SAFETY ANALYSIS REPORT FOR PACKAGING

MODEL 9977

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ADDENDUM 3

JUSTIFICATION FOR

SMALL GRAM QUANTITY CONTENTS

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PREFACE

This Addendum documents a review of the 9977 Safety Analysis Report for Packaging (SARP) for addition of a family of new content envelopes consisting of small quantities of radioactive materials readily shown to be subcritical and to be compliant with regulatory radiation dose-rate limits. The content request stems from the DOE's need to ship these materials between various DOE Sites and Laboratories. The Addendum also supports shipment of such materials by other package users.

The review of any proposed change to an existing authorization basis consists of a comprehensive evaluation of the change against the safety baseline established by the Certificate of Compliance (CoC) and each SARP chapter. It may also require additional analyses to evaluate the effects of the proposed change on the performance of the package as documented in the SARP. These actions are necessary to demonstrate how the proposed changes fit within the certified safety basis.

This Addendum supplements Revision 2 of the 9977 Safety Analysis Report for Packaging (hereafter referred to in this Addendum as the 9977 SARP Revision 2). The safety basis described herein evaluates proposed Small Gram Quantity (SQC) content envelopes, and supports regulatory compliance of so-loaded 9977 packages.

NOTE: The safety basis established by this Addendum is based on existing calculations and analyses that bound the structural and thermal loads associated with the SGC content envelopes.

NOTE: The changes incorporated into this Revision 5 are noted in red text, with a double underline (e.g. safety) and a "Revision Bar" placed in the immediate right-hand margin.

EXECUTIVE SUMMARY

This Addendum establishes a new family of content envelopes consisting of small quantities of radioactive materials. These content envelopes and specific packing configurations are shown to be subcritical. However, the dose rates of some payloads must be measured and shown to comply with applicable radiation limits.

Authorization for shipment of the content envelop requires acceptance of this Addendum by the DOE-HQ certifying official as a supplement to the 9977 SARP Revision 2 and DOE-HQ's subsequent revision of the CoC Revision 10 (which is based on SARP Addendum 2 and SARP Addendum 4) to authorize the additional content envelope. The Small Gram Quantity Content Envelopes and packing configurations will be incorporated in the next revision of the 9977 SARP.

INTRODUCTION

This Addendum documents the safety evaluation of a family of new content envelopes consisting of small quantities of radioactive materials. The materials are readily shown to be subcritical, and to have compliant, external package radiation levels. These contents were requested by the Department of Energy (DOE) in support of general material disposition programs. As a supplement to the 9977 SARP Revision 2, this Addendum establishes content limits and content configurations for the new Small Gram Quantity (SGQ) Content Envelopes.

CONTENT/CONFIGURATION ADDITIONS

In conduct of DOE programs, there are many activities which need to ship and/or store small masses of generic radioactive materials which are greater than Type A quantities. Because of the small amount of radioactive material present, these shipments are typically of low risk to the public, workers, or the environment. However, because of the experimental nature of the work, these contents frequently are not precisely defined or do not precisely conform to previously certified content descriptions for certified packagings. The essential requirements for safe transport of such materials is that they be properly contained, are subcritical at all times and do not expose the public, workers, or the environment to radiation dose levels greater than those permitted by the applicable regulations (10 CFR 71). These requirements would be satisfied if such contents are limited to a subcritical mass, are shown by dose rate measurement to meet the regulatory requirements, are placed in a leak tight containment vessel, and are transported in a package certified for large quantities of similar materials. The 9975, 9977, and 9978 packages meet the requirements for such a package and are currently certified for a transport of a wide range of radioactive materials, both fissile and non-fissile.

The content envelopes evaluated by this Addendum include only small masses of radioactive materials. The materials may consist of previously authorized contents but with small concentrations of other actinides, fission products, decay products, and neutron activation products that exceed previously permitted levels, or may consist of materials not previously authorized as contents. Characterization of these material mixtures may be based on process knowledge.

The Small Gram Quantity content envelopes shall:

- have a decay-heat generation rate of
  - 19 W or less for general contents/configurations
  - 6 W or less in the SGQ-SC1 configuration, and
  - 3 W or less in the SGQ-SC2 configuration,
- have a total radioactive material (RAM) mass
  - less than 100 grams and contain no more than 1000 ppm total of ^{251}Cf, ^{249}Cf, ^{242m}Am, ^{243}Cm, ^{245}Cm, and ^{247}Cm for Content Types 2, 3, and 4, and
  - less than 1 grams and contain no more than 1000 ppm total of ^{251}Cf, ^{249}Cf, ^{242m}Am, ^{243}Cm, ^{245}Cm, and ^{247}Cm for Content Type 5
- have a total Content mass (RAM plus impurities) of
  - less than 150 grams for Content Types 2, 3, and 4, and
  - less than 6 grams for Content Type 5
- have a total Payload mass (Content mass plus packing materials) of no more than 100 pounds,
- be confined a convenience container with an attached top,
- contain less than 100 grams of plastic or other organic packing material,
- be solid (metal, oxide, or carbide),
- contain no free liquids,
- not react chemically with the containment vessel or one another, or cause corrosion; and
- not generate any gas (other than helium by alpha decay).

To help the reader re-establish familiarity with the 9977 design, Addendum Figure A.0.1 presents a cross-section of the 9977 packaging (repeated here from the 9977 SARP Revision 2, Figure 1.3).

EVALUATION OF NEW CONTENT

The 9977 SARP Revision 2 was reviewed comprehensively to determine if the new content presented above was bounded by the safety basis presented in the SARP and approved in the CoC. Where compliance with the stated safety basis could not be established by review, new analyses were performed to evaluate compliance. Conclusions from those efforts follow on a per-chapter basis.

SARP Sections that require revision to incorporate the Small Gram Quantity Content Envelopes are presented in this Addendum. To assist regulator review of this Addendum, revised information presented in SARP tables is highlighted with a gray background, while revised Sections are shown indented and in smaller typeface. In both the Tables and the Sections, new and revised text is colored blue for Revision 4 of this Addendum and is colored red with a double underline, and a "Revision Bar" has been placed in the immediate right-hand margin for Revision 5. The specific text and its location within the SARP may change when the Addendum is incorporated into the next SARP revision submitted to DOE-EM for review and approval.

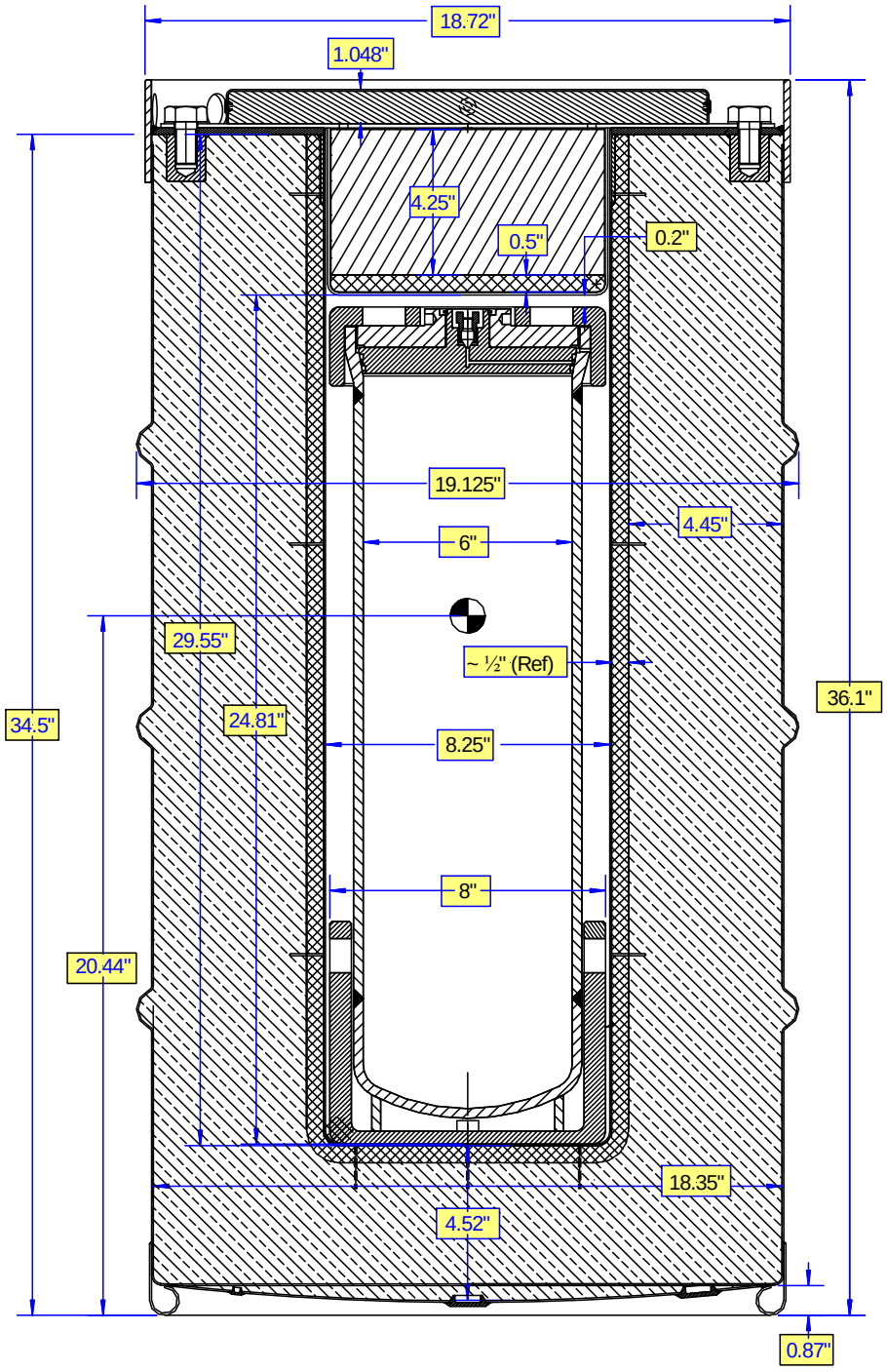

Figure A.0.1 – 9977 Packaging Key Dimensions

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CHAPTER 1 -- GENERAL INFORMATION

The proposed changes to Chapter 1 of Revision 2 of the Safety Analysis Report for Packaging (SARP) [Ref A.1.1] (referred to as the 9977 SARP Revision 2) include a family of new content envelopes and new packaging configurations. The new contents are small quantities of radioactive materials readily shown to be subcritical and limited to packing configurations demonstrated by measurement to meet applicable regulatory radiation limits. Addendum Tables A.1.1 and A.1.2 given in this Chapter define the proposed Small Gram Quantity (SGC) content envelopes and the associated packing configurations, respectively. These contents were not evaluated specifically in the 9977 SARP Revision 2. However, the contents and associated packaging configurations meet all applicable design specifications and parameters described in the 9977 SARP Revision 2. The new contents are discussed in detail in the content configuration sections of this Chapter.

Preface

This Addendum provides the general description of the Model 9977 packaging and physical descriptions of major components and subassemblies. It also describes the new Small Gram Quantity (SGQ) radioactive material contents and associated packing configurations. As summarized in SARP Section 1.2.5, the packaging meets the requirements of 10 CFR 71 and the *Regulations for the Safe Transport of Radioactive Material – 2005 Edition - Safety Requirements*, IAEA Safety Standards, Safety Series No. TS-R-1, International Atomic Energy Agency, Vienna, Austria (2005).

1.1 INTRODUCTION

The Safety Analysis Report for Packaging (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 A.1.2] and the International Atomic Energy Agency (IAEA) Safety Series No. TS-R-1, *Regulations for the Safe Transport of Radioactive Material*. [Ref A.1.3] Results of the original package analysis and testing performed are presented in the 9977 SARP Revision 2, prepared in accordance with U.S. Department of Energy (DOE) Order 460.1B [Ref A.1.4] and in the format specified in the Nuclear Regulatory Commission (NRC) Regulatory Guides (RGs) 7.9 and 7.10. [Refs A.1.5 and A.1.6] This Addendum documents the results of additional package analyses.

The 9977 package complies with the regulatory safety requirements for a Type B(M)F-96 package. The 9977 is designated as "B(M)" because the package design pressure is greater than 100 psi (700 kPa) gauge. 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. [Ref A.1.7]

Limits on package contents are based on nuclear criticality, radiation shielding, and decay heat rate. Small masses of radioactive materials readily shown to be subcritical, to have acceptable radiation levels and decay heat rates are identified herein as Small Gram Quantity (SGQ) content envelopes. The SGQ content envelopes may include previously authorized contents but contain small concentrations of other actinides, fission products, decay products, and neutron activation products greater than that permitted or may consist solely of materials not previously authorized as contents. The supporting analyses demonstrate that the package remains capable of meeting applicable regulatory requirements.

While the SGQ Type 4 Contents may be packaged in convenience cans or metallic capsules which provide contamination control and containment, this Content shipped in the 9977 must be in an approved Shielded or Engineering Container.

A calculational methodology was developed for establishing regulatory dose-rate compliance of the SGQ content envelopes utilizing a number of content or packing configurations.[A.1.11] By the nature of its

need to be "bounding", the SGQ calculations are conservative. Hence, some analytical dose-rate results may exceed regulatory limits, In these cases, radiation levels must be measured and shown to meet regulatory requirements at the surface and 1-meter from a Shielded, Engineering or Convenience Container. These actions support the DOE implementation of ALARA principles.

Compliance with regulatory radiation levels at the surface of a Shielded, Engineering or Convenience Container also adds a margin of safety with the regulatory radiation dose level compliance at the package surface. The margin of safety is further increased for SGQ Types 1 through 3 and Type 4 by imposing 15% and 10% reductions, respectively, to the dose rate limits at all compliance points and for both Non-Exclusive Use and Exclusive Use shipping.

The SGQ content envelopes are further restricted to be within specific decay heat limits. The 9977 package utilizes limits on content decay heat rates and passive cooling to maintain internal temperatures below allowable limits.

Packages are shipped in a closed conveyance under Non-Exclusive Use or Exclusive Use dose-rate limits in the Safe-Secure Trailer, the Safe-Guards Transporter, or by commercial carrier as determined by the contents and DOE Order 470.4A. [Ref A.1.8]

1.2 PACKAGE DESCRIPTION

1.2.1 Packaging

The package assembly is shown in Figures 1.1 through 1.3 in the 9977 SARP Revision 2.

1.2.2 Contents

Small Gram Quantity (SGQ) content envelopes are identified in Addendum Table A.1.1, *Small Gram Quantity Contents*.

The total content mass limits given in Addendum Table A.1.1 do not include the associated packing materials for the SGQ configurations discussed in Addendum Sections 1.2.2.1 and 1.2.2.2.

Requirements common to all SGQ contents and payload configurations are the following.

- The maximum allowable radioactive decay heat rate is 19 watts. Contents shipped in the Shielded Container 1 configuration (SGQ-SC1), Addendum Figure A.1.1, are limited to 6 watts. Contents shipped in the Shielded Container 2 configuration (SGQ-SC2), Addendum Figure A.1.2, are limited to 3 watts.

- Except as stated in Addendum Table A.1.1, 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 Addendum Table A.1.1, 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 Shielded, Engineered, or Content Containers, Convenience Cans, contamination control devices, packing materials, spacers, etc.) is not to exceed 100 lb (43.5 kg mass).

- Approval to ship SGQ Content Types 2 and 3 may be established by either:
  - A documented evaluation of the content per the Packaging Certification Program *Methodology for Determining Dose Rate*. [Ref A.1.11], or
  - Dose rate measurements of no more than 170 mrem/hr at the surface of and/or 8.5 mrem/hr at 1-meter from all sides, top, and bottom of the Engineered, Shielded, or Convenience Container for non-exclusive use shipments or 850 mrem/hr at the container surface for exclusive use shipments.
- While SGQ Type 4 Contents may be packed in Convenience Cans or metallic capsules which provide contamination control and containment, they must be shipped in an approved Shielded or Engineered Container Configuration.
- For SGQ Type 4 Contents, the maximum radiation dose rate at all surfaces (top, sides, and bottom) of the Engineered or Shielded Container is 180 mrem/hr (1.8 mSv/hr) or less.
- For SGQ Type 4 Contents the maximum radiation dose rate one meter from all surfaces (top, sides, and bottom) of the Engineered or Shielded Container is 9 mrem/hr or less.
- The SGQ Type 5 Contents, when shipped in the SGQ-SC3 configuration, is demonstrated by calculation (Chapter 5) to meet the regulatory dose rate limits at the package surface.
- The SGQ materials shall be in solid form (e.g., metal, oxide, or carbide). Materials in liquid form are not permitted.
- When shipped in a "Sealed Source" configuration, the SGQ Type 4 Contents material may contain carbonaceous matrix materials, halides, hydroxides, hydrides, oxycarbides, titanates, silicates, sulfates, or aluminosilicates.

WARNING: The following, while non-comprehensive, lists radionuclides having a high specific gamma dose rate and a significant half-life which could, in sufficient mass, result in high dose rate levels and necessitate being shipped within a Shielded Container Type 1 or Type 3 configuration.

In addition, actinide materials in conjunction with light element impurities may also produce unacceptably high dose rates, necessitating a Shielded Container Type 2 configuration. The presence, form, and quantity of impurities may significantly affect dose rates. Therefore, the use of dose rate measurements per Section 7.1.1.2 is required.

^{22}Na	^{46}Sc	^{54}Mn	^{59}Fe	^{56}Co	^{58}Co	^{60}Co	^{65}Zn
^{75}Se	^{85}Sr	Y^{88}	^{94}Nb	^{95}Nb	^{103}Ru	^{106}Ru	^{110m}Ag
^{125}Sb	^{134}Cs	^{137}Cs	^{152}Eu	^{154}Eu	^{192}Ir	$^{236}Pu/^{208}Tl$	$^{232}U/^{208}Tl$
$^{228}Th/^{208}Tl$	$^{248}Cf/^{208}Tl$						

Table A.1.1 - Small Gram Quantity Contents

Material	Mass Limit [a]				
	Type 1	Type 2	Type 3 [b]	Type 4 [c, f]	Type 5 [d]
^{242m}Am, ^{243}Cm, ^{245}Cm, ^{247}Cm, ^{249}Cf, ^{251}Cf [e]	--	<1000 ppm	<1000 ppm	<1000 ppm	<1000 ppm
^{238}Pu	Withdrawn	← See mass limit	34	0.2	← See mass limit
^{239}Pu			100	66	
^{240}Pu			100	-	
^{241}Pu			100	-	
^{242}Pu			100	-	
^{241}Am + ^{241}Pu			100	-	
^{241}Am			-	1	
^{243}Am			100	-	
^{244}Cm			0.23	1	
^{237}Np			100	-	
^{232}U			0.0044	-	
^{233}U			100	-	
^{234}U			100	-	
^{235}U			100	-	
^{236}U			100	-	
^{238}U			100	-	
^{232}Th			100	-	
^{252}Cf			-	0.0000067	
^{90}Sr			-	1	
^{226}Ra			-	0.2	
^{137}Cs			-	0.1	
^{60}Co			-	0.0001	
^{192}Ir			-	0.0038	
RAM per 10CFR71 Appendix A Table A-1	--	100	-	-	
RAM Specified Addendum Appendix 1.2	--	-	-	-	1
Total RAM	--	100	100	69.5	1
Light Elements and Impurities	--	50	50	50	5
Total Content	--	150	150	119.5	6

a Mass limit in grams, except as parts-per-million total for the "Special Actinides" in SGQ Content Types 2, 3, 4, and 5.

b Material defined by S-SARA-G-00007, Rev. 0, *Justification for 9975 Gram Based Content Envelopes C.10 and C.11 contents*, with mass limits reduced to 100 grams individual and total.

c Material defined by LANL Off-Site Source Recovery Project contents.

d Material defined by INL AGR-1 Compacts (Appendix 1.2).

e The characteristics of these special actinides are not as well established as for other, more common fissile isotopes. Accordingly, a larger safety factor is employed for these contents. Limit is for total material.

f Some mass limits have been reduced based on recommendations from regulatory reviewers and do not reflect the values presented in Chapter 5.

1.2.2.1 Contents Containers

The 9977 is currently authorized for shipment of contents in RTGs, Food-Pack Cans, DOE-Standard 3013 Containers, and Engineered Containers. These content containers are used to prevent inadvertent contamination of the package by providing a level of confinement for the radioactive content and to protect the content being shipped. These content containers are also referred to as product containers. Special Form items per 49 CFR 173.469 [Ref A.1.9] or "Sealed Sources" under ANSI/HPS N43.6 [Ref A.1.10] falling within the SGQ content envelopes may be shipped. SGQ Types 2 or 3 Contents may be packed in any approved Container for shipment. A *Methodology for Determining Dose Rate* (MDDR) developed for the SGQ content envelopes addresses various non-shielded and shielded container configurations and establishes the acceptability of the Content for Non-Exclusive Use or Exclusive Use shipment.

The MDDR is conservative and may not demonstrate dose-rate compliance for some contents or containers. However, the acceptability of a Content Container may also be established by placing it within a Content Container (Food-Pack Can, DOE Standard 3013 Container, or Engineered Container; including one of the three SGQ Shielded Containers) and measuring its dose rates on and at 1-meter from the surface of the Container. Measured at these locations, acceptable dose rates are reduced to 85% of the regulatory limits. Other types of shielding or shielded containers ***may not*** be used for these contents without an explicit evaluation and approval by the Certifying Official. The SGQ-SC1 and SGQ-SC3 provide gamma shielding, and the SGQ-SC2 provides neutron shielding. Descriptions, illustrations, and the packaging limitations for typical Containers and shielded containers SGQ-SC1, SGQ-SC2 and SGQ-SC3 are provided below in Addendum Section 1.2.2.1.1.

SGQ Type 4 Contents, even if Sealed Sources or confined within Convenience Cans or metallic capsules, must be packed in an approved Engineered or Shielded Container for shipment. If additional shielding is required for the contents to meet the contact dose-rate requirement of 1.8 mSv/hr, the Contents may be placed within one of the three SGQ Shielded Containers. The points of compliance for dose-rate measurements are the external surfaces of the Engineered or Shielded Container.

1.2.2.1.1 Small Gram Quantity -- Shielded Containers

The Small Gram Quantity Shielded Containers (SGQ-SC1, SGQ–SC2 & SGQ–SC3) provide shielding appropriate to the radiological hazard of the contents. The SGQ-SC1, SGQ–SC2, and SGQ–SC3 containers provide gamma or neutron shielding. The SGQ–SC1 container provides gamma shielding and consists of a lead body enclosed by a stainless steel container with a threaded closure. The SGQ-SC2 container provides neutron shielding and consists of high density polyethylene, with an integral closure (no encapsulation being required). The SGQ–SC3 container provides gamma shielding and consists of tungsten body enclosed by a stainless steel container with threaded closure. The three containers are able to withstand the worst case Hypothetical Accident Condition (HAC) drop without compromising shielding performance. The containers permit transmission of decay heat released by the radioactive contents as described in Section 3.1.1.4.

The SGQ–SC1 and SGQ-SC3 containers are centered within the 9977 6-inch Containment Vessel (6CV) by aluminum foam Spacers. However, for operator convenience, the SGQ–SC2 is located at the just inside the closure of the 6CV atop a perforated food-pack spacer can. Typical packing configurations are shown in Addendum Figures A.1.1, A.1.2, and A.1.3. Appendix A.1.1 provides the drawing detailing the shielded container components.

1.2.2.1.2 Small Gram Quantity -- Engineered Container

There is one approved engineered container; the Small Gram Quantity Engineered Container Type 1 (SGQ-EC1) is shown in Addendum Figure A.1.4. SGQ-EC1 provides confinement for the contents and a uniform configuration for measurement of surface dose rates. The SGQ-EC1 container is a variation of the SGQ-SC1 (the same stainless steel shell but without the lead shielding body) and is able to withstand the worst case Hypothetical Accident Condition (HAC) drop without compromising its confinement function. The container permits transmission of decay heat released by the radioactive contents as described in Section 3.1.1.5.

