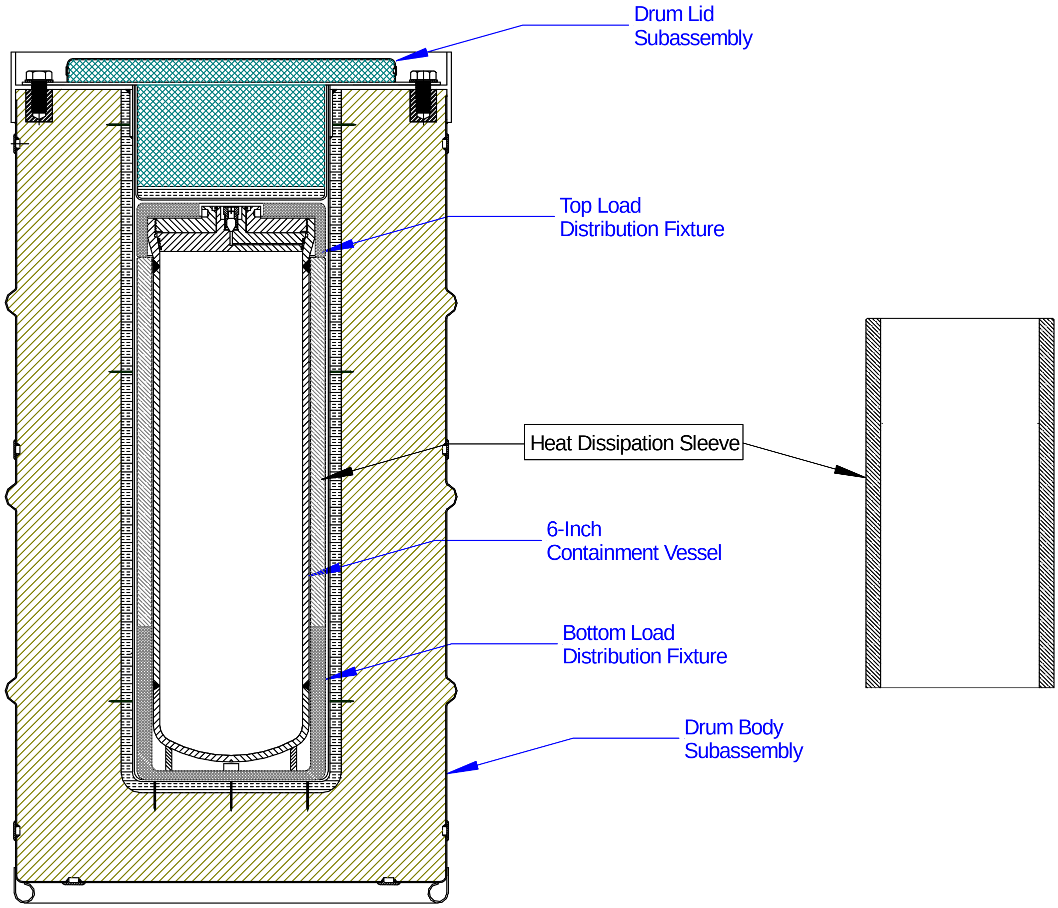

Figure 2 – 9977 with Heat Dissipation Sleeve

The total content mass is listed in Table 1 and applies to each 3013 Container. The Total Mass permitted is 8.8-kg of RAM as 10-kg of oxide. The total content mass listed in Table 1 does not include the materials associated packaging configurations discussed in the content configuration.

The following requirements are typical for any 9977 content and are applicable for the content found in Table 1. Small amounts of actinides, fission products, decay products, and neutron activation products are permitted. Also permitted are inorganic material impurity quantities of less than 100 parts per million each, as long as the total mass is less than 0.1 weight percent of the total content mass.

Contents Containers

The 9977 is presently authorized for the shipment of contents in configurations of Radioistopic Thermoelectric Generators, single or nested Food-Pack Cans, and Engineered Containers. These content containers are used to prevent the inadvertent contamination of the package by providing a level of confinement for the radioactive material contents and to provide protection of the content being shipped. These content containers are also referred to as product containers. Full descriptions, illustrations, and the packaging limitations for these configurations are provided in the SARP.