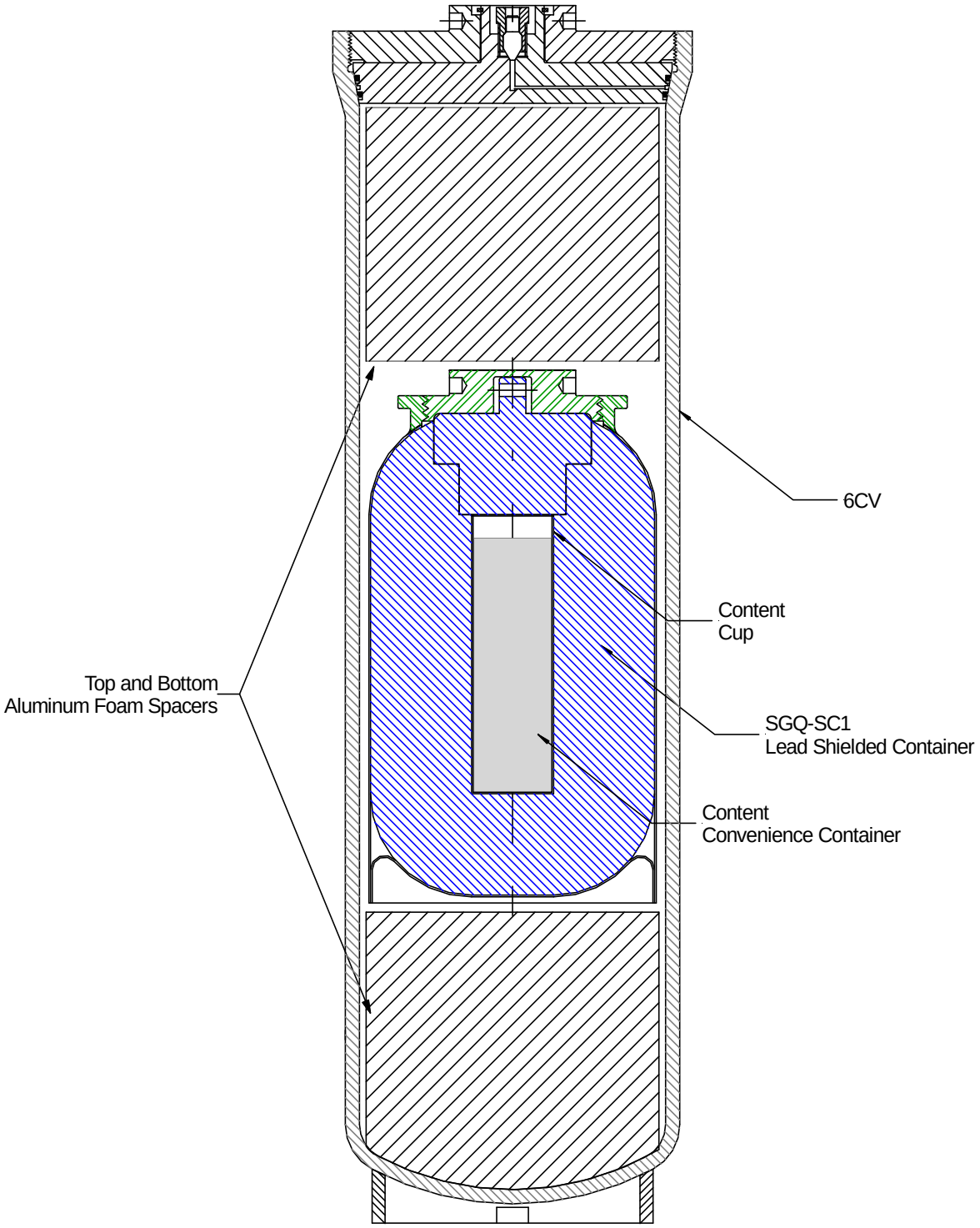

Figure A.1.1 – SGQ-SC1 Configuration in 9977 (Lead Shielding)

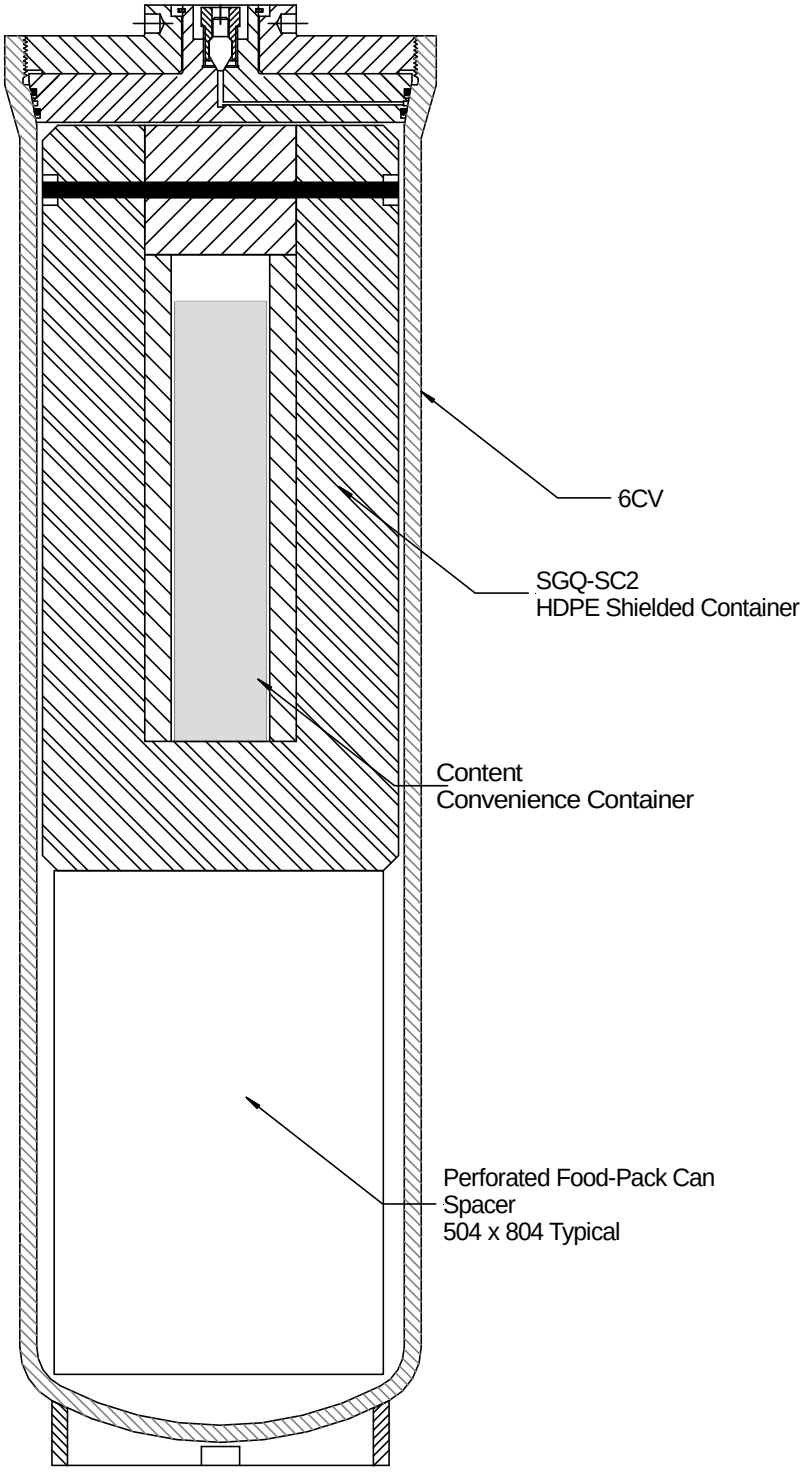

Figure A.1.2 – SGQ-SC2 Configuration in 9977 (HDPE Shielding)

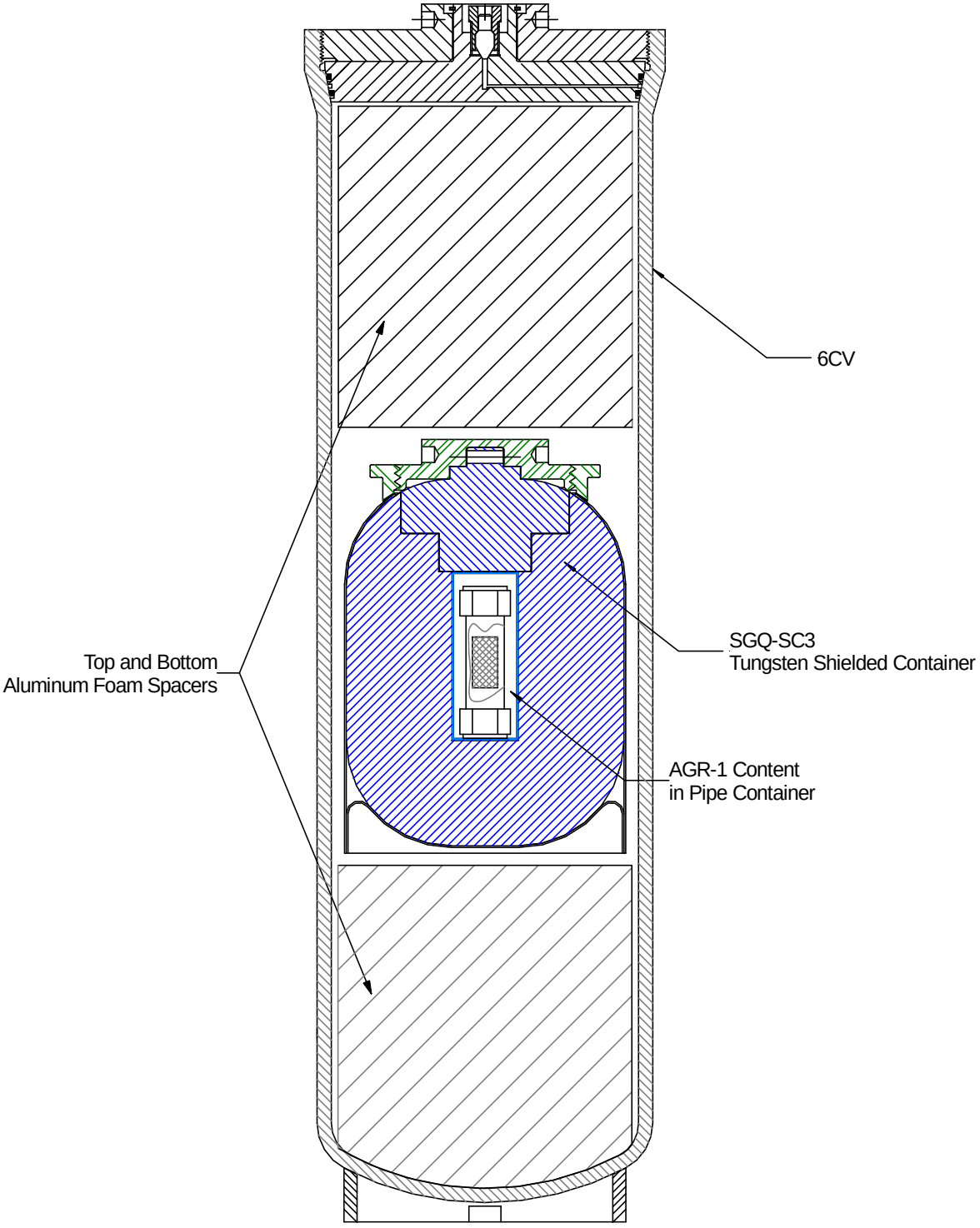

Figure A.1.3 – SGQ-SC3 Configuration in 9977 (Tungsten Shielding)

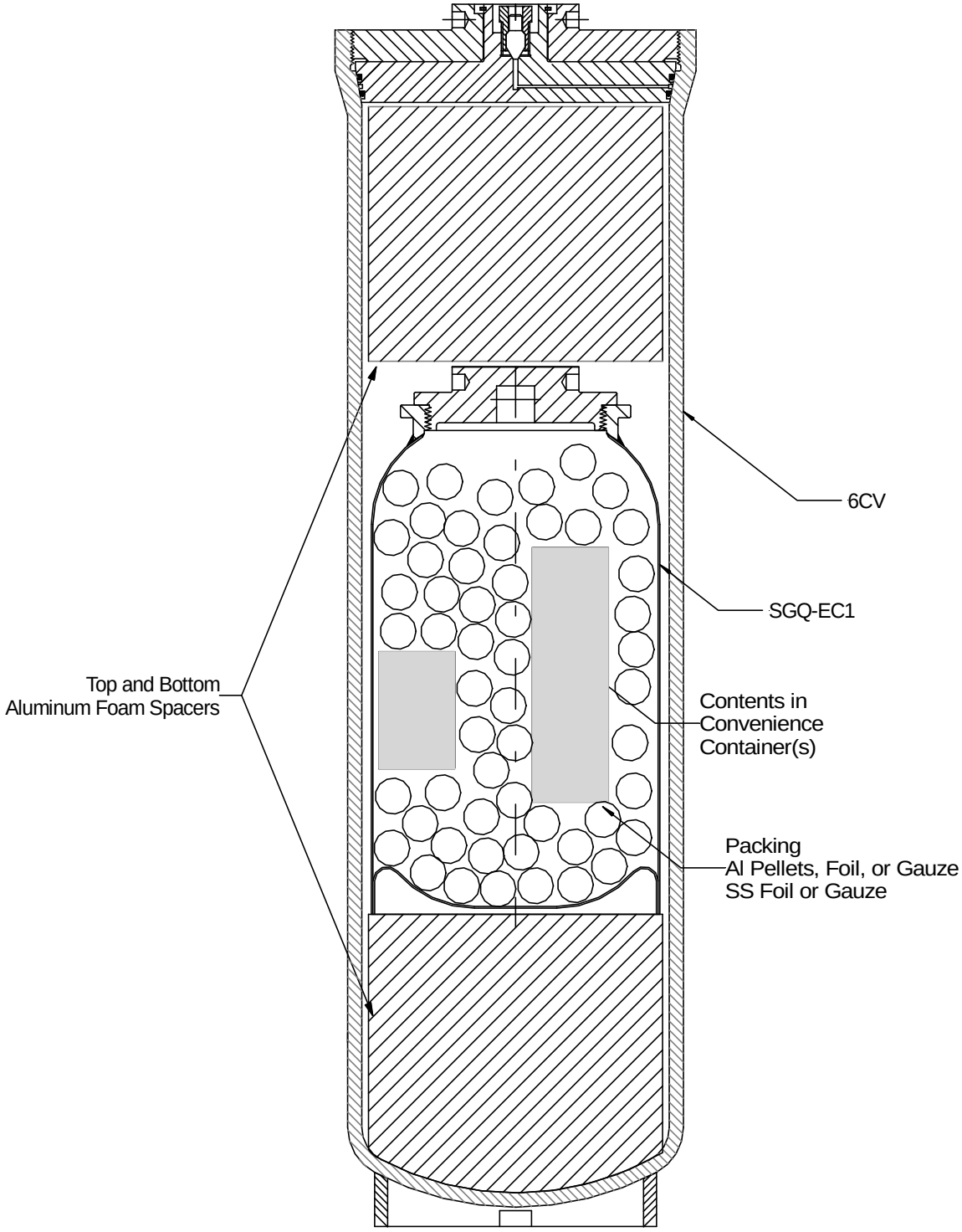

Figure A.1.4 – SGQ-EC1 Configuration in 9977 (Confinement)

1.2.2.2 SGQ Content-Specific Configuration Requirements

As described in this section, loading restrictions vary with content envelope and configuration. A summary of these loading restrictions is included in Addendum Table A.1.2.

1.2.2.2.1 SGQ ENVELOPES TYPE 2 AND 3

ALL CONFIGURATIONS

The Type 2 and 3 Contents may be shipped in an SGQ-SC1, SGQ-SC2, or SGQ-SC3 Shielded Container, an Engineered Container, or a Convenience Container, provided one of the following two methodologies demonstrates the Content/Container to be within the applicable dose rate limits.

1. The Content/Configuration may be approved by a documented calculation in accordance with the *Methodology for Determining Dose Rate* (MDDR) that shows acceptable dose rate limits.
2. After the Shipper has evaluated the Content per the MDDR, the Content may be approved for shipment by being placed in an Engineering or Convenience Container, or in a SGQ-SC1, SGQ-SC2, or SGQ-SC3 Shielded Container, and measured to confirm that the dose rates (at the top, side, and bottom of the container) shall be no greater than 170 mrem/hr on contact and no greater than 8.5 mrem/hr at 1 meter.

1.2.2.2.2 SGQ ENVELOPE TYPE 4

ALL CONFIGURATIONS

Regardless of confinement within metallic capsules or Convenience Containers, all SGQ Type 4 Contents shall be shipped in either an SGQ-EC1 Container – if the capsule/Convenience Container dose rate is less than 180 mrem/hr on contact and below 9 mrem/hr at 1-meter – or in an SGQ-SC1, SGQ-SC2, or SGQ-SC3 Container that provides the required radiation shielding.

1.2.2.2.3 SGQ ENVELOPE TYPE 5 – AGR-1 COMPACTS

SGQ-SC3 CONFIGURATION

The Advanced Gas Reactor (AGR-1) fuel specimen (called a Compact) is a Typical SGQ Type 5 content and contains approximately 4,200 coated fuel particles slightly less than 1 mm in diameter. These particles are bound together with a thermosetting carbonaceous (graphite) matrix material. Each particle consists of a uranium oxycarbide (~75% UO_2, and the remainder UC and UC_2) fuel kernel surrounded successively by the following layers: Porous carbon buffer layer, Inner pyrolytic carbon (PyC) layer, Silicon Carbide (SiC) barrier coating, Outer PyC layer.

The packing configuration of an irradiated AGR-1 Compact within the SGQ-SC3 is shown in Addendum Figure A.1.3. In addition to the general requirements listed in Section 1.2.2 and the isotopic and chemical content restrictions for an irradiated Compact given in Addendum Table A.1.1, the following condition also applies:

- The Compact shall be placed in a Pipe Container (consisting of a threaded pipe section closed with pipe caps) with a closed length of at least 2.8 inches, as shown in Addendum Figure A.1.5. The Pipe Container is sized to confine the Compact and center it within the SGQ-SC3.

Figure A.1.5 – AGR-1 Compact and Pipe Container

Table A.1.2 – Summary of SGQ Requirements by Content and Configuration

SGQ Contents	Packaging Configuration					
	3013	Sealed Source, Convenience or Engineered Container	Engineered Container 1	Shielded Container 1	Shielded Container 2	Shielded Container 3
Type 2	• Dose rate 170 mrem/hr at surface & 8.5 mrem/hr at 1-meter • 19 watts decay heat rate	• Maximum 100-g plastic • Aluminum pellets, foil or gauze for packing • SS foil or gauze for packing • Dose verification by *Methodology for Determining Dose Rate or* • Measurement of 170 mrem/hr at surface & 8.5 mrem/hr at 1-meter • 19 watts decay heat rate	• Maximum 100-g plastic • Aluminum pellets, foil or gauze for packing • SS foil or gauze for packing • Dose verification by *Methodology for Determining Dose Rate or* • Measurement of 170 mrem/hr at surface & 8.5 mrem/hr at 1-meter • 19 watts decay heat rate	• Maximum 100-g plastic • Aluminum foam spacers • Dose verification by *Methodology for Determining Dose Rate or* • Measurement of 170 mrem/hr at surface & 8.5 mrem/hr at 1-meter • 6 watts decay heat rate	• Maximum 100-g plastic • Perforated Food-Pack Can • Dose verification by *Methodology for Determining Dose Rate or* • Measurement of 170 mrem/hr at surface & 8.5 mrem/hr at 1-meter • 3 watts decay heat rate	• Maximum 100-g plastic • Aluminum foam spacers • Dose verification by *Methodology for Determining Dose Rate or* • Measurement of 170 mrem/hr at surface & 8.5 mrem/hr at 1-meter • 19 watts decay heat rate
Type 3						
Type 4			• Maximum 100-g plastic • Aluminum pellets, foil or gauze for packing • SS foil or gauze for packing • Dose rate 180 mrem/hr at surface & 9 mrem/hr at 1-meter • 19 watts decay heat rate	• Maximum 100-g plastic • Aluminum foam spacers • Dose rate 180 mrem/hr at surface & 9 mrem/hr at 1-meter • 6 watts decay heat rate	• Maximum 100-g plastic • Perforated Food-Pack Can • Dose rate 180 mrem/hr at surface & 9 mrem/hr at 1-meter • 3 watts decay heat rate	• Maximum 100-g plastic • Aluminum foam spacers • Dose rate 180 mrem/hr at surface & 9 mrem/hr at 1-meter • 19 watts decay heat rate
Type 5						• Maximum 100-g plastic • Pipe Container • Aluminum foam spacers • 19 watts decay heat rate
All	• less than 1000 ppm other radionuclides (unless otherwise stated) • less than 100 ppm other inorganic impurities with total mass less than 0.1 weight percent (unless otherwise stated) • 100 lb maximum content weight (radioactive contents, product cans, spacers, shielded container, etc.)					

ADDENDUM CHAPTER 1 REFERENCES

A.1.1. Abramczyk, G. and Blanton, P. S., *Safety Analysis Report for Packaging Model 9977*, S-SARP-G-00001, Revision 2, (August 2007).

A.1.2. *Packaging and Transportation of Radioactive Material*, Code of Federal Regulations, Title 10, Part 71, Washington, DC (December 2006).

A.1.3. *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).

A.1.4. *Packaging and Transportation Safety,* DOE Order 460.1B, U.S. Department of Energy, Washington, DC (April 2004).

A.1.5. *Standard Format and Content of Part 71 Applications for Approval of Packaging for Radioactive Material*, Regulatory Guide 7.9, Revision 2, U. S. Nuclear Regulatory Commission, Washington, DC (March 2005).

A.1.6. *Establishing Quality Assurance Programs for Packaging Used in the Transport of Radioactive Material*, Regulatory Guide 7.10, Revision 2, U.S. Nuclear Regulatory Commission, Washington, DC (March 2005).

A.1.7. *Fracture Toughness Criteria of Base Material Ferritic Steel Shipping Cask Containment Vessels with Maximum Wall Thickness of 4 inches (0.1 m)*, Regulatory Guide 7.11, U.S. Nuclear Regulatory Commission, Washington, DC (June 1991).

A.1.8. *Safeguards and Security Program,* DOE Order 470.4A, U.S. Department of Energy, Washington, DC (May 2007).

A.1.9 *Tests for special form Class 7 (radioactive) materials*, Code of Federal Regulations, Title 49, Part 173.469, Washington, DC (October 2007).

A.1.10 *Sealed Radioactive Sources, Classification*, American National Standard ANSI/HPS N43.6-2007, American National Standards Institute, 11 West 42nd Street, New York, New York, 10036 (August 2007).

A.1.11 S, J, Nathan, SRNS, J. M. Risner, ORNL, and S. Sitamaran, LLNL, *Packaging Certification Program Methodology for Determining Dose Rate for Small Gram Quantities in Shipping Packagings*, PCP-2011-0001, Revision 0 (September 2011)

ADDENDUM CHAPTER 1 APPENDICES

Appendix	Description
A.1.1	Drawing, R-R1-G-00037, 9977 – Small Gram Quantity - Shielded Container Type 1 Drawing, R-R1-G-00038, 9977 – Small Gram Quantity - Shielded Container Type 2 Drawing, R-R1-G-00039, 9977 – Small Gram Quantity - Shielded Container Type 3 Drawing, R-R1-G-00045, 9977 – Small Gram Quantity - Engineered Container Type 1 Drawing, R-R4-G-00073, 9977 – Small Gram Quantity - Shielded Container Type 1 Spacers Drawing, R-R4-G-00074, 9977 – Small Gram Quantity - Shielded Container Type 3 Spacers
A.1.2	SGQ Content Type 5 (Advanced Gas Reactor (AGR-1) Compacts) Radionuclide List

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CHAPTER 2 -- STRUCTURAL EVALUATION

The requested addition of several Small Gram Quantity (SGQ) Content envelopes to the 9977 SARP Revision 2 does not increase the total payload mass certified for shipment in the 9977 package (100 lb), therefore, the overall structural performance of the package under NCT and HAC loadings is not adversely affected. These lighter/more compliant package payloads/configurations may produce different local stresses within the 6CV. However, the structural performance of the certified package configuration bounds the structural behavior of the package with the new SGQ Contents.

SGQ Contents are solid and are limited to the baseline 19-watt decay-heat rate. Contents in the SGQ-SC1 configuration are further limited to 6-watts in order to maintain a minimal lead strength. Contents in the SGQ-SC2 configuration are further limited to 3-watts, to maintain the temperature of the HDPE below its melting point. The Maximum Normal Operating Pressure (MNOP) is dependent on factors including increased gas temperature from decay heat, helium generation from radioactive decay of fissile material, degradation of organic matter from high internal temperatures, and radiolysis. The MNOP calculation for previously approved contents bounds the influence of the small quantities of radioactive material defined by the SGQ Content envelopes.

Prior to loading into the 6CV, SGQ contents may be packed within one of a number of functionally specific containers described in Section 1.2.2.1. Of structural relevance are the SGQ-SC1 and SGQ-SC3 Shielded Containers and the SGQ-EC1 Engineered Container. These container designs all use the same weld-nut (mounted by two continuous welds to the carrier outer shell), bottom head (modeled as spot-welded to the carrier outer shell), and threaded plug. The structural analysis uses a content weight of 100lb, which exceeds the maximum weights of the SGQ-SC1, SGQ-SC3, and SGQ-EC1. Therefore, the strength calculations are equally applicable to all three carriers. Appendix A.2.1 shows the SGQ-SC1 and SGQ-SC3 shielded container designs with a 100-lb loads to withstand a worst case Hypothetical Accident Condition (HAC) drop event. That is, under the worst case HAC Drop, the shielded container experiences no failure of the closure threads or slumping or other deformation of the shielding material resulting in significant reduction in shielding effectiveness and consequent increase in package dose rate. The SGQ-EC1, with the same Container design as the SGQ-SC1 but with a lighter content, is also bounded by the structural analysis presented in Appendix A.2.1. Structural analysis of the SGQ-SC2 was not performed because, even with the highest-dose SGQ content envelope meeting NCT dose-rate limits, the shielding provided by the SGQ-SC2 is not necessary for compliance with the post-HAC dose-rate limit.

The package structural performance documented in the 9977 SARP Revision 2 and in this Addendum show that the SGQ Content envelopes do not adversely affect the structural performance of the package.

Chemical, galvanic, thermal and radiation behaviors of the SGQ Contents are bounded by the analyses performed for previously approved contents given in the 9977 SARP Revision 2.

2.1.4 Identification of Codes and Standards for Package Design

The packaging design criteria are based on evaluation of the maximum radiological hazard (A_2s) and curie (Ci) content for "Normal Form" radioactive material. Based on this data, RG 7.11 and NUREG/CR-3854 are used to identify "established codes and standards for design, fabrication, assembly, testing, maintenance and use" requirements for the packaging.

As noted in Addendum Section 1.2.2.1.1, the Small Gram Quantity Shielded Containers SGQ-SC1, SGQ-SC2, and SGQ-SC3 provide shielding appropriate and sufficient to the radiological hazard of the contents such that the surface dose, measured on the container (or Package surface for SGQ Type 5 Contents in the SGQ-SC3) is no more than 2mSv/hr (200 mrem/hr) and the dose measured 1-meter from the surface of the container is no more than 0.1 mSv/hr (10 mrem/hr). These containers are of three types to provide gamma shielding and neutron shielding. The Small Gram Quantity Engineered Container Type 1 (SGQ-EC1) provides confinement. As documented in Addendum Appendix A.2.1, the SGQ Shielded Containers are able to withstand the worst case NCT and HAC drop events without compromise in shielding performance. The outer shell of the SGQ-SC1, SGQ-SC3, and SGQ-EC1 containers are designed to appropriate Code requirements. [Ref A.2.1] The SGQ-SC1, SGQ-SC3, and SGQ-EC1 are located within the 9977 Containment Vessel by suitable aluminum foam Spacers. The SGQ-SC1, SGQ-SC2, SGQ-SC3, and SGQ-EC1 configurations are shown in Addendum Figures A.1.1, A.1.2, A.1.3, and A.1.4, and the component drawings are included in Addendum Appendix A.1.1.

2.2.2 Chemical, Galvanic, or Other Reactions

Chemical and Galvanic Compatibility

There are no significant galvanic cell interactions. The matrix presented in Addendum Table A.2.1 summarizes the interactions between the radioactive material and other materials inside the 6CV. The SGQ-SC1 incorporates a lead shielding body and a removable 304L SS Cup that separates the shielding body from container contents. The SGQ-SC3 incorporates a tungsten shielding body and the same Cup to provide the same chemical contact barrier between shielding body and container contents.

Table A.2.1 – Dissimilar Contacting Materials within the 6-Inch Containment Vessel

Material	Material Number							
	1	2	3	4	5	6	7	8
1 Radioactive content and associated materials	--	✓	✓		✓	✓	✓	✓
2 Steel	✓	--	✓	✓	✓	✓	✓	✓
3 Aluminum (packing material)	✓	✓	--	✓	✓		✓	✓
4 Plastic bag		✓	✓	--		✓		
5 Gasket (elastomer) from food cans	✓	✓	✓		--			
6 High-Density Polyethylene	✓	✓		✓		--		
7 Lead	✓	✓	✓				--	
8 Tungsten	✓	✓	✓					--

☑ ≡ contacting material pairs. ⊟≡ same material. ☐ ≡ non-contacting surfaces.

Other - Thermal Compatibility

The SGQ Contents thermal effects are bounded by the analyses for other, certified 9977 contents.

ADDENDUM CHAPTER 2 REFERENCES

A.2.1 *Standard Specification for lead and lead alloy strip, sheet, and plate products*, ASTM B749-03 (June 2003)

ADDENDUM CHAPTER 2 APPENDICES

Appendix	Description
A.2.1	C.A. McKeel, *Design And Evaluation Of A Shielded Carrier For Use In 6-Inch Containment Vessel Of 9977 Package* (U), M-CLC-A-00371, Revision 1

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CHAPTER 3 -- THERMAL EVALUATION

The decay-heat rates for the SGQ Contents are limited to the 19-Watt package thermal limit for the 9977. Therefore, the package thermal performance documented in the 9977 SARP Revision 2 is equally valid for all three shielded container configurations with the SGQ Content Envelope. The MNOP is reevaluated for the SGQ Contents and SGQ Containers.

3.1 DESCRIPTION OF THERMAL DESIGN

Thermal performance of the package under NCT and HAC was verified by testing and quantified by analysis. The NCT and HAC test results are documented in SARP Appendices 3.1 and 3.2. The NCT and HAC analyses are documented in SARP Appendices 3.3, 3.4, and in Addendum Appendix A.3.1 and summarized in SARP Table 3.2 and Addendum Table A.3.1. The calculated temperatures compare closely with the measured temperatures and are bounding for all SGQ Content envelopes and configurations identified in Section 1.2.2.

Table A.3.1 – Maximum NCT Temperatures – Engineered Container and Shielded Container Configurations

Model	Insolation	Heat Rate (Watts)	CV Wall (°F)	O-Rings (°F)	Payload (Max) (°F)	Payload (Average) (°F)	Drum Wall Actual (°F)	Drum Wall Limit (°F)
SGQ-SC1 (Lead Shielding)	Yes	19	314	284	349	314	na	na
	Yes	6	236	227	247	236	na	na
	No	19	213	180	255	nc	105	122
	No	11.5	172	150	199	nc	103	122
SGQ-SC2 (HDPE Shielding)	Yes	19	297	282	312	298	na	na
	Yes	3	228	228	nc	226	na	na
	No	19	202	181	249	218	105	122
SGQ-SC3 (Tungsten Shielding)	Yes	19	307	276	351	306	na	na
	No	19	215	175	268	nc	105	122
SGQ-EC1 (Engineered Container)	Yes	19 [a]	309	283	1120	nc	nc	nc
	Yes	19 [b]	305	284	349	nc	nc	nc

na not applicable
nc not calculated
a Content modeled as a “point source” ¼-inch diameter × 1-inch long (per baseline model, SARP Section 3.3.1.1.4)
b Content modeled as a “finite source” 2-inches diameter × 6.75-inches long

Addendum Figures A.3.1, A.3.2, and A.3.3 show the material representation of the SGQ-SC1, SGQ-SC2, and SGQ-SC3 configurations, respectively. Addendum Figure A.3.4 is a material representation of the SGQ-EC1 configuration.

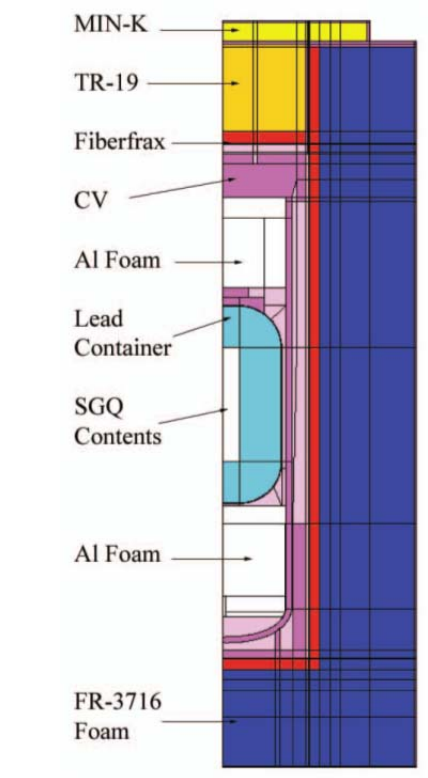

Figure A.3.1 – SGQ-Shielded Container Type 1

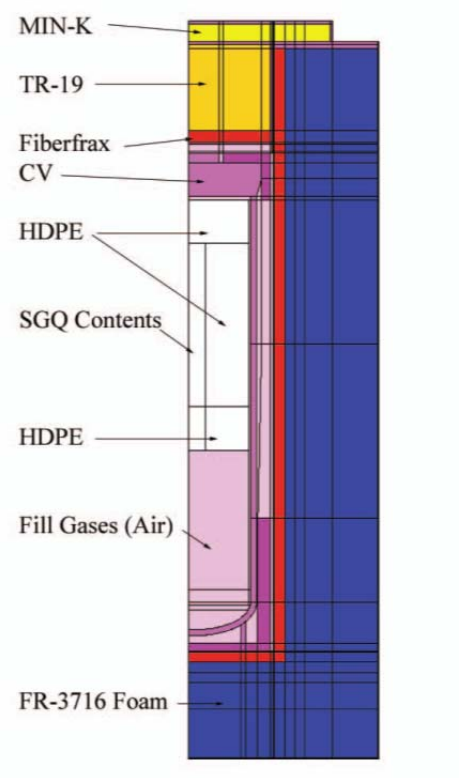

Figure A.3.2 – SGQ-Shielded Container Type 2

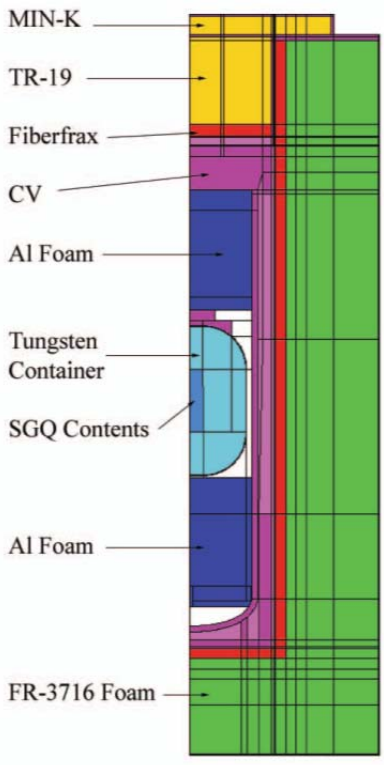

Figure A.3.3 – SGQ-Shielded Container Type 3

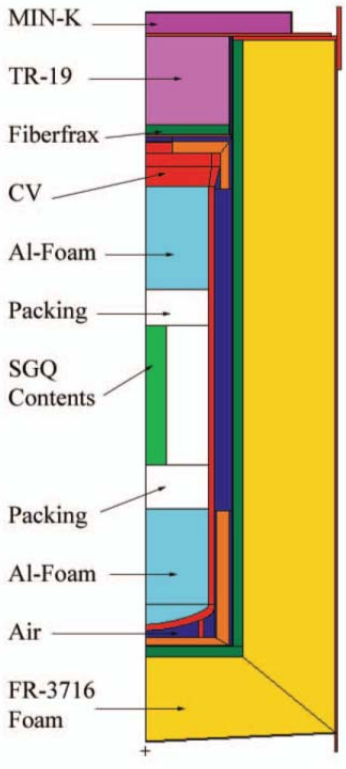

Figure A.3.4 – SGQ-Engineered Container Type 1

The regulatory Maximum Normal Operating Pressure (MNOP) from the SGQ content envelopes is developed in Addendum Section 3.3.2 for NCT. The Containment Vessel pressure during HAC-fire event as developed in SARP Section 3.4.3 is demonstrated to bound the HAC pressures with a large Margin of Safety and, therefore, not calculated here. Both are summarized in Addendum Table A.3.2. The 6CV MNOP pressure corresponds to the SGQ Content with the SC2 configuration, which bounds all other content configurations, see Addendum Appendix A.3.1.

Table A.3.2 - Maximum Pressures for 6CV under NCT and HAC

Condition	Max Pressure (psig)	(Margin)
NCT	102.6	87%
HAC	35.0	96%
Design Limit	800	

Note: Margin is defined as [1-(actual/allowable)]×100%.

3.1.1 Design Features

3.1.1.4 SGQ Shielded Containers

Material thermal properties for the analyses are listed in Addendum Table A.3.3 and SARP Table 3.9. Surface emissivity values for the various materials are given in SARP Table A.3.4. Material properties are consistent with the values used in the analyses in the 9977 SARP Revision 2. The thermal conductivity values of the compressed Fiberfrax are based on the Lo-Con™ material rather than the values used in SARP Appendix 3.3. The difference in the two sets of values is small. The properties of the aluminum alloy 6061-T-6 are also more accurate (temperature dependant) than before.

The aluminum foam inserts are envisioned to be equivalent to aluminum honeycomb. It is difficult to estimate the thermal properties of these anisotropic material components. The thermal properties are based on limited testing at the SRNL of the DURA-CORE II 5052 aluminum honeycomb by ALCORE. Small deviations from the properties used in the analyses affect the local temperature distribution only and the impact on the CV and the overpack temperature profiles is negligible.

Contents are assumed to be the plutonium metal. The volume occupied by the contents is small and deviations in thermal conductivity of the contents affect the temperatures locally only.

3.1.1.5 SGQ Engineered Container Type 1

Material thermal properties for this analysis are the same as for SGQ-SC1 above with the exception of the materials within the SGQ-EC1 Container Body and the specific properties of the aluminum foam. The lead shielding body of the SGQ-SC1 was replaced with aluminum foil compacted to a density of 1.35 lb/ft^3. The aluminum foam inserts are Duocel Aluminum Foam type 6101-T6 with a density of 13.5 lb/ft^3. The aluminum foil thermal conductivity was taken as a proportion of the Duocel Foam value based on density (see Appendix A.3.1).

The RAM source was assumed to be single item located concentric to the SGQ-EC1. If the source is not concentric there will be small local variation in the azimuthal temperature distribution of the CV wall, but this will dissipate in a short distance. The O-Ring temperature will not be affected. If the single source were divided into multiple sources with the same total decay heat, the maximum content temperature will be lower without any adverse impact on the 6CV wall of O-Ring temperatures.

Table A.3.3 - Thermal Properties of Solid Packaging Materials

Material	Thermal Conductivity *k*, (Btu/hr-ft-°F)	Density *ρ*, (lbm/ft^3)	Specific Heat *Cp*, (Btu/lbm-°F)
Fiberfrax (compressed) *k* and *ρ* assumed 2 times the value of uncompressed material	0.0455 @ 200.0°F 0.0600 @ 400.0°F 0.0798@ 600.0°F	20.0	0.27
Vermiculite TR-19®	6.33E-02 @ 400.0°F 6.67E-02 @ 600.0°F 7.00E-02 @ 800.0°F 7.33E-02 @ 1000.0°F 7.75E-02 @ 1200.0°F	23.0	0.20
MIN-K 2000®	1.58E-02 @ 300.0°F 1.67E-02 @ 400.0°F 1.83E-02 @ 600.0°F 2.08E-02 @ 800.0°F 2.50E-02 @ 1000.0°F	20.0	0.23 @ 400.0°F 0.25 @ 800.0°F 0.27 @ 1200.0°F 0.27 @ 1600.0°F
Upper and Lower Al Foam Inserts (Horizontal) – Assumed same as honeycomb [Ref A.3.1]	0.196	12	0.22
Upper and Lower Al Foam Inserts (Vertical) - Assumed same as honeycomb [Ref A.3.1]	0.0982	12	0.22
Tungsten [Ref A.3.2]	97.01	1209.3	0.0344
LAST-A-FOAM® FR-3716 @ 16 lb/ft^3	2.75E-02 @ 76.5°F 3.12E-02 @ 140.7°F 3.71E-02 @ 248.4°F 4.33E-02 @ 348.6°F 4.33E-02 @1000.0°F	16.0	0.353
304L Stainless Steel	7.74108 @ 32.0°F 9.43444 @ 212.0°F 12.5793 @ 932.0°F 14.9983 @ 1292.0°F	494.43	1.200E-01 @ 32.0°F 1.350E-01 @ 752.0°F
Lead [Ref A.3.3]	19.98 @ 68.0°F 19.57 @ 209.0°F 18.31 @ 400.0°F	708.6	3.05E-02 @ 32.0°F 3.15E-02 @ 212.0°F 3.38E-02 @ 622.0°F
Aluminum (6061 T-6)	96.1 @ 70.0°F 98.0 @ 150.0°F 99.0 @ 200.0°F 100.6 @ 300.0°F 101.9 @ 400.0°F	169.3	0.23
High Density Polyethylene (HDPE) [Ref A.3.4]	0.266	59.4	0.537

Table A.3.4 - Surface Emissivities for NCT

Surface	Emissivity
CV	0.30
Load Distributor	0.20
Drum Liner, Lid	0.30
Exterior of Drum	0.21
Lead/Tungsten Container SS Skin	0.30
HDPE [1]	0.8 to 0.9

1 - http://www.infrared-thermography.com/material-1.htm

3.2.2 Component Specifications

Technical specifications for the Shielded Container components are provided on the package drawings included in Addendum Appendix A.1.1. The drawing specifications include the applicable ASME Code requirements for the components and materials. Technical specifications relevant to the thermal analysis are summarized in this section.

3.2.2.5 Component Temperature Limits

Addendum Table A.3.5 lists the temperature limits for the Shielded Container components.

Table A.3.5 – Temperature Limits of the SGQ Shielded Container Materials

Shielded Container	Temperature Limit (°F)
Lead-Shielded SGQ-SC1	200
HDPE-Shielded SGQ-SC2 [1]	226
Tungsten-Shielded SGQ-SC3	6129

1 - http://www.matbase.com/material/polymers/commodity/hdpe/properties

3.3.1.5 NCT Model with SGQ Contents

The NCT component temperatures for the three thermal models are given in Addendum Table A.3.1. The table also lists the component temperatures for storage conditions (no insolation) with ambient temperature as 100°F.

3.3.2 Maximum Normal Operating Pressures

The reference temperature and pressure is representative of the state of the gas when the 6CV was sealed. The pressure calculation includes off-gassing of 100 grams of plastic. Addendum Appendix A.3.1 gives the methodology to calculate the pressure contribution due to off-gassing of plastic. Bare source temperatures are used as the final air temperatures inside the CV for conservatism. Addendum Appendix A.3.1 gives the MNOP calculation.

3.4.2 Fire Test Conditions

No hypothetical accident conditions (HAC) are analyzed. The baseline NCT component temperatures, documented in 9977 SARP Revision 2, bound the equivalent component temperatures calculated for the SGQ Contents. Therefore, the baseline HAC temperatures will also bound the temperatures associated with the SGQ Content envelopes.

ADDENDUM CHAPTER 3 REFERENCES

A.3.1 W. L. Daugherty, *Thermal Conductivity Data for Candidate Materials*, SRNL-MST-2007-00127, (June 2008)

A.3.2 Spacecraft Thermal Control Handbook, Volume 1: Fundamental Technologies, David G. Gilmore, The Aerospace Press, El Segundo, CA (2004).

A.3.3 MSC.Patran/Thermal, Version 2003 Rev. 2, MSC.Software Corporation, Santa Ana, California (2003).

A.3.4 http://www.matbase.com/material/polymers/commodity/hdpe/properties

ADDENDUM CHAPTER 3 APPENDICES

Appendix	Description
A.3.1	N.K. Gupta, *Thermal Evaluation of 9977 Package for SGQ Transport of Nuclear Materials*, N-CLC-A-00368, Revision 1
A.3.2	G.A. Abramczyk, *Determination of Free Volume within 9977 Package for Three Shielded Container Configurations for the Transport of Small Gram Quantity Contents*, (U), N-CLC-G-00370, Revision 1

CHAPTER 4 -- CONTAINMENT

The proposed addition of the SGQ Content envelopes to the 9977 SARP does not increase the impact loading on the containment vessels, the temperatures that must be sustained, nor the pressure that must be contained. Therefore, the package containment performance (leak-tight in accordance with ANSI Standard N-14.5) documented in the 9977 SARP Revision 2 is equally valid for the SGQ Content envelopes.

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CHAPTER 5 -- SHIELDING EVALUATION

Preface

The shielding evaluation performed for the 9977 is described in this Chapter. This evaluation demonstrates the 9977 is in compliance with the performance requirements specified in 10 CFR 71.47 [Ref A.5.1], 10 CFR 71.51, 49 CFR 173.403 [Ref A.5.2], and 49 CFR 173.441. These regulations specify that the dose rate limits for an undamaged package are 200 mrem/h at the accessible surface of the package, 10 mrem/h at 1 meter from the accessible surface of the package, and 1000 mrem/h at 1 meter from the surface of a damaged package after a hypothetical accident. Shielding analysis results based on the Small Gram Quantity (SGQ) Content envelopes indicate that the 9977 complies with the federal regulations for non-exclusive use. The overall results are shown in Addendum Table A.5.1. It has been demonstrated that, for the SGQ Content the requirements of 10 CFR 71 for radiation dose rate limits are met under both Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC).

The information presented in this Chapter is in the format specified in the US NRC Regulatory Guide 7.9. [Ref A.5.3]

The SGQ Content envelopes are defined in Addendum Table A.1.1. 10 CFR 71.47 requires that the radiation level does not exceed 2 mSv/h (200 mrem/h) at any point on the external surface of the package. For SGQ contents with significant radiation levels, a series of handling containers with added shielding has been designed and analyzed (SGQ-SC1, SGQ-SC2, and SGQ-SC3) and may be employed to reduce radiation dose rates below the regulatory limits. For SGQ Contents Types 1, 2, and 3, the basis for conformance with the regulatory limit is established by a two-step process. First, the content is evaluated by the *Method for Determining Dose Rates*. This method conservatively calculates the dose rates at the surface and at 1-meter away from the 9977 package for the Contents in the 6CV or in one of the three (3) Small Gram Quantity Shielded Containers. Alternatively, if compliance can not be established by this calculation, it may be established by measurement of the radiation dose rates at and 1-meter from the surface of the content container (e.g.; a 3013 Container, an Engineered Container, a Convenience Container, or the SGQ-SC1 or SGQ-SC2 or SGQ-SC3). SGQ Content Type 4 is shipped in the Engineered or Shielded Container configurations and is required to have a measured radiation dose level at and 1-meter from the surface of the Engineered or Shielded Container not to exceed the administrative limit of 180 mRem/hr and 9 mRem/hr, respectively. SGQ Content Type 5 shipped in the SGQ-SC3 configuration is demonstrated by calculation to meet the regulatory dose rate limits.

5.1 DESCRIPTION OF SHIELDING DESIGN

5.1.1 Design Features

The 9977 Package is a single containment drum type package with a bolted flange closure and a right circular cylinder Containment Vessel (CV) enclosed by Fiberfrax® and LAST-A-FOAM® insulation. Major materials of construction include a stainless steel (SS) overpack drum, LAST-A-FOAM® polyurethane insulation, aluminum Load Distribution Fixtures (LDFs), and a SS 6-inch diameter Containment Vessel (6CV). The double O-ring sealed 6CV is removable for loading and unloading. The physical arrangement of the 9977 is described in SARP Chapter 1. The 9977 is designed to ship

radioactive contents (Content Envelope C.1, see SARP Table 1.2) as assemblies of Radioisotope Thermoelectric Generators (RTGs) and nested food-pack cans. These content configurations minimize contamination, simplify handling, and facilitate long-term storage.

The shielding evaluation for the package shows that the requirements of 10 CFR 71 for radiation dose rate limits are met for Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC). The Transport Index (TI) for shielding to be placed on the package label is determined by measurement at the time of transport and must be less than 10 as required by 10 CFR 71.47(a). The TI based on dose rate is calculated to be a maximum of 3.6; the NCT dose rate at 1 meter from the side of the drum as listed in Addendum Table A.5.1.

The SGQ Content envelopes are defined in Addendum Table A.1.1. SGQ Content Type 4 (LANL Off-Site Source Recovery Project contents) shipped in either SGQ-SC1 or SGQ-SC2 configurations are demonstrated by analysis to meet the regulatory dose limits for the mass of each isotope. SGQ Content Type 5 shipped in the SGQ-SC3 configuration is demonstrated by calculation to meet the regulatory dose rate limits at the package surface and at 1 m (i.e., the TI is less than 10). For all other SGQ Content envelopes, the basis for conformance with the regulatory limits of 2 mSv/hr (200 mrem/hr) at the package surface and 0.1mSv/hr (10 mrem/hr) at 1 m from the package surface is measurement of the radiation dose rate at and 1 m from the surface of the radioactive material Convenience Container.

For SGQ contents with MDDR-calculated radiation dose rates in excess of regulatory limits, the SGQ Shielded Containers may be utilized to reduce radiation levels below the regulatory limits. Dose rates at the surface of the Shielded Container must meet the 200 mrem/hr limit and rate one meter from the surface of the Shielded Container must meet the 10 mrem/hr limit. Measurements demonstrating that the radiation dose rates at and one meter from the surface of the Shielded Container, the SGQ-SC1, SGQ-SC2, or the SGQ-SC3, meet the regulatory limits ensures that the dose rates at and one meter from the package surface also meet the regulatory limit.