Table 1 - Content Envelopes (Per 3013 Container)

	Material [a, b, c]	Pu Oxide	Pu Oxide Maximum Impurities
Fissile Material (Maximum Weight %)	^{236}Pu	1 x 10^{-7}	1 x 10^{-7}
	^{238}Pu	0.05	0.05
	^{239}Pu [d]	95	95
	^{240}Pu [e]	9	9
	^{241}Pu [d]	1	1
	^{242}Pu	0.1	0.1
	U [f]	50	50
	^{241}Pu + ^{241}Am	1	1
	^{237}Np	0.05	0.05
Imp.3urities (grams)	Be	0.44	11
	Al	0.66	44
	Mg	2.2	44
	Na	1.32	44
	F	1.1	1.54
	B	2.2	44
	Li	2.2	11
Total Mass (kg)	Radioactive Materials	4.4	4.4
	Impurities	0.082	0.582
	All Contents	5.0	5.0

Table Notes.

Notes

a All contents shall be dry.

b Pu/U content bulk density shall be no greater than 19.84 g/cc and no less than 2.0 g/cc.

c Contents shall be stabilized in accordance with DOE-STD-3013, Section 6.1.1.

d Nuclide classified as “fissile” per DOE Good Practices Guide, Criticality Safety Good Practices Program, Guide For DOE Nonreactor Nuclear Facilities, DOE G 421.1-1, 3.79 Fissile Nuclide, 8-25-99.

e ^{240}Pu shall be greater than ^{241}Pu.

f All isotopes except ^{232}U, which is limited to 1 x 10^{-7} weight percent

The Dual 3013 Container Configuration consists of a 3013 outer storage can, a 3013 inner storage can, and optional product material container(s) and is designed to meet the requirements of DOE-STD-3013. Individual package users typically develop site-specific 3013 inner and product containers. 3013 containers used to contain contents from Table 1 must meet the requirements for the reference outer 3013 can as well as the inner and product containers found in DOE-STD-3013, Section 6.2, “Containers.” The 3013 inner and product containers are not permitted to have organic liners. The Dual 3013 Content configuration is shown in Figure 3. The Dual 3013 configuration includes the 3013 Spacer and the Heat Dissipation Sleeve. It was recognized that while a site may wish to ship materials in the Dual 3013 Container configuration, sufficient materials may not be available to fill an even number of 3013s for shipment in a 9977 Package. Therefore, a perforated Food-Pack Can may be used as a spacer in place of either of the 3013 Containers. However, the "per 3013" content requirements listed in Table 1 are still enforced.

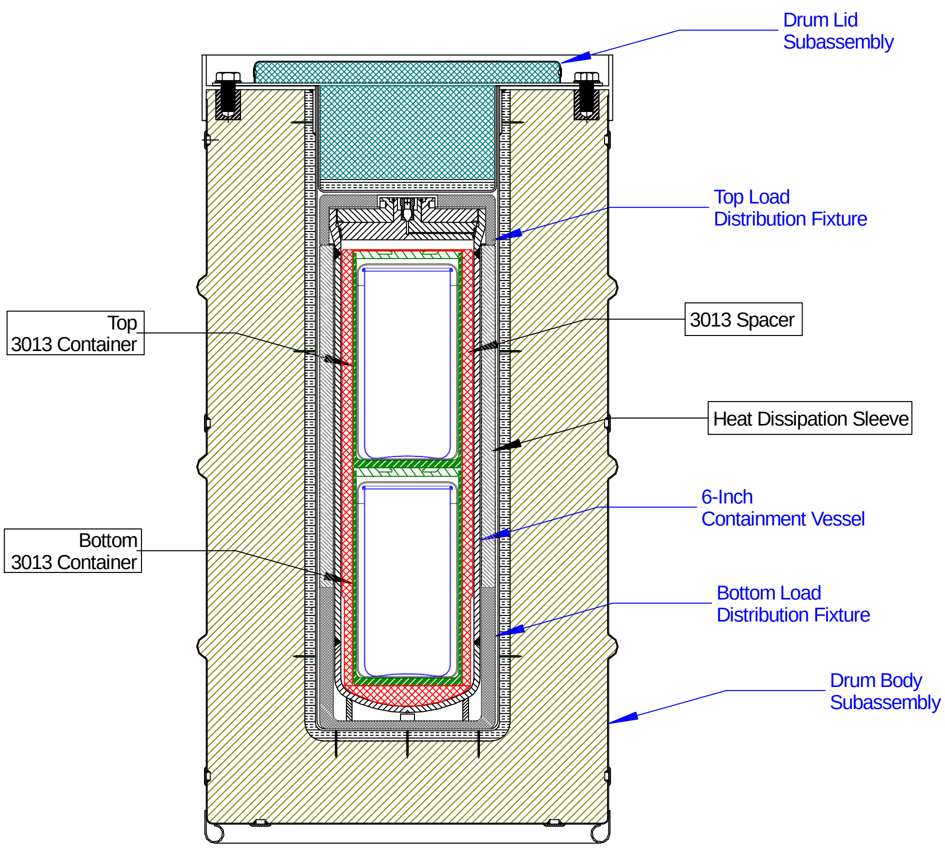

Figure 3 – Typical Dual 3013 Container Configuration in the 9977

The basic requirements of a radioactive material package are that the package contains the RAM, maintains subcriticality, and limits the radiation dose rate to workers and the public to below specified values during normal conditions of transportation and after the hypothetical accident conditions. The 9977 with the Dual 3013 Content Configuration was analyzed for these requirements and the results (and their effect on the Content) are discussed below.