The Small Gram Quantity Shielded Containers can provide shielding appropriate to the radiological hazard of the contents. The SGQ-SC1 provides gamma shielding by a lead body enclosed by a stainless steel container with a threaded closure. The SGQ-SC2 provides neutron shielding with high density polyethylene and incorporates an integral closure (no encapsulation being required). The SGQ-SC3 provides gamma shielding by a tungsten body enclosed by a stainless steel container with a threaded closure. Chapter 2, Structural Evaluation evaluates the ability of the SGQ Shielded Containers to withstand the worst case NCT and HAC drop events without compromising shielding performance.

5.1.2 Summary Table of Maximum Radiation Levels

Addendum Table A.5.1 summarizes a detailed shielding evaluation performed for the specific materials of SGQ Type 5, the AGR-1 fuel Compact [Ref A.5.4] in the SGQ-SC3 Configuration, and of SGQ Type 4, the LANL Off-Site Source Recovery Project contents in the SGQ-SC1 or SGQ-SC2 Configurations.

The dose rates were calculated using the Monte Carlo N Particle Transport Code (MCNP) [Ref A.5.5] with its continuous energy cross-section library. Addendum Table A.5.1 summarizes the maximum calculated dose rates [Ref A.5.6 and A.5.14] for NCT and HAC and compares the results against the regulatory limits for shipment in commerce. The reported dose rate results are within the 99% upper confidence level (i.e., mean plus three standard deviations).

The highest NCT dose rates are calculated on contact at the side of the 9977 drum. This dose rate bounds the dose rates at all other measurement and source locations.

Table A.5.1 – External Radiation Levels (Non-Exclusive Use)

	AGR-1 Fuel Compact	LANL Off-Site Source Recovery Project*	10 CFR Limits
NCT Surface Dose Rates (mrem/hr)			
SIDE			
Neutrons	—	170.2	—
Photons	110.9	19.8	—
Total	110.9	190.0	200
TOP			
Neutrons	—	22.0	—
Photons	4.6	1.9	—
Total	4.7	24.0	200
BOTTOM			
Neutrons	—	100.5	—
Photons	65.2	13.4	—
Total	65.2	113.9	200
NCT 1 m away Dose Rates (mrem/hr)			
SIDE			
Neutrons	—	6.1	—
Photons	3.6	0.7	—
Total	3.6	6.8	10**
TOP			
Neutrons	—	1.2	—
Photons	0.4	0.1	—
Total	0.4	1.4	10**
BOTTOM			
Neutrons	—	3.8	—
Photons	2.4	0.6	—
Total	2.4	4.3	10**
HAC 1 m away Dose Rates (mrem/hr)			
SIDE			
Neutrons	—		—
Photons	6.1		—
Total	6.1		1000
TOP			
Neutrons	—	Not Calculated	—
Photons	0.5	Bounded by NCT	—
Total	0.5		1000
BOTTOM			
Neutrons	—		—
Photons	3.9		—
Total	3.9		1000

* Dose rates derived by scaling dose rate for Cf-252 to 190 mrem/hr at the side surface

** Transport index may not exceed 10.

5.2 SOURCE SPECIFICATION

A typical SGQ Content Type 5, Advanced Gas Reactor (AGR-1) fuel specimen (called a Compact) contains approximately 4,200 coated fuel particles that are slightly less than 1 mm in diameter. These particles are bound together with a thermosetting carbonaceous (graphite) matrix material. Each particle consists of a uranium oxycarbide (~75% UO_2, and the remainder UC and UC_2) fuel kernel surrounded by the following layers: Porous carbon buffer layer, Inner pyrolytic carbon (PyC) layer, Silicon Carbide (SiC) barrier coating, Outer PyC layer. The source isotopic distribution considered for the AGR-1 fuel compact is shown in Addendum Table A.5.2.

SGQ Content Type 4, LANL Off-Site Source Recovery Project contents, consist of various isotopes which are either gamma or neutron sources. One gram of each of the proposed contents was analyzed to determine the gamma and neutron source strength. The ORIGEN-S Module of the SCALE code system [Ref A.5.15] was used to decay each isotope to determine the time of maximum activity and the build-in of daughter isotopes.

5.2.1 Gamma Source

The principal contributing mechanisms for photon (gamma) production include: (1) fission product decay, (2) spontaneous fission, (3) bremsstrahlung, and (4) neutron activation of the shielding containers. The source strengths (photons/sec) and normalized photon spectra for the evaluated contents are shown in Addendum Table A.5.3.

The SRNS RASTA computer code [Ref A.5.16] was used to calculate the energy dependent gamma source terms in a twenty-four group structure based on the BUGLE-80 [Ref A.5.7] twenty-group structure, but emphasizing the lower energy groups. The source spectrum was input into MCNP as a histogram and the total source strength was used as a multiplier to convert the dose rates per source particle to total dose rate.

Table A.5.1 – External Radiation Levels (Non-Exclusive Use)

	AGR-1 Fuel Compact	LANL Off-Site Source Recovery Project*	10 CFR Limits
NCT Surface Dose Rates (mrem/hr)			
SIDE			
Neutrons	—	170.2	—
Photons	110.9	19.8	—
Total	110.9	190.0	200
TOP			
Neutrons	—	22.0	—
Photons	4.6	1.9	—
Total	4.7	24.0	200
BOTTOM			
Neutrons	—	100.5	—
Photons	65.2	13.4	—
Total	65.2	113.9	200
NCT 1 m away Dose Rates (mrem/hr)			
SIDE			
Neutrons	—	6.1	—
Photons	3.6	0.7	—
Total	3.6	6.8	10**
TOP			
Neutrons	—	1.2	—
Photons	0.4	0.1	—
Total	0.4	1.4	10**
BOTTOM			
Neutrons	—	3.8	—
Photons	2.4	0.6	—
Total	2.4	4.3	10**
HAC 1 m away Dose Rates (mrem/hr)			
SIDE			
Neutrons	—		—
Photons	6.1		—
Total	6.1		1000
TOP			
Neutrons	—	Not Calculated	—
Photons	0.5	Bounded by NCT	—
Total	0.5		1000
BOTTOM			
Neutrons	—		—
Photons	3.9		—
Total	3.9		1000

* Dose rates derived by scaling dose rate for Cf-252 to 190 mrem/hr at the side surface

** Transport index may not exceed 10.

5.2 Source Specification

A typical Type 5 Content, Advanced Gas Reactor (AGR-1) fuel specimen (called a compact) contains approximately 4,200 coated fuel particles that are slightly less than 1 mm in diameter. These particles are bound together with a thermosetting carbonaceous (graphite) matrix material. Each particle consists of a uranium oxycarbide (~75% UO2, and the remainder UC and UC2) fuel kernel surrounded by the following layers: Porous carbon buffer layer, Inner pyrolytic carbon (PyC) layer, Silicon Carbide (SiC) barrier coating, Outer PyC layer. The source isotopic distribution considered for the AGR-1 fuel compact is shown in Addendum Table A.5.2.

Table A.5.2 – Isotopic Breakdown of an Individual Fuel Specimen

Radioactive Isotopes			Isotopes with No Radioactivity	
Isotope	Activity (Ci/compact)	Mass (g/compact)	Isotope	Mass (g/compact)
PR144	5.34E+00	7.06E-08	C 12	4.05E+00
CE144	5.34E+00	1.67E-03	SI 28	4.33E-01
NB 95	3.07E+00	7.84E-05	O 16	8.48E-02
ZR 95	1.53E+00	7.13E-05	SI 29	2.28E-02
RH106	1.24E+00	3.48E-10	SI 30	1.56E-02
RU106	1.24E+00	3.70E-04	XE136	1.12E-02
Y 91	1.03E+00	4.19E-05	XE134	6.84E-03
PM147	7.41E-01	7.99E-04	BA138	6.11E-03
CS134	6.76E-01	5.22E-04	LA139	5.82E-03
SR 89	5.60E-01	1.93E-05	CE140	5.72E-03
CS137	4.77E-01	5.48E-03	PR141	5.39E-03
BA137M	4.51E-01	8.38E-10	CS133	5.29E-03
Y 90	4.05E-01	7.44E-07	ND143	4.98E-03
SR 90	4.05E-01	2.97E-03	ND146	4.82E-03
RU103	3.01E-01	9.31E-06	XE132	4.65E-03
RH103M	2.71E-01	8.33E-09	MO100	4.24E-03
PU241	2.00E-01	1.94E-03	ZR 96	3.88E-03
CE141	1.98E-01	6.95E-06	MO 98	3.82E-03
PR144M	6.41E-02	3.53E-10	MO 97	3.76E-03
KR 85	5.03E-02	1.28E-04	ZR 94	3.74E-03
EU154	4.02E-02	1.49E-04	MO 95	3.61E-03
EU155	3.75E-02	8.07E-05	ZR 92	3.43E-03
PM148M	3.55E-02	1.66E-06	RU101	3.40E-03
SB125	3.47E-02	3.35E-05	RU102	3.21E-03
CM242	2.53E-02	7.66E-06	ZR 91	3.15E-03
TE127M	2.08E-02	2.21E-06	Y 89	2.51E-03
TE127	2.04E-02	7.72E-09	RH103	1.97E-03
NB 95M	1.14E-02	2.98E-08	XE131	1.94E-03
TE125M	8.26E-03	4.58E-07	SR 88	1.92E-03
AG110M	7.00E-03	1.47E-06	RU104	1.81E-03
TE129M	5.28E-03	1.75E-07	ND148	1.69E-03
SN123	5.17E-03	6.29E-07	ND145	1.66E-03
PU238	5.05E-03	2.95E-04	TE130	1.43E-03
TE129	3.44E-03	1.64E-10	SM150	1.22E-03
H 3	2.18E-03	2.26E-07	PD105	1.18E-03
PM148	2.00E-03	1.22E-08	KR 86	1.03E-03
CM244	1.70E-03	2.10E-05	ND150	7.07E-04
PU240	9.30E-04	4.08E-03	KR 84	6.03E-04
PR143	8.91E-04	1.32E-08	PD104	5.96E-04
SB124	8.05E-04	4.60E-08	RB 85	5.23E-04
LA140	5.89E-04	1.06E-09	PD106	4.85E-04
TB160	5.49E-04	4.87E-08	EU153	4.84E-04
BA140	5.12E-04	7.02E-09	TE128	3.96E-04
PU239	4.89E-04	7.86E-03	SM152	3.95E-04
SN119M	3.68E-04	8.21E-08	RU100	3.41E-04
SM151	3.54E-04	1.35E-05	PD108	3.40E-04
CD115M	2.62E-04	1.03E-08	BA134	1.99E-04
AM241	2.61E-04	7.59E-05	KR 83	1.97E-04
EU156	1.18E-04	2.13E-09	SE 82	1.69E-04
CD113M	1.00E-04	4.61E-07	AG109	1.66E-04
AG110	9.31E-05	2.23E-14	I127	1.66E-04
TC 99	6.30E-05	3.71E-03	BA137	1.64E-04
ND147	4.08E-05	5.08E-10	SM154	1.22E-04
NP239	2.28E-05	9.82E-11	MO 96	1.18E-04
AM243	2.28E-05	1.14E-04	BR 81	1.07E-04
CM243	1.76E-05	3.41E-07	PD110	1.07E-04
GD153	1.74E-05	4.93E-09	GD156	9.92E-05
RB 86	1.41E-05	1.73E-10	ZR 90	9.78E-05
CS136	1.36E-05	1.86E-10	CD110	7.08E-05
TE123M	9.91E-06	1.12E-09	SE 80	6.47E-05
ZR 93	9.24E-06	3.68E-03	CD111	5.75E-05
U237	4.94E-06	6.05E-11	BA136	5.04E-05
XE131M	4.52E-06	5.39E-11	ND142	4.26E-05
PU242	4.26E-06	1.11E-03	XE130	4.04E-05
BA136M	2.24E-06	8.33E-18	GD158	3.95E-05
SB126M	2.21E-06	2.81E-14	CD114	3.87E-05

Radioactive Isotopes			Isotopes with No Radioactivity	
Isotope	Activity (Ci/compact)	Mass (g/compact)	Isotope	Mass (g/compact)
SN126	2.21E-06	7.78E-05	CD112	3.16E-05
AM242M	2.11E-06	2.17E-07	SN124	2.98E-05
AM242	2.10E-06	2.59E-12	C 13	2.22E-05
SE 79	1.88E-06	2.70E-05	SB123	2.13E-05
PM146	1.72E-06	3.87E-09	SN122	1.96E-05
U236	1.57E-06	2.43E-02	SN120	1.76E-05
CS135	9.26E-07	8.04E-04	SN118	1.75E-05
PA233	8.91E-07	4.29E-11	SB121	1.74E-05
NP237	8.90E-07	1.26E-03	SN119	1.70E-05
I131	8.58E-07	6.92E-12	BE 9	1.69E-05
EU152	7.26E-07	4.20E-09	CD116	1.65E-05
SN121M	6.68E-07	1.13E-08	SN117	1.62E-05
NB 93M	5.66E-07	2.00E-09	GD154	1.16E-05
RH102	4.82E-07	3.98E-10	TE125	1.12E-05
SB126	4.79E-07	5.73E-12	SE 78	1.08E-05
PU236	2.78E-07	5.23E-10	SN116	9.58E-06
PD107	2.67E-07	5.18E-04	HE 4	9.01E-06
PA234M	2.36E-07	3.44E-16	XE128	6.24E-06
TH234	2.36E-07	1.02E-11	TB159	5.99E-06
U238	2.36E-07	7.02E-01	GD155	5.87E-06
IN114M	1.95E-07	8.42E-12	SE 77	4.95E-06
IN114	1.86E-07	1.35E-16	CD113	4.58E-06
CM245	1.67E-07	9.75E-07	GD160	2.76E-06
I129	1.19E-07	6.46E-04	P 31	2.63E-06
PU237	1.12E-07	9.25E-12	KR 82	2.62E-06
SN125	9.35E-08	8.62E-13	GE 76	2.20E-06
U235	5.78E-08	2.67E-02	TE126	2.12E-06
TH231	5.78E-08	1.09E-13	SR 86	1.55E-06
U234	1.94E-08	3.11E-06	TE124	1.27E-06
IN115M	1.84E-08	2.90E-15	MG 25	1.25E-06
SN117M	1.58E-08	1.98E-13	TE122	1.12E-06
AG111	1.22E-08	7.74E-14	DY161	1.06E-06
NP238	1.05E-08	4.06E-14	AS 75	7.48E-07
TM170	7.96E-09	1.33E-12	DY160	5.92E-07
CM246	5.63E-09	1.83E-08	SN115	5.85E-07
XE127	4.35E-09	1.54E-13	MG 26	5.73E-07
U232	3.90E-09	1.82E-10	DY162	5.37E-07
HO166M	3.16E-09	1.76E-09	BA135	5.15E-07
P 32	1.11E-09	3.90E-15	DY163	5.00E-07
BI212	8.38E-10	5.72E-17	XE129	3.46E-07
PB212	8.38E-10	6.03E-16	GE 74	3.23E-07
PO216	8.38E-10	2.40E-21	H 1	2.81E-07
RA224	8.38E-10	5.26E-15	HO165	2.24E-07
RN220	8.38E-10	9.08E-19	GE 73	1.24E-07
TH228	8.35E-10	1.02E-12	GD157	1.17E-07
NP235	7.63E-10	5.44E-13	ER166	6.49E-08
XE133	5.40E-10	2.88E-15	DY164	6.07E-08
C 14	5.40E-10	1.42E-10	EU151	5.64E-08
PO212	5.37E-10	3.02E-27	GE 72	4.39E-08
NB 94	3.61E-10	1.93E-09	IN113	2.54E-08
PA234	3.07E-10	1.54E-16	O 17	2.15E-08
TL208	3.01E-10	1.02E-18	SE 76	2.08E-08
TM171	1.58E-10	1.45E-13	RU 99	1.53E-08
AG109M	1.47E-10	5.63E-20	ER168	8.99E-09
CD109	1.47E-10	5.70E-14	AL 27	6.18E-09
CM241	1.32E-10	8.76E-15	SR 87	6.15E-09
CE142	1.30E-10	5.42E-03	ER167	4.59E-09
RB 87	1.17E-10	1.33E-03	LI 6	3.29E-09
BK249	6.77E-11	4.13E-14	SN114	7.23E-10
TB161	6.30E-11	5.37E-16	KR 80	6.73E-10
AG108M	6.03E-11	2.31E-12	BR 79	3.84E-10
XE129M	3.55E-11	2.80E-16	S 32	3.22E-10
BE 10	1.34E-11	8.10E-10	NB 93	2.08E-10
NP236	1.23E-11	9.33E-10	H 2	1.40E-10
SM147	8.10E-12	3.56E-04	BA132	1.06E-10
SI 32	7.91E-12	4.60E-13	CD108	8.91E-11
AG108	5.36E-12	7.30E-21	AG107	6.05E-11
U233	5.18E-12	5.35E-10	LI 7	4.66E-11

Radioactive Isotopes			Isotopes with No Radioactivity	
Isotope	Activity (Ci/compact)	Mass (g/compact)	Isotope	Mass (g/compact)
PA231	4.80E-12	1.02E-10	NE 22	4.12E-11
TC 98	2.90E-12	3.34E-09	TM169	3.68E-11
EU150	2.90E-12	4.38E-14	HE 3	1.61E-11
CF250	1.04E-12	9.51E-15	YB170	4.16E-12
KR 81	9.07E-13	4.31E-11	GA 71	3.35E-12
ER169	4.60E-13	5.59E-18	NA 23	3.34E-12
PU244	3.72E-13	2.10E-08	SF250	2.14E-12
U240	3.72E-13	4.01E-19	ZN 66	2.06E-13
NP240M	3.72E-13	3.51E-21	PB208	1.77E-13
CF252	2.13E-13	3.96E-16	YB171	8.06E-14
AC227	2.06E-13	2.84E-15	S 33	6.94E-14
TH227	1.92E-13	6.26E-18	MG 24	9.34E-15
BI211	1.89E-13	4.51E-22	ZN 67	9.31E-15
PB211	1.89E-13	7.65E-21	ER170	6.39E-15
PO215	1.89E-13	6.41E-27	YB172	2.67E-15
RA223	1.89E-13	3.69E-18	N 14	2.48E-15
RN219	1.89E-13	1.45E-23	ZN 68	1.32E-16
TL207	1.88E-13	9.89E-22	B 11	1.12E-16
TH230	1.58E-13	7.81E-12	HF176	6.80E-17
CS132	1.12E-13	7.32E-19	HF180	6.61E-17
CF249	1.02E-13	2.48E-14	PB207	6.57E-17
SM146	3.56E-14	1.02E-09	B 10	6.18E-17
CM248	2.08E-14	4.89E-12	HF179	5.28E-17
CM247	1.36E-14	1.46E-10	HF178	4.87E-17
PU243	1.36E-14	5.21E-21	SM144	4.07E-17
TH229	1.21E-14	5.69E-14	LU175	3.23E-17
AT217	1.21E-14	7.51E-27	GD160	3.16E-17
BI213	1.21E-14	6.26E-22	HF174	1.37E-17
FR221	1.21E-14	6.82E-23	BI209	1.28E-17
PB209	1.21E-14	2.66E-21	CD106	1.26E-17
AC225	1.21E-14	2.08E-19	HF177	8.99E-18
RA225	1.21E-14	3.08E-19	NE 20	2.39E-18
PO213	1.18E-14	9.38E-31	TA181	1.63E-18
CF251	6.44E-15	4.06E-15	GA 69	1.95E-19
AM246	5.84E-15	1.91E-22	W183	1.13E-19
PU246	5.83E-15	1.19E-19	W182	5.35E-20
ND144	4.38E-15	3.70E-03	PB206	5.35E-20
HF175	3.33E-15	3.13E-19	N 15	4.32E-20
SB127	3.28E-15	1.23E-20	NE 21	1.70E-20
FR223	2.84E-15	7.34E-23	W184	2.90E-21
AM245	9.82E-16	1.59E-22	GE 70	1.64E-22
LA138	7.45E-16	3.88E-08	YB173	7.15E-27
PO211	5.29E-16	5.54E-27	AG111	3.98E-32
BI210	3.61E-16	2.91E-21	**Total**	**4.73E+00**
PB210	3.61E-16	4.72E-18		
TL209	2.61E-16	6.39E-25		
PO210	2.59E-16	5.77E-20		
SM148	2.51E-16	8.33E-04		
HF181	1.97E-16	1.16E-20		
I132	1.57E-16	1.52E-23		
TE132	1.52E-16	5.01E-22		
ES253	1.44E-16	5.73E-21		
PO214	9.96E-17	3.10E-31		
TH232	9.08E-17	8.28E-10		
TA182	5.82E-17	9.33E-21		
RA222	5.19E-17	3.88E-26		
RN218	5.19E-17	3.51E-29		
TH226	5.19E-17	1.93E-24		
U230	5.09E-17	1.86E-21		
PO218	4.77E-17	1.69E-25		
RA226	4.77E-17	4.83E-17		
RN222	4.77E-17	3.10E-22		
BI214	4.77E-17	1.08E-24		
PB214	4.77E-17	1.46E-24		
IN115	4.61E-17	7.40E-06		
SM145	3.90E-17	1.47E-20		
BK250	3.79E-17	9.73E-24		
ES254	3.78E-17	2.03E-20		

Radioactive Isotopes			Isotopes with No Radioactivity	
Isotope	**Activity** (Ci/compact)	**Mass** (g/compact)	**Isotope**	**Mass** (g/compact)
CF253	1.36E-17	4.68E-22		
P 33	1.20E-17	7.56E-23		
CF254	1.17E-17	1.38E-21		
AC228	6.01E-18	2.68E-24		
RA228	6.01E-18	2.57E-20		
LU177M	4.05E-18	8.51E-22		
TE123	3.38E-18	1.16E-08		
PM145	2.71E-18	1.95E-20		
SM149	2.33E-18	9.70E-06		
LU177	9.31E-19	8.47E-24		
NB 92	3.53E-19	2.53E-24		
MO 99	1.71E-19	3.56E-25		
TC 99M	1.64E-19	3.12E-26		
GD152	6.59E-20	3.02E-09		
AG106	5.16E-20	3.56E-25		
CM249	4.21E-20	3.58E-27		
HO166	1.39E-20	1.97E-26		
ES255	1.06E-20	8.10E-25		
DY166	9.34E-21	4.03E-26		
CM250	1.62E-21	1.97E-20		
SB122	5.61E-23	1.41E-28		
U231	2.06E-24	1.53E-29		
HF182	1.58E-24	7.23E-21		
PM149	7.70E-25	1.94E-30		
XE133M	8.21E-26	1.83E-31		
LU176	6.79E-26	1.00E-18		
CD115	1.95E-26	3.82E-32		
W185	2.93E-27	3.12E-31		
SM153	3.26E-28	7.42E-34		
TM172	5.75E-32	2.01E-37		
GA 72	2.38E-32	7.70E-39		
ZN 72	1.66E-32	1.77E-38		
AM240	8.98E-34	3.49E-39		
AS 77	4.30E-36	4.10E-42		
RH105	7.55E-37	8.95E-43		
TA183	0.00E+00	0.00E+00		
CU 67	0.00E+00	0.00E+00		
Total	**2.39E+01**	**8.04E-01**		

5.2.1 Gamma Source

The principal contributing mechanisms for photon (gamma) production include: (1) fission product decay, (2) spontaneous fission, (3) bremsstrahlung, and (4) neutron activation of the shielding containers. The source strengths (photons/sec) and normalized photon spectra for the evaluated contents are shown in Addendum Table A.5.3.

The SRNS RASTA computer code [Ref A.5.16] was used to calculate the energy dependent gamma source terms in a twenty-four group structure based on the BUGLE-80 [Ref A.5.7] twenty-group structure, but emphasizing the lower energy groups. The source spectrum was input into MCNP as a histogram and the total source strength was used as a multiplier to convert the dose rates per source particle to total dose rate.