The Dual 3013 Content Configuration is within the baseline limits for the content weight and uses materials demonstrated to be compatible with the 6CV. The increased content decay-heat rate, from 19 to 38 watts, was analyzed for its effect on the package component temperatures and the expected 6CV maximum normal operating pressure. The package components (both the 6CV and the drum assembly) must be maintained within their design temperature limits. The temperature of the 6CV closure O-Rings are particularly critical as they are known to maintain their sealing capability if kept at a temperature of 200ºF or less. The calculated package temperatures are listed below. Since the Dual 3013 Contents consist of Pu Oxides per the DOE

3013 Standard, each 3013 container may hold up to 25 grams of water. Pu radiolyzes water producing free oxygen and hydrogen. This not only increases the pressure of the gas, but the resulting mixture is flammable and explosive under the right conditions. To preclude a flammable gas mixture within the 6CV, it is backfilled upon loading with CO_2 to take the free oxygen below the lower flammability limit of hydrogen.

Table 2 - Maximum Temperatures under NCT and HAC Thermal (Fire and Cool-down)

Condition	Drum (°F)	LDFs (°F)	Polyurethane Foam (°F)	6 Inch CV (°F)		
				Body	O-rings	Contents
NCT in Shade {Design Limit}	110 {800}	242 {300}	236 {300}	257 {300}	257 {400}	513 {n/a}
NCT w/ Insolation {Design Limit}	189 {800}	279 {300}	291 {300}	310 {300}	299 {400}	559 {n/a}
HAC Thermal - Fire {Design Limit}	1,475 {n/a}	n/a	n/a	344 {500}	344 {700}	577 {n/a}
HAC Thermal - Cool-down w/ Insolation {Design Limit}	204 {n/a}	n/a	n/a	395 {500}	385 {700}	588 {n/a}

It is noted that the maximum temperature of the 6CV is 10ºF above its design temperature (310ºF vs 300ºF). This minor exceedance is easily accommodated by the large margins of safety in the 6CV structural design. The key to maintaining the component temperatures within their limits is the inclusion of the Heat Dissipation Sleeve. The sleeve is made of 6061-T6 aluminum. This aluminum is strong, compatible with other content and container materials, has good thermal conductance (replaces air which has poor conductance), aids in heat conductance away from the CV (and hence, away from the O-Rings), spreads decay-heat throughout the Packaging Assembly eliminating “hot spots” in foam in the 6CV and the foam, and makes the temperatures uniform throughout. Figure 4 shows the temperature distribution within the package when loaded with two 19-watt 3013 containers. The HDS does not count against the 100 pound “content” weight, since it is outside the 6CV, but it does count against the total package weight.

A Shielding Analysis was performed of the Dual 3013 Content Configuration with each 3013 loaded at their maximum impurities levels. The calculated dose rates are all within the regulatory limits as shown in Table 3 below.

A Nuclear Criticality Safety Evaluation (NCSE) was performed for the Dual 3013 Content Configuration. [Ref. 5] For these analyses, it was conservatively assumed that all the content’s fissile material was ^{239}Pu. Since the permitted ^{239}Pu mass exceeds its minimum subcritical mass limit of (450 grams) [Ref. 6] the content needs to be configured in an inherently safe configuration in order to pass the 10CFR71.55 Single Package Flooded scenario. A 5-inch inside-diameter tube is critically safe irregardless of the content configuration or any moderation. Therefore, a 3013 Spacer was added to the content configuration. The Spacer is made of 6061-T6 aluminum, which is strong, compatible with the other materials within the 6CV, has good thermal conductance, consumes free volume between the 3013 containers and the inside surface of the of the 6CV (both radially and axially), and maintains the critically safe configuration. Because of the good thermal conductance of the 3013 Spacer, it also aids in heat transport out of the CV (and hence, away from the O-Rings), and spreads decay-heat throughout the CV eliminating "hot spots". A consequence of the 3013 Spacer greatly reducing free-volume is that it also increases the Maximum Normal Operating Pressure (MNOP), by eliminating space for evolved gases to expand into. While the MNOP has increased from the baseline 46.3 psig to 422 psig for the Dual 3013 Content Configuration, this is still well below the 6CV design pressure of 800 psig. The 3013 Spacer also counts against the 100-pounds of "content" weight.