Table A.5.3 - Photon Source Strength

Energy Limit (MeV)		**Normalized Source Strength**					
Upper	Lower	AGR-1	Ir-192	Cs-137	Co-60	Sr-90	Ra-226
1.00E+01	8.00E+00	4.24E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8.00E+00	7.00E+00	2.14E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7.00E+00	6.00E+00	2.40E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6.00E+00	5.00E+00	5.61E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5.00E+00	4.00E+00	1.60E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4.00E+00	3.00E+00	1.43E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.65E-05
3.00E+00	2.00E+00	1.98E-03	0.00E+00	0.00E+00	4.69E-06	3.19E-07	1.87E-02
2.00E+00	1.50E+00	5.40E-04	0.00E+00	7.98E-09	0.00E+00	7.21E-05	6.60E-02
1.50E+00	1.00E+00	7.12E-03	1.95E-04	8.21E-07	9.86E-01	1.06E-03	8.19E-02
1.00E+00	8.00E-01	5.81E-03	1.16E-03	2.68E-06	3.44E-05	1.76E-03	1.43E-02
8.00E-01	7.00E-01	2.78E-01	2.13E-05	8.00E-01	3.96E-08	1.62E-03	1.89E-02
7.00E-01	6.00E-01	6.99E-02	4.94E-02	5.54E-05	7.62E-08	2.46E-03	1.09E-01
6.00E-01	4.00E-01	4.75E-02	2.12E-01	6.11E-04	4.03E-07	9.70E-03	8.83E-03
4.00E-01	2.00E-01	1.86E-02	5.88E-01	3.46E-03	4.59E-05	2.98E-02	1.77E-01
2.00E-01	1.00E-01	6.20E-02	2.73E-03	2.25E-03	9.96E-05	5.36E-02	2.67E-02
1.00E-01	8.00E-02	1.96E-02	1.17E-03	3.66E-03	1.31E-04	2.43E-02	2.20E-02
8.00E-02	6.00E-02	1.86E-02	5.31E-02	2.41E-04	2.57E-04	3.53E-02	6.06E-02
6.00E-02	5.90E-02	1.15E-03	1.27E-04	2.60E-03	1.84E-05	2.21E-03	7.54E-04
5.90E-02	5.00E-02	1.23E-02	1.37E-03	3.91E-03	2.08E-04	2.30E-02	1.05E-02
5.00E-02	4.00E-02	2.50E-02	2.07E-03	6.75E-02	3.36E-04	3.30E-02	2.12E-02
4.00E-02	3.00E-02	5.28E-02	3.08E-03	9.54E-03	5.36E-04	4.64E-02	1.63E-02
3.00E-02	2.00E-02	3.94E-02	5.09E-03	1.94E-02	9.47E-04	7.22E-02	2.58E-02
2.00E-02	1.00E-02	7.04E-02	1.92E-02	8.71E-02	2.06E-03	1.38E-01	1.23E-01
1.00E-02	1.00E-08	2.70E-01	6.11E-02	0.00E+00	9.15E-03	5.25E-01	1.98E-01
Total (p/s)		7.08E+11	8.72E+14	3.47E+12	8.50E+13	3.80E+12	1.46E+11

Energy Limit (MeV)		**Normalized Source Strength**				
Upper	Lower	Am-241	Cf-252	Cm-244	Pu-238	Pu-239
1.00E+01	8.00E+00	2.22E-08	1.77E-10	2.51E-08	6.06E-13	7.60E-17
8.00E+00	7.00E+00	6.54E-07	5.64E-07	1.27E-08	1.23E-06	9.55E-08
7.00E+00	6.00E+00	2.12E-08	1.00E-09	1.42E-07	3.44E-12	8.11E-16
6.00E+00	5.00E+00	4.94E-08	2.34E-09	3.32E-07	8.02E-12	2.19E-15
5.00E+00	4.00E+00	4.24E-06	3.46E-06	9.48E-07	7.25E-06	5.44E-07
4.00E+00	3.00E+00	5.29E-07	2.50E-08	3.55E-06	8.59E-11	1.91E-14
3.00E+00	2.00E+00	1.75E-06	8.30E-08	1.18E-05	2.85E-10	5.75E-14
2.00E+00	1.50E+00	1.87E-06	8.83E-08	1.25E-05	3.03E-10	6.18E-14
1.50E+00	1.00E+00	4.07E-06	1.93E-07	2.73E-05	3.04E-09	7.63E-12
1.00E+00	8.00E-01	3.19E-06	1.51E-07	2.14E-05	1.54E-08	1.42E-10
8.00E-01	7.00E-01	1.87E-06	8.84E-08	1.26E-05	7.87E-08	3.59E-09
7.00E-01	6.00E-01	2.27E-06	1.07E-07	1.53E-05	3.69E-10	9.93E-09
6.00E-01	4.00E-01	5.21E-06	2.46E-07	3.50E-05	8.46E-10	2.49E-07
4.00E-01	2.00E-01	5.00E-06	2.36E-07	3.36E-05	5.70E-09	9.79E-07
2.00E-01	1.00E-01	2.47E-06	1.17E-07	1.65E-05	1.78E-06	1.43E-06
1.00E-01	8.00E-02	3.29E-07	1.56E-08	2.21E-06	1.42E-05	1.30E-06
8.00E-02	6.00E-02	3.29E-07	1.56E-08	2.21E-06	9.56E-11	2.29E-07
6.00E-02	5.90E-02	1.64E-08	7.78E-10	1.10E-07	2.67E-12	5.48E-16
5.90E-02	5.00E-02	1.48E-07	7.00E-09	9.94E-07	2.40E-11	3.27E-06
5.00E-02	4.00E-02	2.25E-07	1.64E-05	2.33E-03	6.26E-05	1.02E-07
4.00E-02	3.00E-02	3.15E-07	1.49E-08	2.11E-06	5.41E-11	1.03E-06
3.00E-02	2.00E-02	3.10E-07	6.23E-04	8.84E-02	1.73E-03	6.20E-05
2.00E-02	1.00E-02	2.68E-07	6.40E-03	9.09E-01	1.70E-02	5.99E-04
1.00E-02	1.00E-08	1.24E-07	5.85E-09	8.30E-07	2.01E-11	2.29E-04
Total (p/s)		**3.08E+10**	**3.18E+11**	**3.18E+11**	**7.15E+10**	**1.31E+08**

5.2.2 Neutron Source

The contributing mechanism for neutron sources is primarily spontaneous fission. The total neutron source strength and normalized neutron spectra corresponding to Addendum Table A.5.2 are shown in Addendum Table A.5.4.

The SRNS RASTA computer code was used to calculate the energy dependent neutron source terms in the BUGLE-80 forty-seven group structure. The neutron source strength listed in Addendum Table A.5.4 is so low that neutron dose rate will not be a significant contributor to total dose rate for the AGR-1 fuel compact.

Table A.5.4 - Neutron Source Strength

Energy Limit (MeV)		**Normalized Spectrum**					
Upper	Lower	AGR-1	Am-241	Cf-252	Cm-244	Pu-238	Pu-239
1.73E+01	1.42E+01	3.15E-05	5.53E-12	3.36E-05	1.25E-06	9.34E-10	4.16E-12
1.42E+01	1.22E+01	1.54E-04	2.51E-11	1.62E-04	6.05E-06	5.10E-09	2.09E-11
1.22E+01	1.00E+01	9.96E-04	8.97E-03	1.04E-03	1.22E-02	9.02E-03	6.10E-03
1.00E+01	8.61E+00	2.49E-03	7.92E-02	2.57E-03	8.64E-02	7.95E-02	7.14E-02
8.61E+00	7.41E+00	5.85E-03	1.05E-01	6.01E-03	1.03E-01	1.05E-01	1.05E-01
7.41E+00	6.07E+00	1.72E-02	1.25E-01	1.75E-02	1.33E-01	1.25E-01	1.25E-01
6.07E+00	4.97E+00	3.36E-02	1.26E-01	3.40E-02	1.33E-01	1.26E-01	1.02E-01
4.97E+00	3.68E+00	8.86E-02	2.26E-01	8.92E-02	2.19E-01	2.26E-01	2.22E-01
3.68E+00	3.01E+00	8.27E-02	1.34E-01	8.29E-02	1.20E-01	1.34E-01	1.44E-01
3.01E+00	2.73E+00	4.50E-02	4.03E-02	4.50E-02	3.45E-02	4.01E-02	5.04E-02
2.73E+00	2.47E+00	4.81E-02	2.51E-02	4.81E-02	2.31E-02	2.50E-02	2.98E-02
2.47E+00	2.37E+00	2.02E-02	8.40E-03	2.02E-02	7.97E-03	8.38E-03	9.39E-03
2.37E+00	2.35E+00	4.17E-03	1.64E-03	4.16E-03	1.57E-03	1.64E-03	1.83E-03
2.35E+00	2.23E+00	2.59E-02	9.64E-03	2.58E-02	9.28E-03	9.62E-03	1.07E-02
2.23E+00	1.92E+00	7.36E-02	2.25E-02	7.35E-02	2.23E-02	2.24E-02	2.46E-02
1.92E+00	1.65E+00	7.22E-02	1.46E-02	7.20E-02	1.58E-02	1.46E-02	1.52E-02
1.65E+00	1.35E+00	8.85E-02	1.60E-02	8.82E-02	1.77E-02	1.60E-02	1.67E-02
1.35E+00	1.00E+00	1.12E-01	2.35E-02	1.12E-01	2.48E-02	2.35E-02	2.55E-02
1.00E+00	8.21E-01	5.92E-02	1.21E-02	5.90E-02	1.20E-02	1.21E-02	1.33E-02
8.21E-01	7.43E-01	2.58E-02	4.78E-03	2.57E-02	4.73E-03	4.76E-03	5.82E-03
7.43E-01	6.08E-01	4.41E-02	7.22E-03	4.40E-02	7.32E-03	7.18E-03	9.04E-03
6.08E-01	4.98E-01	3.49E-02	4.64E-03	3.47E-02	4.95E-03	4.62E-03	5.81E-03
4.98E-01	3.69E-01	3.86E-02	3.58E-03	3.85E-02	4.26E-03	3.56E-03	4.48E-03
3.69E-01	2.97E-01	2.00E-02	8.43E-04	1.99E-02	1.41E-03	8.40E-04	1.06E-03
2.97E-01	1.83E-01	2.81E-02	2.68E-04	2.80E-02	1.26E-03	2.69E-04	3.36E-04
1.83E-01	1.11E-01	1.46E-02	6.70E-05	1.45E-02	5.95E-04	6.75E-05	8.39E-05
1.11E-01	5.74E-02	8.46E-03	3.59E-05	8.44E-03	3.43E-04	3.62E-05	4.50E-05
5.74E-02	4.09E-02	2.03E-03	7.32E-06	2.03E-03	8.14E-05	7.40E-06	9.17E-06
4.09E-02	3.18E-02	9.71E-04	3.12E-06	9.68E-04	3.86E-05	3.16E-06	3.90E-06
3.18E-02	2.61E-02	5.45E-04	1.60E-06	5.43E-04	2.15E-05	1.63E-06	2.01E-06
2.61E-02	2.42E-02	1.70E-04	4.74E-07	1.69E-04	6.68E-06	4.81E-07	5.93E-07
2.42E-02	2.19E-02	1.97E-04	5.33E-07	1.96E-04	7.74E-06	5.41E-07	6.67E-07
2.19E-02	1.50E-02	5.28E-04	1.32E-06	5.27E-04	2.07E-05	1.34E-06	1.65E-06
1.50E-02	7.10E-03	4.68E-04	9.35E-07	4.67E-04	1.82E-05	9.57E-07	1.17E-06
7.10E-03	3.35E-03	1.53E-04	1.85E-07	1.53E-04	5.85E-06	1.92E-07	2.31E-07
3.35E-03	1.58E-03	4.97E-05	2.54E-08	4.96E-05	1.87E-06	2.81E-08	3.19E-08
1.58E-03	4.54E-04	2.02E-05	2.06E-09	2.01E-05	7.52E-07	3.17E-09	2.59E-09
4.54E-04	2.14E-04	2.49E-06	2.96E-13	2.48E-06	9.25E-08	1.38E-10	3.96E-13
2.14E-04	1.01E-04	8.04E-07	9.58E-14	8.02E-07	2.99E-08	4.47E-11	1.28E-13
1.01E-04	3.73E-05	2.99E-07	3.56E-14	2.98E-07	1.11E-08	1.67E-11	4.77E-14
3.73E-05	1.07E-05	7.32E-08	8.73E-15	7.31E-08	2.73E-09	4.08E-12	1.17E-14
1.07E-05	5.04E-06	9.00E-09	1.07E-15	8.98E-09	3.35E-10	5.01E-13	1.43E-15
5.04E-06	1.86E-06	3.33E-09	3.97E-16	3.33E-09	1.24E-10	1.86E-13	5.31E-16
1.86E-06	8.76E-07	6.52E-10	7.77E-17	6.51E-10	2.43E-11	3.63E-14	1.04E-16
8.76E-07	4.14E-07	2.10E-10	2.51E-17	2.10E-10	7.82E-12	1.17E-14	3.35E-17
4.14E-07	1.00E-07	8.92E-11	1.06E-17	8.90E-11	3.32E-12	4.97E-15	1.42E-17
1.00E-07	1.00E-11	1.20E-11	1.43E-18	1.20E-11	4.47E-13	6.69E-16	1.91E-18
Total (n/s)		**3.96E+02**	**9.72E+06**	**2.31E+12**	**1.08E+07**	**4.87E+07**	**1.40E+05**

5.3 SHIELDING MODEL

The 9977 is a single-containment drum type package with a bolted flange closure and a right circular cylinder Containment Vessel enclosed by LAST-A-FOAM® and Fiberfrax® insulation. Major materials of construction include stainless steel, polyurethane, and aluminum.

5.3.1 Configuration of Source and Shielding

The drum consists of a SS outer shell with a SS liner, aluminum Load Distribution Fixtures and miscellaneous other hardware, as shown in Addendum Figure A.5.1. The drum is modeled as a right circular cylinder, simplifying some of the components. The simplifications are conservative since they place the source material closer to the surface of the drum being analyzed. These simplifications include:

- The bottom of the drum is modeled as flat rather than convex.
- The drum top rim and bottom wear ring are not modeled.
- The drum rolling hoops are not modeled.

The 6CV is modeled as a cylindrical main portion with a conical transition at the top, a short upper cylinder, a Cone-Seal Plug, and the Cone-Seal Nut. Some of the components of the 6CV that are easy to model (e.g., the conical transition at the top) are included exactly. Other components that are more complex are modeled as simpler shapes; these are discussed below.

- The Gland Nut is a complex set of cones and cylinders inside the Gland Nut Plug. For simplicity the nut and plug are modeled together as a single cylinder of 304L stainless steel with a small cylindrical cavity at the top to account for the nut being shorter than the plug. This does not impact the radiation transport calculations.
- The End Cap of the 6CV is modeled as a 2:1 ellipse with the axis of rotation (the "z-axis") set to half the radius of the 6CV cylindrical portion and the minor axis set to the radius of the 6CV cylindrical portion. The bottom of the cylindrical portion of the 6CV is extended down to the point at which the ellipse intersects it.

The SGQ-SC1 Shielded Container (Addendum Figure A.5.2) was modeled as a right circular cylinder (9.5 inches tall and filling the 6CV radially). The content cavity was modeled as 5.5 inches tall by 1.625 inches diameter, 2 inches above the outside bottom of the container. The fixture was ignored, and the AGR-1 fuel compact was placed on the bottom of the cavity touching the side of the cavity.

The SGQ-SC2 Shielded Container (Addendum Figure A.5.3) was modeled as a right circular cylinder (12.25 inches tall and 5.875inches in diameter). The content cavity was modeled as 7.98 inches tall by 1.625 inches diameter, 2.25 inches above the outside bottom of the container.

The SGQ-SC3 Shielded Container (Addendum Figure A.5.4) was modeled as a right circular cylinder (7.15 inches tall and 5.40 inches in diameter[1]). The content cavity was modeled as 3.0 inches tall by 1.25 inches diameter, 2.075 inches above the outside bottom of the container. The fixture was centered on the bottom of the cavity, and the AGR-1 fuel compact was centered in the fixture.

[1] These dimensions are based on an earlier design of the SGQ-SC3 Shielded Container. The impact of the differences on calculated dose is minimal since the thickness of tungsten is the same as the current design.

Representing the SGQ Shielded Containers as right circular cylinders simplifies the geometric modeling without impacting calculated dose rates since the detectors are located on the fuel compact axis or mid-plane.

For NCT, the package is considered to be intact and dose rates are calculated on contact and at 1 meter from the side, bottom, and top. The NCT models for the AGR-1 Fuel Compact with SGQ-SC1 and SGQ-SC3 are shown in Addendum Figures A.5.5 and A.5.6 respectively. The NCT models for SGQ Content Type 4 (LANL Off Site Source Recovery Project contents) in SGQ-SC1 and SGQ-SC2 are shown in Addendum Figures A.5.7 and A.5.8 respectively. For these models, the cavity of the Shielded Container is modeled as a void.

For HAC, the drum, Fiberfrax®, and LAST-A-FOAM® are assumed to be lost leaving only the 6CV. This model (Addendum Figure A.5.9) is obtained from the NCT model by defining the material outside the 6CV as void. Dose rates are calculated at 1 meter from the side, bottom, and top of the 6CV. The aluminum fixture was centered on the bottom of the cavity, and the AGR-1 fuel compact was centered in the aluminum fixture. HAC calculations were not performed for SGQ Content Type 4.

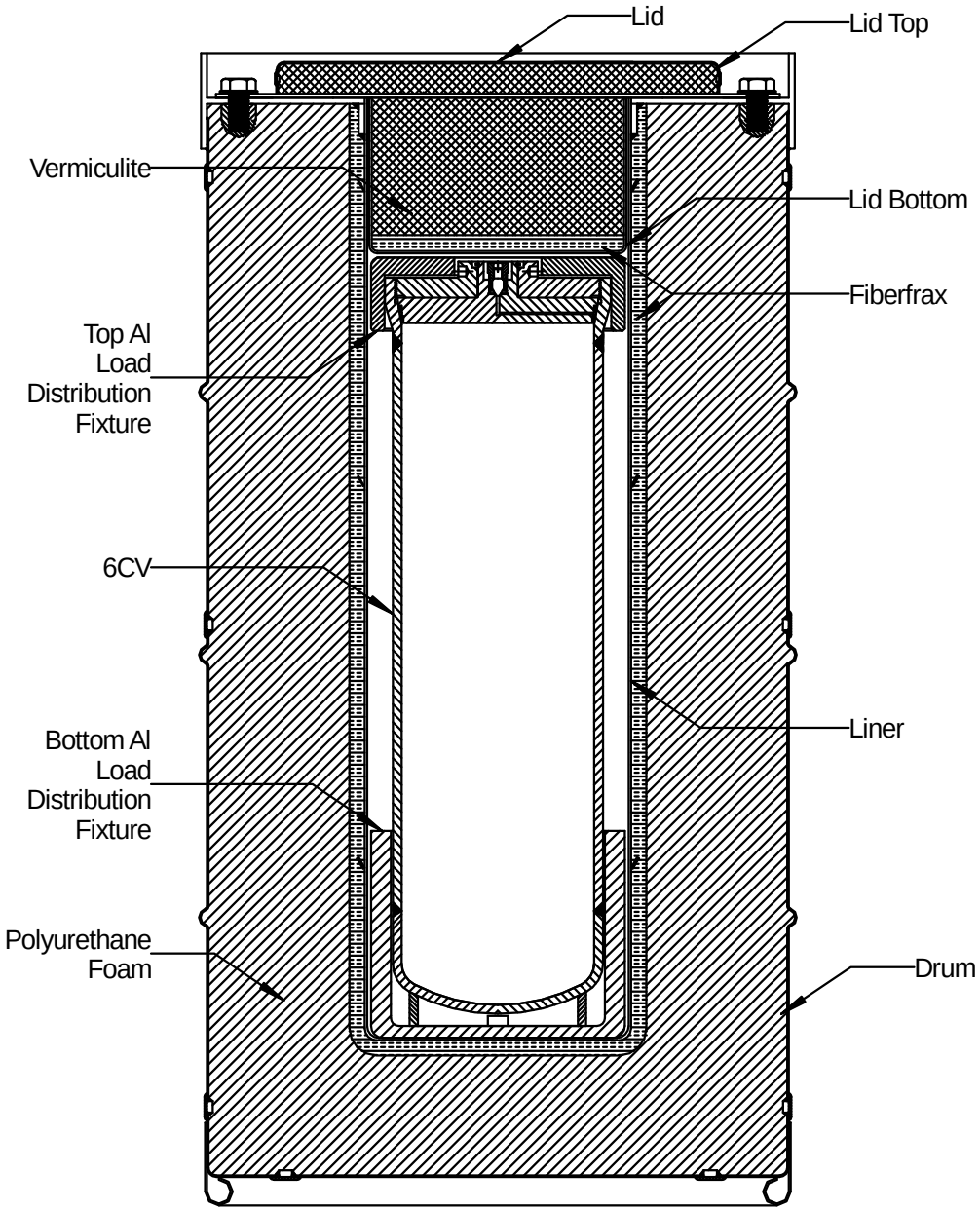

Figure A.5.1 - Shielding Model of 9977 Under NCT

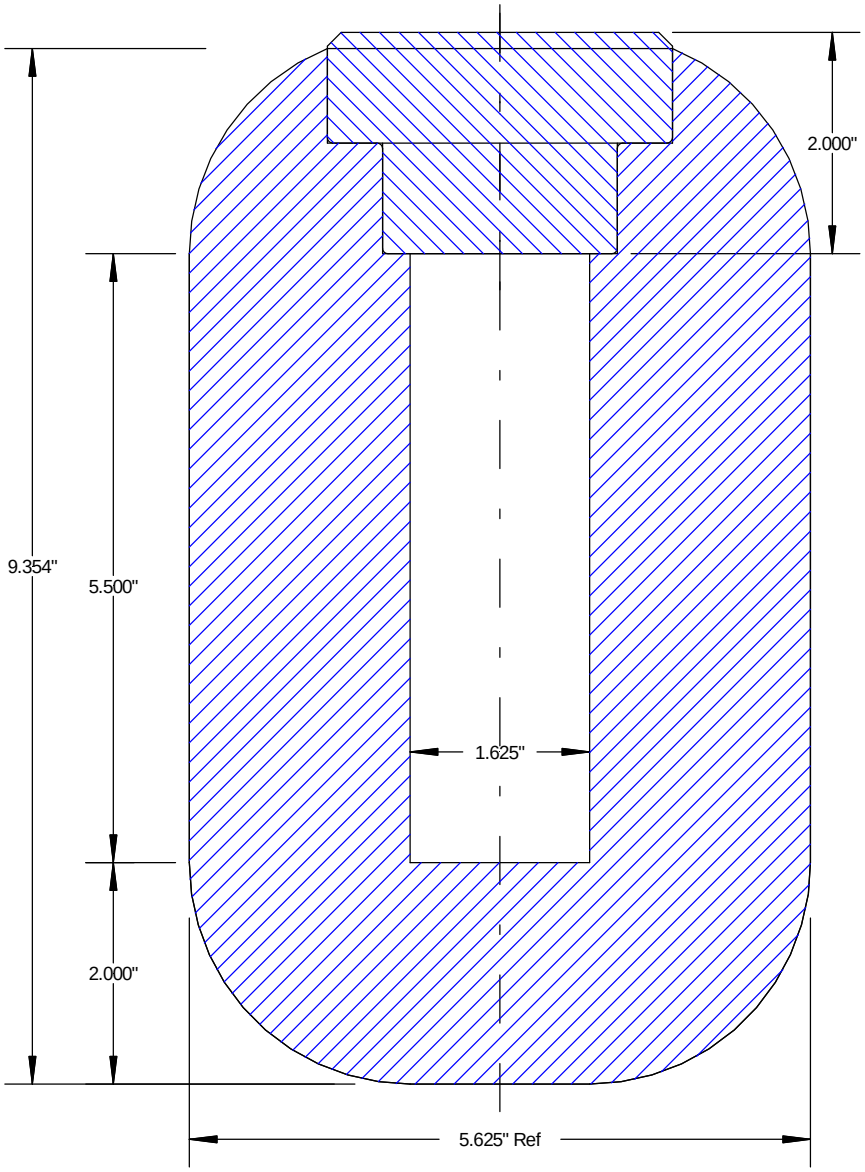

Figure A.5.2 - SGQ-SC1 Lead-Shielded Container

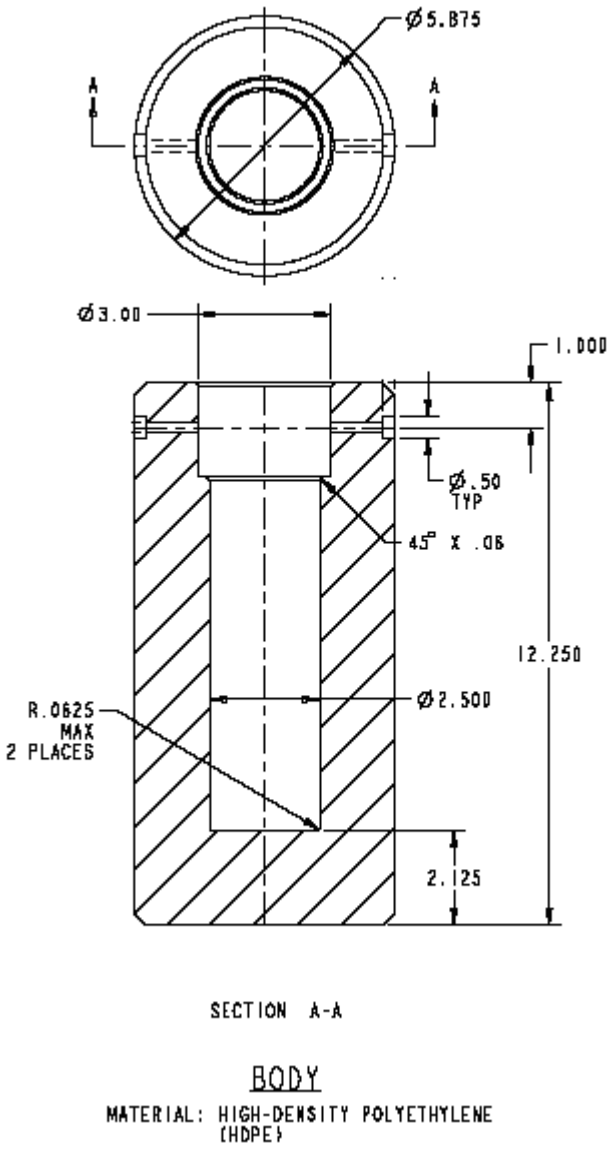

Figure A.5.3 - SGQ-SC2 HDPE-Shielded Container

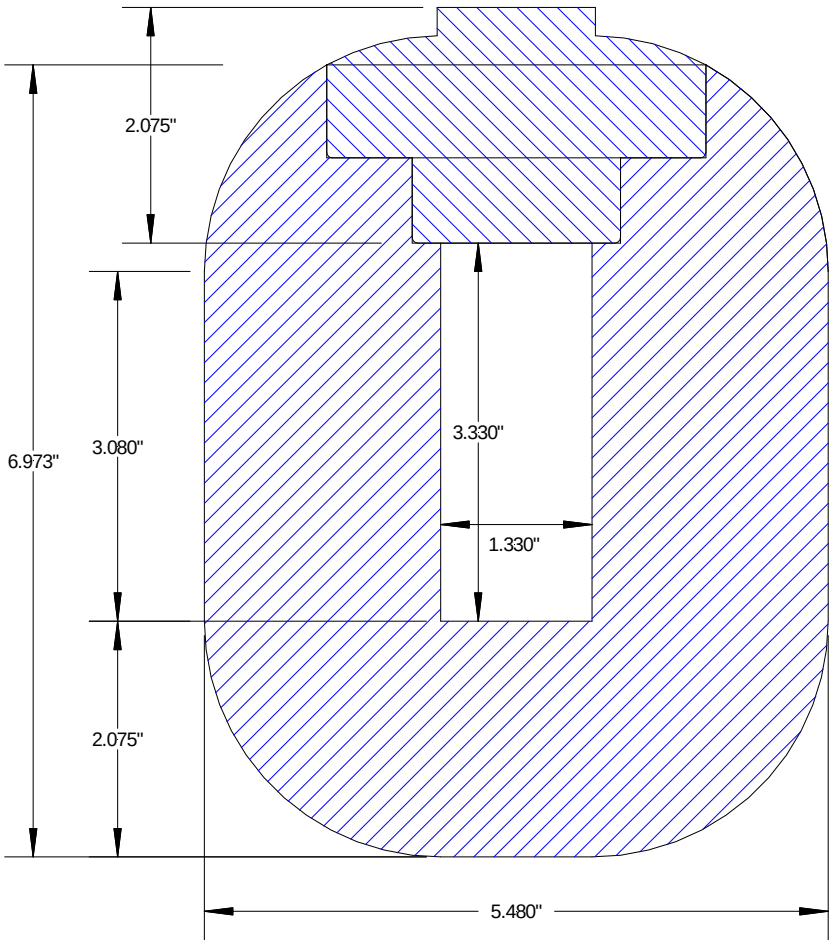

Figure A.5.4 - SGQ-SC3 Tungsten-Shielded Container

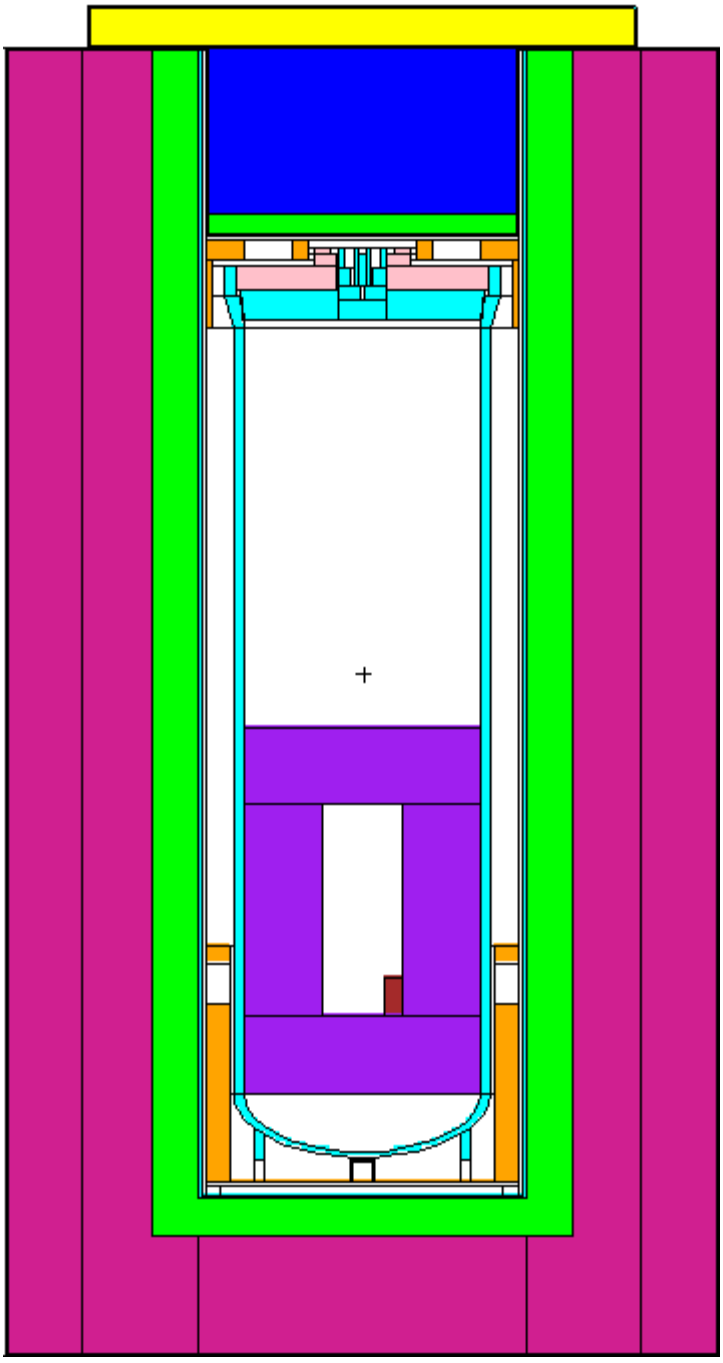

Figure A.5.5 - NCT Model with AGR-1 Fuel Compact in SGQ-SC1 Shielded Container

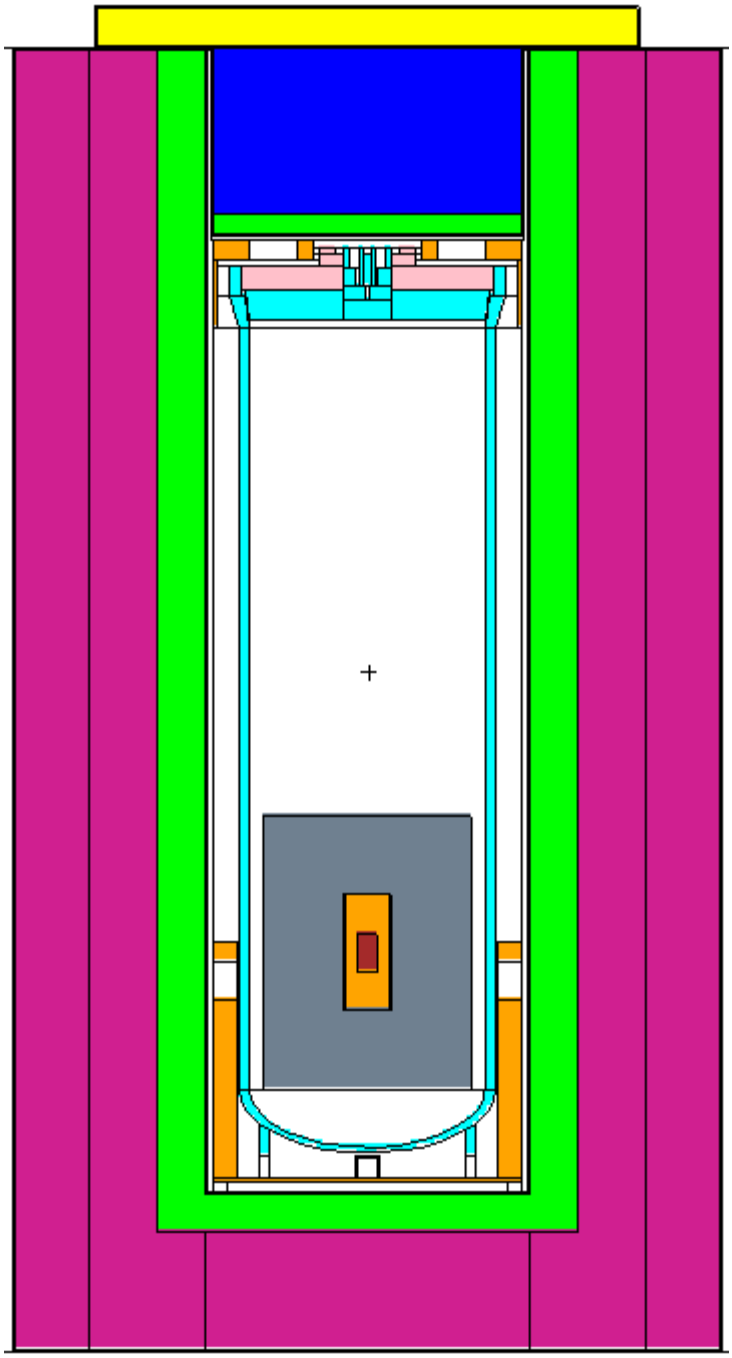

Figure A.5.6 - NCT Model with AGR-1 Fuel Compact in SGQ-SC3 Shielded Container

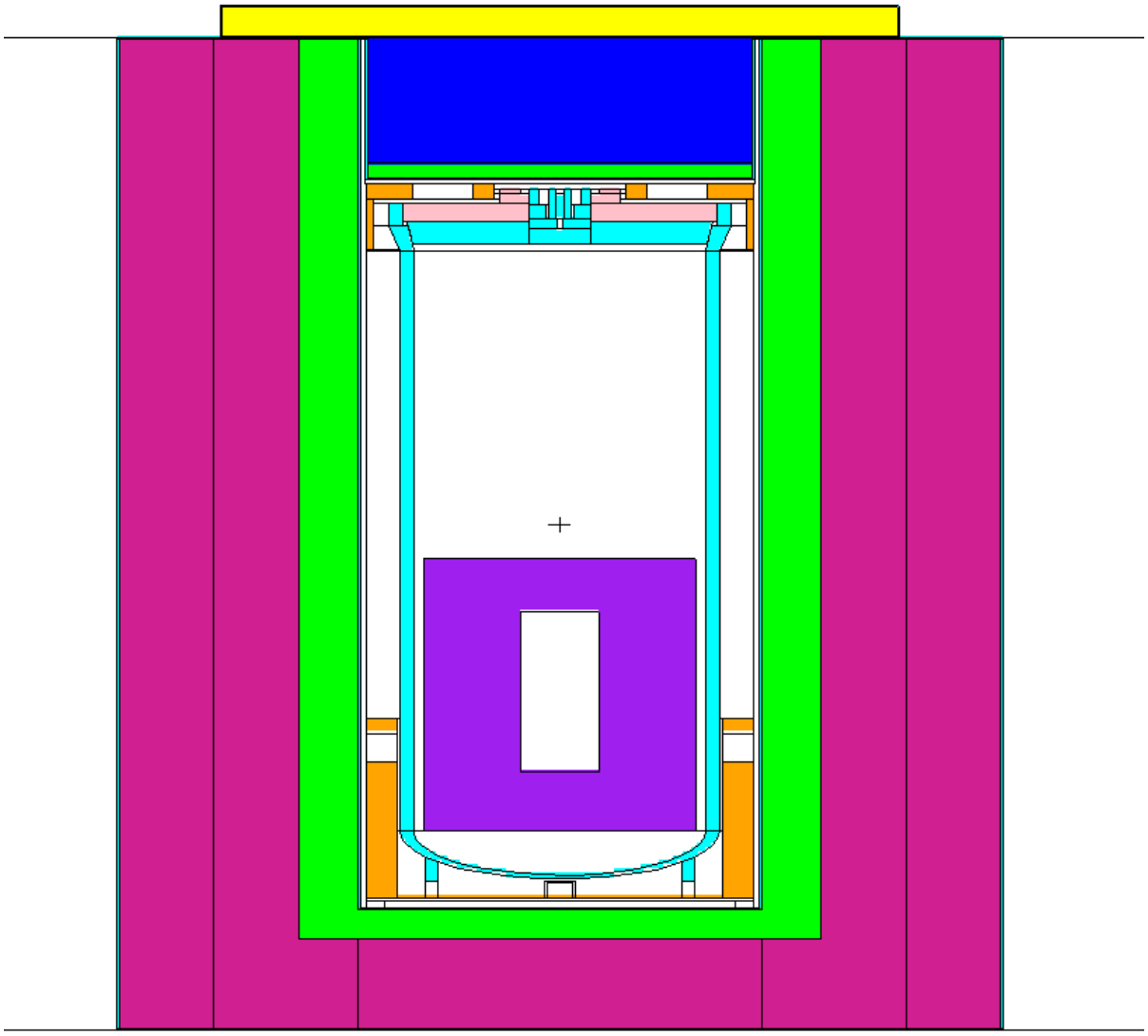

Figure A.5.7 - NCT Model with SGQ Content Type 4 in SGQ-SC1 Shielded Container

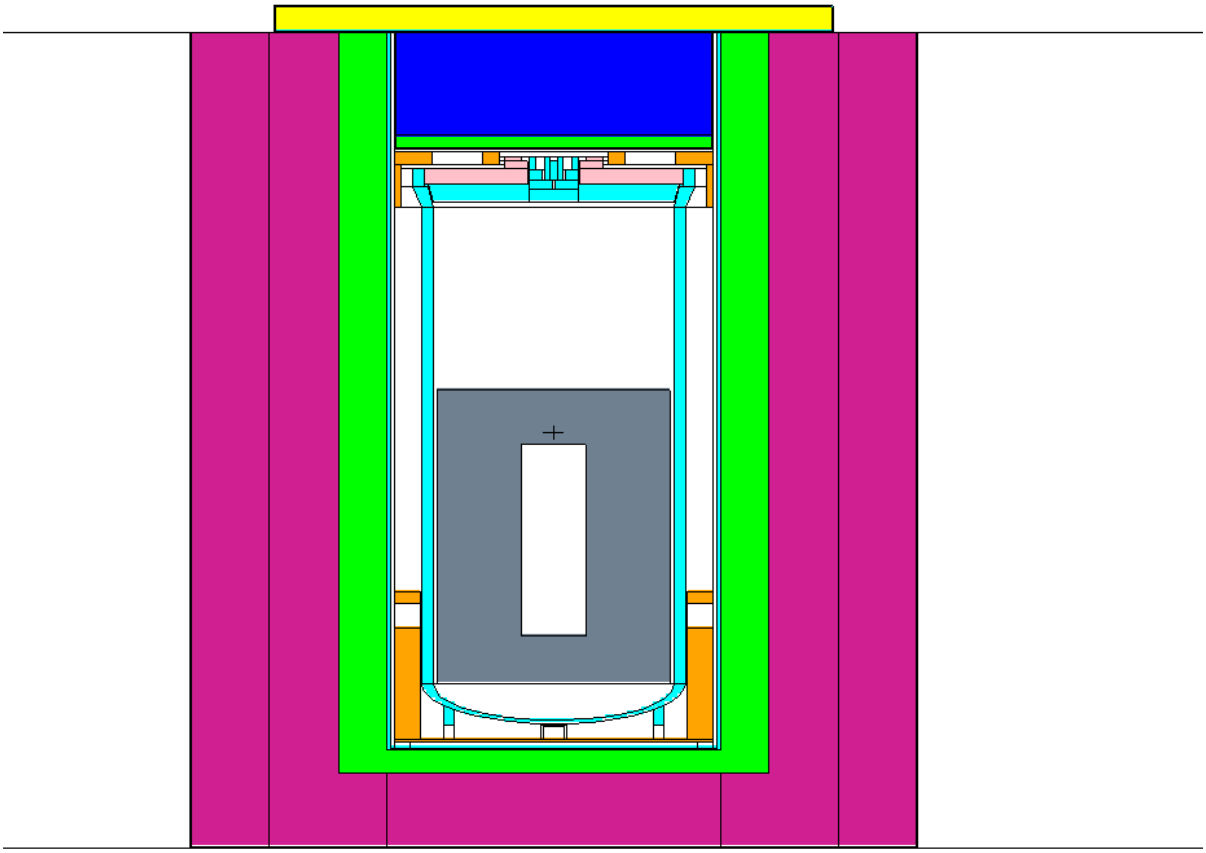

Figure A.5.8 - NCT Model with SGQ Content Type 4 in SGQ-SC2 Shielded Container

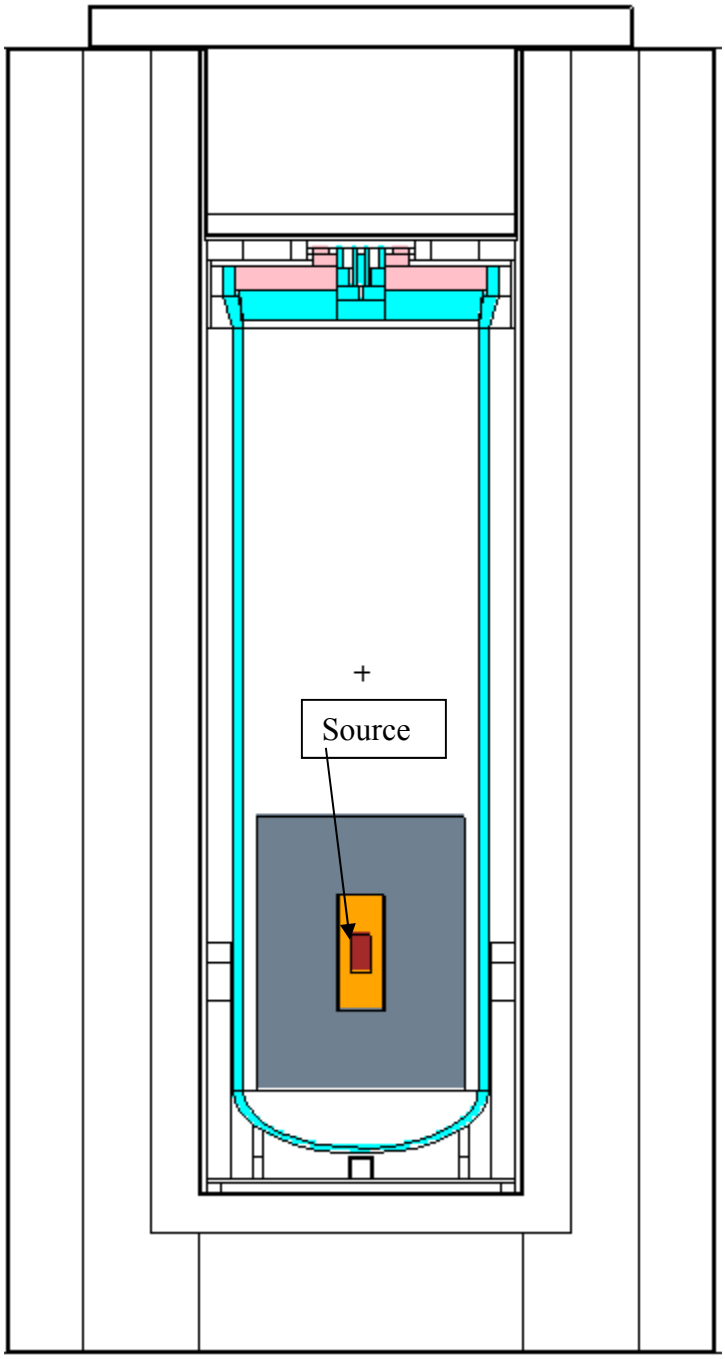

Figure A.5.9 - Shielding Model of 9977 with AGR-1 Fuel Compact in SGQ-SC3 Under HAC

5.3.2 Material Properties

The 9977 Package consists of a stainless steel cylindrical Containment Vessel, a 35-gallon steel drum, Fiberfrax®, LAST-A-FOAM® insulation, aluminum Load Distribution Fixtures, and a drum-closure lid filled with TR-19 Block/Min-K® 2000.

Ten material compositions (Addendum Table A.5.5), other than the source region, are used to model the 9977. [Refs A.5.8, A.5.9, A.5.10]

Table A.5.5 - Material Compositions

	Nitronic® 60	SS 304L	6061 Aluminum	Foam	Vermiculite	Min-K® 2000	Fiberfrax®	Lead	Tungsten	HDPE
density (g/cc)	7.584	7.9	2.7	0.256	0.3684	0.3204	0.2563	11.34	17	0.95
Element	Weight Percent									
H				4.1		0.84				0.00
C		0.03		54.4		1.28				0.00
O				29.4	45.53	48.01	50.03			
N	0.14			12.1						
Si	4	1	0.6		21.22	37.71	23.14			
Ni	8.5	10							6	
Cr	17	19	0.2							
Mn	8	2								
Fe	62.36	67.895			5.4					
P		0.045								
S										
Al			97.9		5.47	6.39	26.46			
Cu			0.28						4	
Mg			1		8.9					
Ti					0.82	5.53				
Na					1.09		0.37			
K					1.22					
Ga						0.15				
Sb						0.09				
W									90	
Pb								100		

5.4 SHIELDING EVALUATION

5.4.1 Methods

The ORIGEN-S Module of the SCALE code system was used to decay each isotope to determine the time of maximum activity and the build-in of daughter isotopes. The radiation source terms were characterized using RASTA. The MCNP code package was used for subsequent three dimensional Monte Carlo transport calculations to determine dose rates outside the 9977 Package.

The following are excerpts from the reference documentation for each of the computer codes used in the calculations. These excerpts are selected to provide general descriptions of the analytical methods employed.

> **ORIGEN-S** computes time-dependent concentrations and source terms of a large number of isotopes, which are simultaneously generated and depleted through neutronic transmutation, fission, radioactive decay, input feed rates, and physical or chemical removal rates. The matrix exponential model of the ORIGEN code is unaltered in ORIGEN-S. The version of ORIGEN applied in the SCALE system, ORIGEN-S, has several improvements over the original program. The code has been modified to include dynamic storage allocation, free-form input processing, and flexible dimensioning.

> **RASTA** (Radiation Source Term Analysis) computes neutron and photon source terms arising from (α, n) events, spontaneous fission, bremsstrahlung, and decay. The code was written to consolidate existing capabilities into a single, easy to use code with flexible, extensive output edits, while also adding new capabilities. Specifically, the gamma decay calculation from the GAMSRC code, bremsstrahlung production calculations from the BREMRAD code, and the (α, n) and spontaneous fission neutron calculations from the SOURCES code have been incorporated into RASTA. These three codes require different inputs and output their results on different bases. RASTA provides a single, easy to use input and output for these modules. In addition, RASTA provides calculational routines to find the photon source arising from decay of the product isotope resulting from an (α, n) calculation, and to find the photon source arising from both prompt and

delayed spontaneous fission events. Finally, RASTA incorporates a methodology similar to that used in KMULT to account for subcritical neutron multiplication.

MCNP treats an arbitrary three - dimensional configuration of materials in geometric cells bounded by first- and second-degree surfaces and some special fourth-degree surfaces. Point-wise continuous-energy cross section data are used, although multi-group data may also be used. Fixed-source adjoint calculations may be made with the multi-group data option. For neutrons, all reactions in a particular cross-section evaluation are accounted for. Both free gas and S (alpha, beta) thermal treatments are used. Criticality sources as well as fixed and surface sources are available. For photons, the code takes account of incoherent and coherent scattering with and without electron binding effects, the possibility of fluorescent emission following photoelectric absorption, and absorption in pair production with local emission of annihilation radiation. A very general source and tally structure is available. The tallies have extensive statistical analysis of convergence. Rapid convergence is enabled by a wide variety of variance reduction methods. Energy ranges are 0 - 60 MeV for neutrons (data generally only available up to 20 MeV) and 1 keV - 1 GeV for photons and electrons.

The ORIGEN-S, MCNP, and RASTA calculations were performed on the SRNS Criticality Safety Advanced Computing Center stand-alone computers, using code and libraries verified on that system.[Refs A.5.11, A.5.12, and A.5.17]

5.4.2 Input and Output Data

The input files of the computer codes are listed in Reference A.5.6 (Appendix A.5.1) and A.5.14 (Appendix A.5.2). Input and output files are available on CD.

5.4.3 Flux-to-Dose-Rate Conversion

Neutron and photon dose conversion factors were obtained from American National Standards ANSI/ANS-6.1.1-1977 [Ref A.5.13] and are given in Addendum Table A.5.6. The 1977 values were used rather than those from the 1991 standard because the neutron dose conversion factors more closely reflect those provided in 49 CFR 173.403, and the photon dose conversion factors more closely correspond to the response measured by instrumentation.