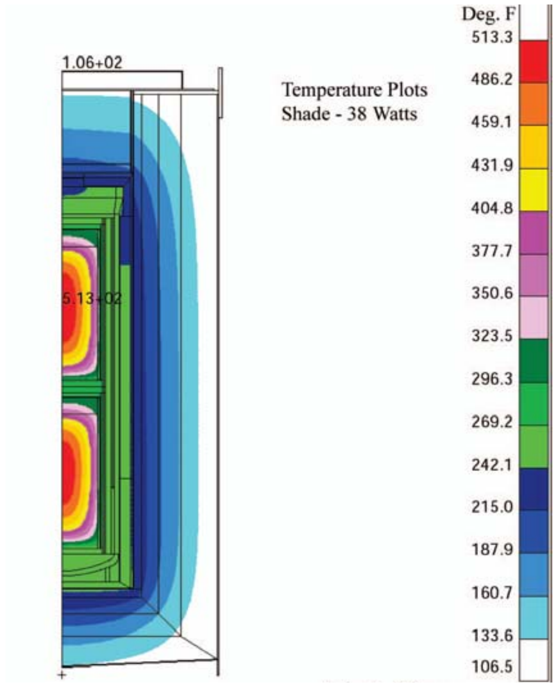

Figure 4 – Overall NCT non-Solar/pre-fire HAC Temperature Profiles

Table 3 - External Radiation Levels

Content Envelope Material	**Pu Oxide Content Envelope** Nominal Beryllium	Maximum Beryllium	**10 CFR 71 Limit**
NCT at Surface (mrem/hour)			
SIDE	20.50	152.53	200
TOP	5.17	41.55	
BOTTOM	7.80	57.84	
NCT 1 meter away (mrem/hour)			
SIDE	0.98	7.22	10
TOP	0.19	1.43	
BOTTOM	0.30	2.23	
HAC 1 meter away (mrem/hour)			
SIDE	1.58	10.96	1000
TOP	0.27	1.67	
BOTTOM	0.39	2.57	

SUMMARY

The bounding Dual 3013 Content is listed in Table 1 and the packing configuration within the 6CV is shown in Figure 3. In addition to the isotopic and chemical content restrictions listed in Table 1 and the configuration criteria listed in Section 1.2.2.1.1, the following conditions apply:

- The maximum allowable radioactive decay heat rate is 19 watts per 3013 Container and 38 watts total per Package.
- The 3013 Spacer must be used.
- Atmosphere within the 6CV shall be diluted to at least 75% CO_2.
- The 3013 container (consisting of the outer can, the inner can(s), and convenience cans), shall be inerted with helium or nitrogen such that oxygen content in all void spaces is no greater than 5% by volume at the time the outer 3013 container is welded closed.
- The 3013 containers; the outer can, the inner can(s), and convenience cans, shall be sized such that the maximum inter-container radial gap, measured as a difference in diameters, shall be no more than 0.75 inch.
- Except as stated in Table 1, small concentrations (<1000 ppm each) of other actinides, fission products, decay products, and neutron activation products are permitted. Assessment of these impurities may be based on process knowledge.
- Except as stated in Table 1, inorganic material impurity quantities of less than 100 ppm each are permitted as long as the total mass is less than 0.1 weight percent of the total content mass. Assessment of these impurities may be based on process knowledge.
- The maximum weight of the payload (everything that goes into the 6CV (containment vessel), including radioactive contents, the 3013 Spacer, convenience cans, contamination control devices, packing materials, spacers, etc.) is not to exceed 100 lb.

References

1 *Stabilization, Packaging, And Storage Of Plutonium-Bearing Materials*, DOE Standard, DOE-STD-3013-2004 (April 2004)

2 *Packaging and Transportation of Radioactive Material*, Code of Federal Regulations, Title 10, Part 71, Washington, DC (December 2006).

3 Abramczyk, G. and Blanton, P. S., *Safety Analysis Report for Packaging Model 9977*, S-SARP-G-00001, Revision 2, (August 2007).

4 *Regulations for the Safe Transport of Radioactive Material – 2005 Edition - Safety Requirements*, IAEA Safety Standards Series No. TS-R-1, International Atomic Energy Agency, Vienna, Austria (April 2005).

5 *9977 Shipping Package With Two 3013 Containers - Analysis For SARP Addendum 7*, N-NCS-A-00023, Revision 0 (November 2010)

6 ANSI/ANS-8.15-1981 (R 2007), "Nuclear Criticality Control of Special Actinide Elements," American Nuclear Society