5.4.4 External Radiation Levels

The NCT and HAC dose rates associated with SGQ Content Type 5, AGR-1 Fuel Compact, are given in Addendum Table A.5.1. The NCT dose rate calculations show that the maximum package dose rate is on the side of the drum.

The dose rates associated with SGQ Content Type 4, LANL Off-Site Source Recovery Project materials, were determined by calculating the dose rate for one gram of each isotope and then calculating the mass limit such that the total dose rate at the maximum dose point was less that 190 mrem/hr (a five percent margin below the regulatory limit). The calculated dose rate from one gram of each isotope is shown in Addendum Tables A.5.7 and A.5.8. The resulting mass limits are listed in Addendum Table A.5.9. The dose rates reported in Addendum Tables A.5.7 and A.5.8 are based on a distributed source. Scoping calculations indicate that dose rates from a point source would be 30% higher. To ensure that the mass limits are conservative, the limits reported in Addendum Table A.5.9 were reduced by 30% from those that would be calculated based on the distributed source.

Table A.5.6 - Flux-to-Dose Conversion Factors

Neutron		Photon	
Energy (MeV)	**Biological**	**Energy** (MeV)	**Biological**
2.50E-08	3.67E-06	1.00E-02	3.96E-06
1.00E-07	3.67E-06	3.00E-02	5.82E-07
1.00E-06	4.46E-06	5.00E-02	2.90E-07
1.00E-05	4.54E-06	7.00E-02	2.58E-07
1.00E-04	4.18E-06	1.00E-01	2.83E-07
1.00E-03	3.76E-06	1.50E-01	3.79E-07
1.00E-02	3.56E-06	2.00E-01	5.01E-07
1.00E-01	2.17E-05	2.50E-01	6.31E-07
5.00E-01	9.26E-05	3.00E-01	7.59E-07
1.00E+00	1.32E-04	3.50E-01	8.78E-07
2.50E+00	1.25E-04	4.00E-01	9.85E-07
5.00E+00	1.56E-04	4.50E-01	1.08E-06
7.00E+00	1.47E-04	5.00E-01	1.17E-06
1.00E+01	1.47E-04	5.50E-01	1.27E-06
1.40E+01	2.08E-04	6.00E-01	1.36E-06
2.00E+01	2.27E-04	6.50E-01	1.44E-06
		7.00E-01	1.52E-06
		8.00E-01	1.68E-06
		1.00E+00	1.98E-06
		1.40E+00	2.51E-06
		1.80E+00	2.99E-06
		2.20E+00	3.42E-06
		2.60E+00	3.82E-06
		2.80E+00	4.01E-06
		3.25E+00	4.41E-06
		3.75E+00	4.83E-06
		4.25E+00	5.23E-06
		4.75E+00	5.60E-06
		5.00E+00	5.80E-06
		5.25E+00	6.01E-06
		5.75E+00	6.37E-06
		6.25E+00	6.74E-06
		6.75E+00	7.11E-06
		7.50E+00	7.66E-06
		9.00E+00	8.77E-06
		1.10E+01	1.03E-05
		1.30E+01	1.18E-05
		1.50E+01	1.33E-05

Table A.5.7 – SGQ Content Type 4 Dose Rate Outside Package Under NCT with 1 gram in SGQ-SC1

Location	Dose Rate (rem/hr)			Total (mrem/hr)
	mean	FSD	mean + 3 σ	
Co-60				
Bottom	9.26E+02	0.0044	9.38E+02	9.38E+05
Bottom 1 m	3.67E+01	0.0015	3.68E+01	3.68E+04
Side	1.24E+03	0.0032	1.25E+03	1.25E+06
Side 1m	4.56E+01	0.0013	4.57E+01	4.57E+04
Top	1.01E+02	0.0416	1.13E+02	1.13E+05
Top 1m	8.08E+00	0.0019	8.13E+00	8.13E+03
Cs-137				
Bottom	9.23E-01	0.0158	9.66E-01	9.66E+02
Bottom 1 m	3.38E-02	0.0063	3.45E-02	3.45E+01
Side	1.16E+00	0.0269	1.25E+00	1.25E+03
Side 1m	3.98E-02	0.0060	4.05E-02	4.05E+01
Top	9.67E-02	0.1027	1.26E-01	1.26E+02
Top 1m	5.96E-03	0.0393	6.66E-03	6.66E+00
Ir-192				
Bottom	2.49E+01	0.0178	2.63E+01	2.63E+04
Bottom 1 m	9.65E-01	0.0168	1.01E+00	1.01E+03
Side	3.12E+01	0.0383	3.48E+01	3.48E+04
Side 1m	1.12E+00	0.0139	1.17E+00	1.17E+03
Top	2.15E+00	0.0485	2.47E+00	2.47E+03
Top 1m	1.63E-01	0.0093	1.67E-01	1.67E+02
Sr-90/Y-90				
Bottom	7.86E-02	0.0201	8.34E-02	8.34E+01
Bottom 1 m	3.17E-03	0.0141	3.30E-03	3.30E+00
Side	1.07E-01	0.0282	1.16E-01	1.16E+02
Side 1m	3.96E-03	0.0115	4.09E-03	4.09E+00
Top	8.70E-03	0.1387	1.23E-02	1.23E+01
Top 1m	6.53E-04	0.008	6.68E-04	6.68E-01
Ra-226				
Bottom	4.95E-01	0.0051	5.02E-01	5.02E+02
Bottom 1 m	2.03E-02	0.0018	2.04E-02	2.04E+01
Side	6.55E-01	0.0048	6.65E-01	6.65E+02
Side 1m	2.50E-02	0.0047	2.54E-02	2.54E+01
Top	5.73E-02	0.0247	6.15E-02	6.15E+01
Top 1m	5.05E-03	0.0024	5.09E-03	5.09E+00

Table A.5.8 - SGQ Content Type 4 Dose Rate Outside Package Under NCT with 1 gram in SGQ-SC2

Location	Dose Rate (Rem/Hr)									Total (mrem/hr)
	Neutron			Secondary Photon			Primary Photon			
	mean	FSD	Total	mean	FSD	Total	mean	FSD	Total	
Am-241										
Bottom	7.75E-02	0.0036	7.83E-02	1.09E-03	0.0033	1.10E-03	4.40E-03	0.0878	5.56E-03	8.50E+01
Bottom 1 m	3.21E-03	0.0003	3.22E-03	3.69E-05	0.0006	3.70E-05	1.90E-04	0.0078	1.95E-04	3.45E+00
Side	1.27E-01	0.0029	1.28E-01	1.82E-03	0.0032	1.83E-03	4.24E-03	0.0188	4.48E-03	1.35E+02
Side 1m	4.71E-03	0.0003	4.71E-03	6.64E-05	0.0005	6.65E-05	1.67E-04	0.0104	1.72E-04	4.95E+00
Top	1.69E-02	0.0062	1.73E-02	2.76E-04	0.0632	3.28E-04	4.52E-04	0.0758	5.55E-04	1.81E+01
Top 1m	1.09E-03	0.0006	1.09E-03	1.42E-05	0.0015	1.43E-05	4.50E-05	0.0198	4.77E-05	1.15E+00
Cf-252										
Bottom	8.71E+03	0.0059	8.87E+03	3.20E+02	0.0046	3.24E+02	8.48E+02	0.0033	8.56E+02	1.00E+07
Bottom 1 m	3.32E+02	0.0005	3.32E+02	1.11E+01	0.0008	1.11E+01	4.03E+01	0.0004	4.03E+01	3.84E+05
Side	1.49E+04	0.0035	1.50E+04	5.44E+02	0.0028	5.48E+02	1.19E+03	0.0024	1.20E+03	1.68E+07
Side 1m	5.37E+02	0.0004	5.38E+02	2.01E+01	0.0006	2.01E+01	4.59E+01	0.0004	4.59E+01	6.04E+05
Top	1.87E+03	0.0124	1.94E+03	6.90E+01	0.0128	7.16E+01	9.56E+01	0.0160	1.00E+02	2.11E+06
Top 1m	1.08E+02	0.0009	1.08E+02	4.11E+00	0.0012	4.12E+00	8.31E+00	0.0010	8.33E+00	1.20E+05
Cm-244										
Bottom	4.43E-02	0.0050	4.50E-02	1.47E-03	0.0126	1.53E-03	6.51E-03	0.0773	8.01E-03	5.45E+01
Bottom 1 m	1.72E-03	0.0007	1.72E-03	5.05E-05	0.0009	5.06E-05	2.88E-04	0.0077	2.95E-04	2.07E+00
Side	7.63E-02	0.0053	7.75E-02	2.54E-03	0.0090	2.61E-03	8.52E-03	0.0212	9.06E-03	8.92E+01
Side 1m	2.75E-03	0.0006	2.75E-03	9.14E-05	0.0008	9.16E-05	3.30E-04	0.0077	3.37E-04	3.18E+00
Top	9.66E-03	0.0144	1.01E-02	3.16E-04	0.0219	3.37E-04	6.10E-04	0.1079	8.08E-04	1.12E+01
Top 1m	5.59E-04	0.0012	5.61E-04	1.87E-05	0.0016	1.88E-05	5.64E-05	0.0173	5.94E-05	6.39E-01
Pu-238										
Bottom	3.88E-01	0.0032	3.91E-01	5.47E-03	0.0036	5.53E-03	1.34E-02	0.0319	1.47E-02	4.12E+02
Bottom 1 m	1.61E-02	0.0003	1.61E-02	1.87E-04	0.0094	1.92E-04	6.90E-04	0.0028	6.96E-04	1.70E+01
Side	6.37E-01	0.0027	6.42E-01	9.06E-03	0.0022	9.12E-03	1.89E-02	0.0106	1.95E-02	6.71E+02
Side 1m	2.36E-02	0.0003	2.36E-02	3.33E-04	0.0005	3.33E-04	7.40E-04	0.0028	7.46E-04	2.47E+01
Top	8.59E-02	0.0134	8.94E-02	1.33E-03	0.0151	1.39E-03	2.11E-03	0.0158	2.21E-03	9.30E+01
Top 1m	5.45E-03	0.0006	5.46E-03	7.14E-05	0.0015	7.18E-05	2.24E-04	0.0049	2.27E-04	5.76E+00
Pu-239										
Bottom	1.09E-03	0.0037	1.10E-03	1.58E-05	0.0035	1.60E-05	4.63E-05	0.0103	4.78E-05	1.16E+00
Bottom 1 m	4.51E-05	0.0003	4.51E-05	5.40E-07	0.0105	5.57E-07	2.36E-06	0.0019	2.37E-06	4.81E-02
Side	1.79E-03	0.0028	1.81E-03	2.64E-05	0.0028	2.66E-05	6.63E-05	0.0081	6.79E-05	1.90E+00
Side 1m	6.64E-05	0.0003	6.65E-05	9.65E-07	0.0006	9.66E-07	2.57E-06	0.0019	2.59E-06	7.01E-02
Top	2.40E-04	0.0064	2.45E-04	3.82E-06	0.0145	3.99E-06	7.11E-06	0.0562	8.31E-06	2.57E-01
Top 1m	1.52E-05	0.0006	1.53E-05	2.06E-07	0.0013	2.07E-07	6.82E-07	0.0037	6.89E-07	1.62E-02

Table A.5.9 - Mass Limits for SGQ Content Type 4

Isotope	Dose Rate (mrem/hr)	Mass Limit (grams)	
		Original	Reduced*
SGQ-SC1			
Co-60	1.25E+06	1.5E-04	1.0E-04
Cs-137	1.25E+03	1.5E-01	1.0E-01
Ir-192	3.48E+04	5.5E-03	4.0E-03
Sr-90/Y-90	1.16E+02	1.6E+00	1.0E+00
Ra-226	6.65E+02	2.9E-01	2.0E-01
SGQ-SC2			
Am-241	1.35E+02	1.4E+00	1.0E+00
Cf-252	1.65E+07	1.2E-05	8.0E-06
Cm-244	8.92E+01	2.1E+00	1.0E+00
Pu-238	6.71E+02	2.8E-01	2.0E-01
Pu-239	1.90E+00	1.0E+02	7.0E+01

*The mass limit is reduced by 30%.

The dose rate outsides the SGQ Type 5, AGR-1 Fuel Compact, are within regulatory limits for "non-exclusive use" shipments as long as a SGQ-SC3 Shielded Container remains intact.

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A.5.10 Midwest Tungsten Service, Tungsten Alloy. [Included as Appendix B of N-CLC-G-00136]

A.5.11 MCNP Verification

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A.5.12 RASTA Verification

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A.5.15 Hermann, O. W. & Westfall, R. M., *ORIGEN-S: Scale System Module to Calculate Fuel Depletion, Actinide Transmutation, Fission Product Buildup and Decay, and Associated Radiation*

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A.5.17 ORIGEN-S Verification

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ADDENDUM CHAPTER 5 APPENDIX

Appendix	Description
A.5.1	*Shielding Analysis for Addendum 3 to 9977 Shipping Package SARP (U)*, N-CLC-G-00136, Revision 0
A.5.2	*Shielding Analysis of Content Type 4 for Addendum 3 to 9977 Shipping Package SARP (U)*, N-CLC-G-00138, Revision 0

Note: Input and output files associated with this chapter are listed in Addendum Appendices A.5.1 and A.5.2 and are available on CD.

CHAPTER 6 -- CRITICALITY EVALUATION

Proposed SGQ Content envelopes are limited to a mass of material which is subcritical, under all conditions of reflection, moderation and array size. The SGQ Contents, described in Addendum Table A.1.1, include categories for 1) non-fissile contents; 2) fissile contents sufficiently small that the material is subcritical for any isotope; and 3) small amounts of common fissile materials, with typical impurities, which are subcritical under all conditions. A criticality evaluation is moot for non-fissile SGQ Contents. A Nuclear Criticality Safety Evaluation (NCSE) which provides justification for the SGQ Content envelopes was performed for the two fissile cases. [Addendum Appendix A.6.1] This Nuclear Criticality Safety Evaluation (NCSE) uses the models (geometry and material specifications) and general analysis approach used in the 9977 SARP baseline NCSE. [Ref A.6.1] The NCSE confirms that the SGQ Contents are subcritical for all three cases. All materials conforming to 10 CFR 71.15 may be shipped, as fissile exempt.

The analyses in the NCSE demonstrate that the 9977 shipping package is subcritical with adherence to design features, limits and controls specified.

6.1 DESCRIPTION OF CRITICALITY DESIGN

6.1.1 Design Features

The 9977 Shipping Package is a single containment drum type package with a bolted flange closure and a right circular cylindrical Containment Vessel enclosed by stainless steel (SS), Fiberfrax® and Last-A-Foam® insulation. Major component materials of construction include a SS overpack drum, Last-A-Foam® insulation impact absorbers, and a SS 6-inch inside diameter Containment Vessel (6CV). The 6CV may be removed from the drum for loading and unloading. The physical configuration of the 9977 is described in SARP Chapter 1. The package is designed for heat source transport. The design features of the 9977 that are important to criticality control are the loading of fissile material contents into the 6CV, which prevents their release, and the drum, which remains intact maintaining spacing between contents.

6.1.2 Summary Table of Criticality Evaluation

The criticality evaluation for SGQ Content Envelopes Type 2 is summarized in Addendum Table A.6.2.

6.1.2.1 SGQ CONTENT ENVELOPE TYPE 1

Withdrawn.

6.1.2.2 SGQ CONTENT ENVELOPE TYPE 2

SGQ Content Envelope Type 2 is specified as up to 100 grams of fissile material with only trace amounts (<1,000 ppm) of special actinides. The Type 2 Content Envelope is analyzed in the NCSE by considering 100 grams of ^{239}Pu, ^{241}Pu, ^{233}U, or ^{235}U in Addendum Sections 6.4 (Single Package Analyses), 6.5 (NCT Array Analyses), and 6.6 (HAC Analyses).

The presence of the trace amounts of special actinides is accounted for by modeling some cases with an extra 10% of the fissile material in Addendum Section 6.4.2. The effects of trace amounts of special actinides on NCT or HAC arrays was not analyzed since the results in Addendum Section 6.3 bound the array calculations reported in Addendum Sections 6.4 and 6.5.

The criticality safety evaluation includes the single package (SP) analyses required by 10 CFR 71.55 and array analyses for Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) required by 10 CFR 71.59. The 9977 is analyzed for the transport of SGQ Content envelopes defined in Addendum Section 1.2.2 and bounded by SGQ content envelopes listed in Addendum Table A.6.1.

6.1.2.3 SGQ CONTENT ENVELOPES TYPE 3, 4, AND 5

SGQ Content Envelope Type 3 (Material defined by S-SARA-G-00007, Rev. 0), Type 4 (Material defined by LANL Off-Site Source Recovery Project), and Type 5 (Material defined by INL AGR-1 Compacts) are bounded by the analysis for SGQ Content envelope Type 2 given in Addendum Sections 6.4 (Single Package Analyses), 6.5 (NCT Array Analyses), and 6.6 (HAC Analyses).

6.1.3 Criticality Safety Index

The calculation of the Criticality Safety Index (CSI) for the 9977 shipping package is required to follow the explicit equations specified in 10 CFR Part 71.59.

The calculation of the CSI for both NCT and HAC conditions is conservatively based on infinite arrays. The CSI calculations for NCT and HAC are shown in parallel in Addendum Appendix A.6.1. The CSI is equal to zero (0.0) for the 9977 package for SGQ Content envelopes.

Table A.6.1 - Analyzed SGQ Content Envelopes

	Material [a, b]	Type 1	Type 2
Radioisotope (grams)	^{239}Pu [c]	Withdrawn	100
	^{241}Pu [c]		100
	^{233}U [c]		100
	^{235}U [c]		100
	^{242m}Am [c]		< 1,000 ppm
	^{243}Cm [c]		< 1,000 ppm
	^{245}Cm [c]		< 1,000 ppm
	^{247}Cm [c]		< 1,000 ppm
	^{249}Cf [c]		< 1,000 ppm
	^{251}Cf [c]		< 1,000 ppm
Total Mass (grams)	Radioactive Materials		100
	Light Elements and Impurities		50
	All Contents		150

Table A.6.1 Notes	
a	All contents shall be dry.
b	Content bulk density shall be no greater than 19.84 g/cc and no less than 2.0 g/cc.
c	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.

Table A.6.2 - Summary of Criticality Safety Analysis Results (ksafe=0.831)

SGQ Content Envelope [a]	Type 1	Type 2
Single Package Results		
Package calculated to be subcritical under conditions for maximum reactivity (for flooded conditions)	N/A	Max. k_{eff} = 0.6792
Most reactive configuration		^{241}Pu solution with 1000 ppm ^{251}Cf, 0.010 g/cc
Moderation for most reactive configuration		Flooded 6CV
Reflection for most reactive configuration (package materials and/or 30 cm water)		30 cm water
NCT Array Results		
Array calculated to be subcritical under conditions for maximum reactivity (for flooded conditions)	Bound by Type 2	Max. k_{eff} = 0.2968
Number of packages		Infinite
Water in CV		Yes
Water in drum voids		Yes
Most reactive fissile content		^{239}Pu metal (100g) 19.84 g/cc surrounded by Be (50g) in SGQ-SC2
Reflection surrounding array		Not applicable for infinite array
HAC Array Results		
Array calculated to be subcritical under conditions for maximum reactivity	Bound by Type 2	Max. k_{eff} = 0.3711
Number of packages		Infinite
Water in CV		No
Water in drum voids		Yes
Most reactive fissile content		^{233}U metal (100g) 19.84 g/cc wrapped in polyethylene (100g)
Reflection surrounding array		Not applicable for infinite array

Notes:
a. The fissionable material mass limits for SGQ Content envelopes are shown in Addendum Table A.6.1.

6.2 FISSILE MATERIAL CONTENTS

The package content loading limits are given in Addendum Table A.1.1 and are defined as SGQ Type 1 and Type 2 Contents. The limits on fissile, non-fissile and non-fissionable materials include consideration of typical packing materials, product impurities, moisture content and fissile and non-fissile contents of alloy metals. The limits presented for radionuclides and impurities apply for both the Single Package and array analyses. Contents are solid metal form and have fissionable components as shown in column one of Addendum Table A.6.3.

The following limits/controls apply to the 9977 shipping packages evaluated in this analysis:

1. Only the SGQ material within the bounds of the SGQ content envelopes defined in Addendum Table A.1.1 may be shipped.
2. Each package shall be assigned a CSI = 0.0 for material within the bounds of SGQ Content envelopes defined in Addendum Table A.1.1.

The SGQ Content envelopes with a brief discussion of their modeling are summarized below.

A. SGQ Content Type 1

Withdrawn

B. SGQ Content Type 2

The total fissile material mass in SGQ Content Type 2 is limited to 100 g with the further restriction that the mass of special actinides (i.e., ^{242m}Am, ^{243}Cm, ^{245}Cm, ^{247}Cm, ^{249}Cf, and ^{251}Cf) is less than 1,000 ppm.

C. SGQ Content Type 3

These contents are bounded by SGQ Content Type 2.

D. SGQ Content Type 4

These contents are bounded by SGQ Content Type 2.

E. SGQ Content Type 5

These contents are bounded by SGQ Content Type 2.

6.3 GENERAL CONSIDERATIONS

The computational models used in the criticality analysis for the SP and NCT and HAC arrays are presented in this section.

Some models include 100 grams of polyethylene material (density 0.95 g/cc) to account for the presence of nylon/plastic/PVC or equivalent hydrogenous materials used for contamination control and for moisture inside the 6CV. The polyethylene is conservatively assumed to be a shell of uniform thickness on the outer surface of the fissile material.

Table A.6.3 - Fissile Isotopes Considered in SGQ Subcriticality Evaluation

Nuclide	Subcritical Mass Limit (g)		Material Density (g/cc)
Pu-239	450	ANS-8.15[Ref A.6.2] Table 2	19.84
Pu-241	200		19.84
Am-242m	13		13.67
Cm-243	90		13.57
Cm-245	30		13.57
Cm-247	900		13.57
Cf-249	10		15.1
Cf-251	5		15.1
U-233	500	ANS-8.1 [Ref A.6.3] Sect 5.2	19.05
U-235	700		19.05
Pu-238	4000	ANS-8.15 Table 1[2]	19.84
Pu-240	20000		19.84
Pu-242	60000		19.84

[2] Values listed are for water reflected systems. The limits for some non-fissile materials are lower for steel reflected systems.

6.3.1 Model Configuration

The 9977 shipping package consists of a 35-gallon stainless steel drum with an external (nominal) diameter and height of 18.72 inches and 36.1 inches, respectively. Each 9977 has one 6CV.

The 6CV is a stainless steel pressure-rated vessel with a nominal 6.065-inch inside diameter (ID) and is 23.12 inches high. [Ref A.6.4] Nuclear material, contained in a product can, is loaded into the 6CV and sealed with a stainless steel Cone-Seal Plug and locking Cone-Seal Nut creating a leak tight seal. The confinement boundary is the flanged stainless steel 35-gallon drum. The containment boundary is defined as the 6CV body, the outer O-ring, the Cone-Seal Plug, and the Leak Test Port Plug.

The 6CV body is placed on an aluminum bottom load distribution fixture (LDF). There is also an aluminum top LDF to cover the 6CV head. The 6CV and the LDFs are placed inside the steel liner. The liner is welded to the top lid flange. Polyurethane foam and Fiberfrax® surround the liner to fill the remainder of the 35-gallon package. The package lid has a bottom liner filled with Vermiculite and Fiberfrax® insulation and a top liner filled with Min-K® 2000 insulation.

Addendum Figure A.0.1 shows an axial cross sectional view and provides the dimensions of the 9977 shipping package with its 6CV. Addendum Table A.6.4 lists the specification dimensions of various components of the 9977 shipping package, the as-modeled dimensions of each component, and the reference drawings providing the specification for each component.

The 9977 is currently authorized for the shipment of contents in RTGs, Food-Pack Cans, 3013 Containers, 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. Special Form items falling within the Small Gram Quantity (SGQ) Content envelopes, may be shipped, packed in aluminum peanuts, aluminum or stainless steel wire gauze or aluminum foil, and placed directly in the 6CV. Other SGQ Contents may be shipped in Food Pack Cans or Engineered Containers. If additional shielding is required to meet dose-rate requirements the Contents may be placed within an SGQ Shielded Container (SGQ-SC1, SGQ-SC2, or SGQ-SC3).

Small Gram Quantity Shielded Containers (SGQ-SC1, SGQ-SC2, or SGQ-SC3) provide shielding appropriate for the radiological hazard of the contents. The SGQ-SC1 and SGQ-SC3 containers provide gamma and SGQ-SC2 provides neutron shielding. Gamma shielding consists of a lead or tungsten body enclosed by a stainless steel container with threaded closure. Neutron shielding consists of high density polyethylene, with an integral closure (no encapsulation being required). The SGQ Shielded Containers are able to withstand the worst case HAC drop event without shielding compromise.

The SGQ-SC1 and SGQ-SC3 are located within the 9977 6CV by prescribed aluminum honey comb spacers or aluminum peanuts as shown in Addendum Figures A.1.1 and A.1.3. The SGQ-SC2 is located within the 6CV with a perforated food-pack can used as packing material as shown in Addendum Figure A.1.2.

Table A.6.4 - Geometric Specifications for the 9977 Shipping Package

Sheet 1 of 4

Component	Parameter	Specification (inch)	KENO Model (cm)	Reference
Drum Lid Plate	OD	17.8	--	R-R2-G-00018
	OR	8.9	22.606	
	Thickness	0.125	0.318	
Drum Liner	OD	8.346	--	R-R2-G-00017
	OR	4.173	10.5994	
	ID	8.25	--	
	IR	4.125	10.4775	
	Internal Height	29.5	74.930	
	Thickness	0.048 (18 GA)	0.1219	
Drum	ID	18.25	--	R-R2-G-00017
	IR	9.125	23.1775	
	OR	9.125 + 0.048 (18 GA) = 9.173	23.2994	
	External Height	36.1	86.868 †	
	Inner Height	33.1	86.7461 †	
	Thickness	0.048 (18 GA)	0.1219	

† It is noted that the KENO model values (in centimeters) differ from the specification value (in inches). These differences are conservative for this analysis. For example, the modeled external drum height is smaller than the specification value, resulting in fissile masses in stacked drums being closer than actual (the associated calculated k_{eff} values would be larger than if the specification external height was modeled). Modeling a larger than specified inner height increases the space for the foam insulation, which increases the calculated effect of moderation and reflection by the insulation.

Table A.6.4 - Geometric Specifications for the 9977 Shipping Package (continued)

Sheet 2 of 4				
Component	**Parameter**	**Specification** (inch)	**KENO Model** (cm)	**Reference**
Aluminum Bottom Load Distribution Fixture	ID	6.75	--	R-R4-G-00032
	IR	3.375	8.5725	
	OD	8.00		
	OR	4.00	10.160	
	Internal Height	6.13	15.5702	
	External Height	6.50	16.51	
	Side Thickness	0.625	1.5875	
	Bottom Thickness	0.370	0.9398	
Aluminum Top Load Distribution Fixture	ID	7.15	--	R-R4-G-00032
	IR	3.575	9.0805	
	OD	8.0		
	OR	4.0	10.160	
	Internal Height	1.75	4.445	
	External Height	2.30	5.842	
	Side Thickness	0.425	1.0795	
	Top Thickness	0.550	1.397	
	Central Hole	2.75×2.75	6.985×6.985	

Table A.6.4 - Geometric Specifications for the 9977 Shipping Package (continued)

Sheet 3 of 4				
Component	**Parameter**	**Specification** (inch)	**KENO Model** (cm)	**Reference**
6CV	Upper OD	7.12	--	R-R2-G-00042
	Upper OR	3.56	9.042	
	Upper ID	6.31	16.028	
	Cylinder OD	6.625		
	Cylinder OR	3.313	8.414	
	Cylinder ID	6.065		
	Cylinder IR	3.033	7.703	
	External Height	23.12	58.725	
	Max. Internal Solution Height	21.22	53.57 †	
	Side Thickness	0.28	0.7112	
	Top Steel portion Height	0.75	1.905	
	Tapered Portion Height	0.82	2.21 †	
	Height up to Leg	23.5	59.69	
	Leg OD	5.563	OR = 7.705	
	Leg ID	5.047	IR = 6.41	
† See footnote on Addendum Table A.6.4 Sheet 1 of 4				

Table A.6.4 - Geometric Specifications for the 9977 Shipping Package (continued)

Sheet 4 of 4				
Component	**Parameter**	**Specification** (inch)	**KENO Model** (cm)	**Reference**
Lid Liner Bottom	ID	7.98	--	R-R2-G-00018
	IR	3.995	10.147 †	
	OD	8.13		
	OR	4.065	10.325	
	Internal Height	4.81	12.207 †	
	External Height	4.88	12.395	
	Thickness	0.07	0.178 †	
Lid Liner Top	ID	13.904		R-R2-G-00018
	IR	6.952	17.658	
	OD	14.0	--	
	OR	7.00	17.780	
	Internal Height	0.952	2.418	
	External Height	1.00	2.54	
	Thickness	0.048 (18 GA)	0.122	
Drum Flange	Thickness	3/16	0.4763	R-R2-G-00017
† See footnote on Addendum Table A.6.4 Sheet 1 of 4				

Addendum Figure A.0.1 shows the package dimensions that are modeled in the base case for the SP, NCT, and HAC models. The drum radial dimensions used in the NCT and HAC cases for the KENO model are shown in Addendum Figure A.0.1.

The base KENO model was developed from the set of drawings referenced in Addendum Table A.6.4. Addendum Table A.6.5 includes specifications and as-modeled dimensions for various components of the 9977 shipping package.

Nominal 9977 component dimensions were used, because the dimensional tolerances are tight and the effect on reactivity of slight variations in material thicknesses was judged to be insignificant. Any variations from the specified dimensions (e.g., external height) in the models were conservative (i.e., increasing the calculated k_{eff} value). In this analysis, the three rolling hoops of the 9977 containers were neglected. Neglecting these geometric details reduces the effective drum diameter, which in turn conservatively models the array pitch.

Simplifications made to the 9977 SCALE/KENO model include:

- Drum is approximated as a right circular cylinder with a flat bottom,
- Rolling hoops are ignored.

Table A.6.5 - Drum Dimensions for Various Models

Dimension	Specification	Single Package Model [a]	NCT Model (cm)	HAC Model [b] (cm)
Drum Inner Radius	23.1775 cm	23.1775 cm	Same as SP	19.3063 - 0.1684 = 19.1379
Drum Wall Thickness	(0.048 inch) 0.1219 cm	0.1219 cm	Same as SP	0.1684 (thickness is increased to conserve the drum mass)
Drum Outer Radius	23.2994 cm	23.2994 cm	Same as SP	(23.2994-2.54)*0.93 = 19.3063 Note: 2.54 cm is the drum radial reduction due to impact (see Addendum Table A.6.7)

a - The Single Package Model is described in Addendum Section 6.3.1.2

b - The HAC Model is described in Addendum Section 6.3.1.4

The following conservative choices are made in developing the criticality models:

1. Geometric shape of fissile content: The fissile content is modeled as spherical and cylindrical. This is the most reactive configuration in the SP and array analyses.
2. Plastics: 100 grams of plastic, C_2H_4 polymer (polyethylene) at a density of 0.95 g/cc, is modeled as a shell surrounding the fissile content in some configurations.
3. Fissile density: The maximum theoretical densities of fissile metals are modeled. The theoretical densities are higher than the actual densities that are commonly achieved. A maximized density for fissile material results in the largest neutron multiplication factor, k_{eff}.
4. Fissile composition: The content envelopes permit a wide range of isotopic compositions. The most reactive isotopes are modeled in the criticality analyses.
5. Drum dimensions: The rolling hoops and the drum lid closure hardware are ignored. This reduces the modeled space between package centers.
6. Moderation: Any amount of interstitial water in any form (ice, mist, etc.) between adjacent drums in an array reduces reactivity, because this increases isolation between units. Therefore, the absence of moderating material between drums is the most reactive condition.

6.3.1.2 Single Package Model

A single 9977 package was modeled as surrounded by 30 cm of water on all sides. The contents of the package were varied to include solid actinide metal as a sphere and solutions of actinides and water. The solution analysis meets a 10 CFR 71 requirement to demonstrate that a single package fully flooded under worst case conditions remains subcritical.

For the metal material models, a sphere of the fissile material was modeled in the radial center of the SGQ-SC2. Three cases were considered: a fissile metal sphere closely surrounded by 100 g of polyethylene, a fissile metal sphere closely surrounded by 50 grams of beryllium, and a sphere of fissile metal intimately mixed 50 grams of beryllium. All void space inside and outside the SGQ-SC2 in the 6CV was modeled as water, representing water intrusion.

To model the effect of water intrusion and mixing with the fissile material, a series of calculations was performed by varying the concentration of fissile material in an aqueous mixture. The solution and water were modeled as the only materials present in the 6CV. The 6CV was filled with solution to a solution height corresponding to the fissile mass and concentration selected. Water was modeled above the solution inside the 6CV. The SGQ Shielded Containers were not modeled for solution cases since their presence would limit the amount of water available to mix with the fissile material.

The foam, Vermiculite, Fiberfrax®, and Min K® 2000 were replaced with water. The package was surrounded by 30 cm of water on all sides.

6.3.1.3 NCT Model

The NCT array models in the NCSE are infinite in the x, y, and z direction. In an infinite model, there is no neutron leakage from the system and drum spacing is irrelevant. A single 9977 package was modeled inside a tight fitting cuboid and mirror boundary conditions were defined for the four x-axis and y-axis faces. Periodic boundary conditions were defined for the z-axis faces of the cuboid. These boundary conditions reflected all incident neutrons back into the system thus simulating an infinite square pitch array of packages.

The NCT conditions examined in this evaluation correspond to the most reactive conditions reported for the 6CV NCT analyses in Addendum Reference A.6.1. The fissile material spheres were closely wrapped by 100 g of polyethylene or 50 grams of beryllium, or inside a SGQ-SC2 polyethylene container. Because the drum does not have a gasket, there is a possibility for water to enter the drum and fill the liner (outside the CV). Each NCT case was analyzed with water present in the void spaces inside the drums. Even though the 6CV is designed to prevent water intrusion, cases were run with the 6CV dry or flooded to determine the effect of water in the 6CV. An additional set of cases was run with the foam, Vermiculite, Fiberfrax®, and Min-K® 2000 replaced with water. Water was not modeled outside the drum as Addendum Reference A.6.1 had shown that the presence of water between drums reduces the calculated k_{eff} values.

6.3.1.4 HAC Model

The basic HAC model is described in this section. The variations of the basic model are discussed in Addendum Section 6.6.

For the HAC array model (taken from Addendum Reference A.6.1), the drum radius was uniformly decreased corresponding to drop and crush test damage in the amount specified in Addendum Figure A.6.2, and then the radial component was further reduced by 7% [Ref A.6.5] to simulate a triangular pitch array. The values listed in Addendum Table A.6.6 are bounding of the maximum dents and bulges observed in localized areas on the packages following the completion of all accident testing. The HAC models in this NCSE uniformly reduced the radial and axial dimensions based on these maximum damage values. Therefore, the uniform dimension reductions modeled are very conservative, representing a closer spacing than actually possible with the observed drum damage.

A triangular pitch array model places fissile material units (drums) as close as possible, maximizing the areal density of fissile units, and thereby increasing the reactivity effect due to interaction. It was shown in Reference A.6.5 that if the drum radius in the rectangular array is reduced by 7%, it is equivalent to a triangular pitch drum array in terms of resulting k_{eff} values. In order to preserve the drum wall mass, the drum wall thickness was adjusted (see Addendum Table A.6.5).

Conservative assumptions regarding the radial and axial reduction of drum dimensions due to drop impact and the amount of insulation charred due to fire were used in the damaged array model as shown in Addendum Table A.6.6. (see Addendum Figure A.6.2). Charred insulation is assumed to be completely vaporized. Additional reduction factors were added to the burn and drop test data for conservatism. The effect of the amount of insulation was also studied in Addendum Reference A.6.1. Addendum Figure A.6.2 is a sketch of the 9977 package that indicates the dimensions reduced for HAC analysis and contains more detail (e.g., rolling hoops) than present in the model.

The HAC model used a nearly cubic 6 × 6 × 3 array of damaged 9977 containers, reflected by 30 cm of water along all sides of the array. Additional cases modeled an infinite square pitched array of 9977 packages with and without water in the 6 CV. The damaged 9977 container was dry. Addendum Reference A.6.1 demonstrated that the “2-cluster” configuration of the HAC model was the most reactive. Therefore, the “2-cluster” configuration was used for all HAC calculations for this evaluation.

Table A.6.6 - Fire and Drop Test Data for the 9977 HAC Model

Dimension	Insulation Burn Test Data	HAC Model	Drop Test Data (inch)	HAC Model (inch)
Radial	All foam	All foam and Fiberfrax® replaced with void or water	0.5	1.0
Axial (top/bottom)	All Vermiculite	All Vermiculite, Fiberfrax® and Min-K® 2000 replaced with void or water	1 ⅛ (total)	2.0/1.0
Reference	Addendum Reference A.6.6		Addendum Reference A.6.7	

A conservative HAC model is constructed by assuming maximum movement of the 6CV within the 9977 package and of the fissile material container within the 6CV. This modeled movement results in the fissile mass adjacent to the side of the 6CV and as close as possible to the outside of the package. As with the Single Package models, metal content was modeled as a sphere. The fissile material spheres were closely wrapped by 100 g of polyethylene or 50 g of beryllium. The two-cluster configuration is discussed further in Addendum Section 6.6.

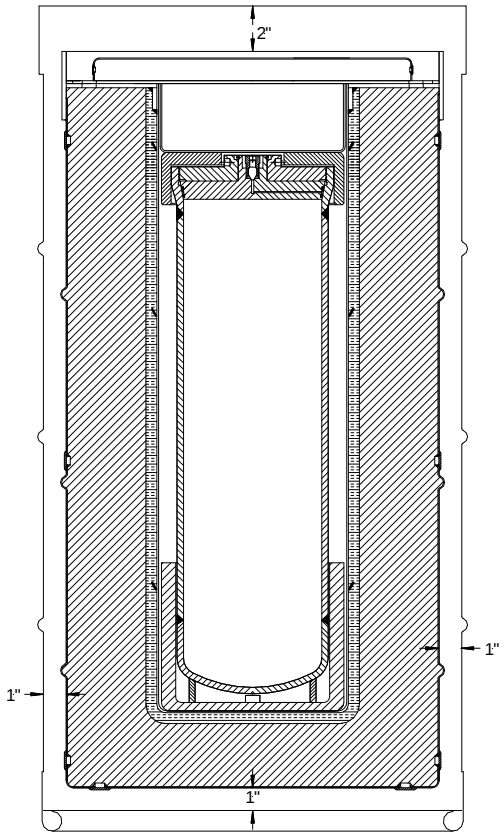

Figure A.6.2 - Outer Dimension Reductions for HAC Analyses

6.3.2 Material Properties

The 6CV and the drum are made of 304L stainless steel. The liner, lid plate, and top and bottom lid liner shells are also made of 304L stainless steel. Addendum Reference A.6.9 provides material specifications for most 9977 components modeled in this NCSE.

There are four types of insulating materials used in the 9977. The polyurethane foam used in the drum is General Plastics Last-A-Foam® FR-3716. Polyurethane foam has a nominal density of 16 lb/ft^3 (0.2563 g/cc) in Addendum Reference A.6.8. Fiberfrax® insulation surrounds the liner in the drum and is also placed on the bottom of the bottom lid liner. It consists of Fiberfrax® HSA, Grade E, is 1 inch thick and has a nominal density of 16 lb/ft^3 (0.2563 g/cc). The Fiberfrax® insulation is sheathed with Fiberglass, Grade E on both sides. Vermiculite insulation in the bottom lid liner is a type of thermal ceramic, TR-19®, and is made of Vermiculite granules and high temperature bonding material with a nominal density of 23 lb/ft^3 (0.3684 g/cc). This material exhibits minimal shrinkage at high temperature and will not decompose even when exposed directly to flame. The top lid liner contains a thermal ceramics material called Min-K® 2000. It is made of silica and glass wool products and the nominal density is 20 lb/ft^3 (0.3204 g/cc).

The top and bottom load distribution fixtures (LDFs) are of aluminum with a density of 2.7 g/cc.

The 9977 shipping package material data are shown in Addendum Tables A.6.7 through A.6.11. Addendum Table A.6.7 also lists other materials (e.g., water) and densities used in the Addendum Sections 6.4, 6.5 and 6.6 analysis in addition to the 9977 package construction materials.

Table A.6.7 - Material Specifications for the 9977 Package

Components	Material	Density (g/cc) (as-modeled)	Addendum Reference
Water	H_2O	0.9982 at 20°C 0.99998 at 4°C (used 1.0 g/cc)	A.6.9 and A.6.10
CV & Liner	304L-Stainless Steel (used SS 304)	7.94	A.6.10
Aluminum Top and Bottom Support Plates	Aluminum	2.7	A.6.10
Polyethylene	C_2H_4	0.92 (used 0.95 g/cc)	A.6.10
Foam Insulation See Table A.6.8	General Plastics Last-A-Foam®, FR-3716	16 lb/ft^3 (0.2563 g/cc)	A.6.9
Fiberfrax® Insulation See Table A.6.9	Fiberfrax® HSA, Grade E	16 lb/ft^3 (0.2563 g/cc)	A.6.9
Vermiculite Insulation See Table A.6.10	Thermal Ceramics, TR-19®	23 lb/ft^3 (0.3684 g/cc)	A.6.9
Min-K® 2000 Insulation See Table A.6.11	Thermal Ceramics	20 lb/ft^3 (0.3204 g/cc)	A.6.9

Table A.6.8 - Last-A-Foam® Composition

Element	Wt %, Sample A	Wt %, Sample B	Wt %, Normalized for KENO input
Cl	0.10	0.20	0.15
Si	*	*	0.82
P	*	*	0.82
O	22.42	22.78	22.60
C	62.85	62.90	62.88
H	6.84	6.84	6.84
N	5.90	5.88	5.89
Total	98.11	98.60	100.00
* Si and P are known to be present, but were not measured. Their contributions are assumed to be equal and are specified to result in normalized total of 100%.			

Table A.6.9 - Fiberfrax® Composition

Compound	Wt %	Wt %, (average) For KENO
Al_2O_3	46-54	50
SiO_2	46-54	49.5
Na_2O	0.5	0.5
Total		100
Element		**Calculated**
Al		26.46
Si		23.14
Na		0.37
O		50.03
Total		100

Table A.6.10 - Vermiculite (TR-19) Composition

Compound	Wt % after fire	Wt % before fire (normalized)	Element	Wt% For KENO
SiO_2	40.0	45.403	Si	21.22
Al_2O_3	9.1	10.3292	Al	5.47
CaO	15.0	17.0261	Ca	12.17
Fe_2O_3	6.8	7.7185	Fe	5.40
TiO_2	1.2	1.36209	Ti	0.82
MgO	13.0	14.756	Mg	8.90
Na_2O	1.3	1.4756	Na	1.09
K_2O	1.3	1.4756	K	1.22
SO_3	0.4	0.45403	S	0.18
Total	88.1	100.000	O	43.53
			Total	100.

Table A.6.11 - Min-K® 2000 Composition

Compound Name	Compound	Minimum Wt%	Maximum Wt%	Average Wt%	Normalized Wt%
Amorphous Silica	SiO_2	35	95	65	48.01
Fibrous Silica	SiO_2	5	30	17.5	12.92
Micronized Silicon	Si	0	25	12.5	9.23
Titanium Dioxide	TiO_2	0	25	12.5	9.23
Hydrated Alumina	$Al(OH)_3$	0	50	25	18.46
Decabromodiphenyl Oxide	$C_{12}Br_{10}O$	0	5	2.5	1.85
Antimony Trioxide	Sb_2O_3	0	0.3	0.15	0.11
Phenol Formaldehyde Resin	$C_7H_8O_2$	0	0.5	0.25	0.18
Total				135.4	100.

Used in Models	
Element	Calculated wt%
Si	37.71
Ti	5.53
Al	6.39
C	1.28
H	0.84
O	48.01
Sb	0.09
Br	0.15
Total	100.

6.3.3 Computer Codes and Cross-Section Libraries

The CSAS26 driver of the SCALE 5 Computer Code System was used. It calls the BONAMI and CENTRM modules for the generation of a problem-dependent cross-section library (accounting for resonance self-shielding) and then calls the KENO-VI module to perform Monte Carlo k_{eff} calculations. SCALE 5 is an industry recognized computational tool for criticality analysis.

Criticality calculations were made using the 238-group ENDF/B-V cross section set. All calculations employed a P3 Legendre expansion. Calculations were performed using numbers of generations and neutrons per generation to achieve a calculated statistical uncertainty (σ) less than 0.002. In all cases, convergence on k_{eff} is checked by viewing the graph of average k_{eff} by generation and by checking the k_{eff} histogram to verify that a normal distribution has been produced. KENO-VI provides plots showing the geometry of the system and the distribution of materials. In all cases, these plots are examined to ensure the model is performing as intended. Validation of KENO-VI for transport package criticality calculations is discussed in Addendum Section 6.8.

The calculated value of k_{eff} must be less than the value of k_{safe}, where k_{safe} includes a subcritical margin, the system bias, and uncertainties in that bias. The reported values of k_{eff} are the calculated values plus 2 standard deviations. SCALE 5 has been certified on the SRNS Criticality Safety Advanced Computing Center (CSACC) in accordance with approved quality assurance procedures.

6.3.4 Demonstration of Maximum Reactivity

The contingencies that are considered for the 9977 shipping package criticality analysis are specified in 10 CFR 71. Specifically, the objective of this evaluation is to demonstrate compliance with the performance requirements for each content envelope as specified in

- 10 CFR 71.55 – General requirements for fissile material packages,
- 10 CFR 71.59 – Standards for arrays of fissile material packages.

The requirements of 10 CFR 71 are thorough and ensure that the maximum value of k_{eff} is found in the analysis based on credible scenarios. The following specific scenarios are analyzed based on the 10 CFR 71 requirements:

Single Package (SP) – dry and flooded

Normal Conditions of Transport (NCT) array – dry and flooded

Hypothetical Accident Conditions (HAC) array – dry and flooded

The following conservative modeling choices are used in the criticality analysis for the 9977 shipping package:

- Water is assumed to leak into the 6CV as well as the overpack package container for the single package (SP) analysis. The foam, Fiberfrax®, Vermiculite, and MIN-K® 2000 were conservatively assumed to be lost and replaced by water corresponding to extreme HAC conditions for the SP analysis. This maximizes the reflection and moderation of packaging materials.
- Nominal dimensions of the 9977 components are used in this analysis, except for the HAC analysis.
- A conservative HAC model is used and includes the radial and axial reduction of drum dimensions due to drop and the amount of insulation charred due to fire, and extreme movement of the 6CV within the drum. The 9977 shipping package drop test data and the foam burn data taken from the test reports form the basis of the HAC dimensions.
- The effect of reflection by SGQ Shielded Containers is conservatively modeled in the Single Unit analyses using the polyethylene container (SGQ-SC2).
- The SGQ-SC2 Shielded Container (polyethylene) with an interior cavity 1.625-inch diameter by 5.5-inch high is modeled as filling the cylindrical portion of the 6CV. This cavity matches that specified for the SGQ-SC1 which is representative of the space needed for anticipated contents.

- A mass of about 100 grams of plastic material (polyethylene or equivalent) is conservatively assumed to be closely wrapped around the fissile metal units to account for the presence of nylon/plastic/PVC or equivalent hydrogenous materials used for contamination control. Polyethylene $(C_2H_4)_n$ with a density not exceeding 0.95 g/cc is used as the plastic material, as it has the highest hydrogen density among the common forms of plastic materials and has the highest reactivity effect.
- The light element and impurity mass listed in Addendum Table A.6.1 is conservatively assumed to be beryllium either closely wrapped around the fissile material or intimately mixed with it. Beryllium has the highest reactivity effect of any of the common light element impurities that may be included with the fissile material.
- The effect of water intrusion into the 6CV was analyzed by considering the solution of fissile material as an aqueous mixture based on a volume additive model. The use of a volume additive model is appropriate since the actinide metals present do not readily dissolve in water.

6.4 SINGLE PACKAGE ANALYSES

10 CFR 71.55 contains the following requirements for SP analyses:

> (b) Except as provided in paragraph (c) or (g) of this section, a package used for the shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water were to leak into the containment system, or liquid contents were to leak out of the containment system so that, under the following conditions, maximum reactivity of the fissile material would be attained:
>
> (1) The most reactive credible configuration consistent with the chemical and physical form of the material;
>
> (2) Moderation by water to the most reactive credible extent; and
>
> (3) Close full reflection of the containment system by water on all sides, or such greater reflection of the containment system as may additionally be provided by the surrounding material of the packaging.

The SP analysis consists of two sets of moderation conditions, one for dry material and one for solution. The dry analysis models fissile metal nominally as a sphere within its container within the 6CV. The fissile material was modeled as a cylinder when the spherical radius corresponding to the specified mass exceeded the inner radius of the aluminum sleeve. The solution cases model a fissile solution in the 6CV at various concentrations to account for the dispersion of fissile material due to water in the 6CV. All SP cases were reflected on all six sides by 30 cm of water per the requirements of 10 CFR Part §71.55 (e).

6.4.1 Intact Fissile Units

The fissile contents are plutonium metal or uranium metal. The fissile material was modeled in the form of a sphere inside the 6CV or inside an SGQ-SC2 polyethylene container. The polyethylene container is modeled as essentially filling the cylindrical portion of the 6CV and has a cavity with a 1.625-inch ID and a 5.5-inch height with the bottom thickness equal to the side thickness. Five cases were considered:

- a bare fissile metal sphere inside a SGQ-SC2 polyethylene container,
- a bare fissile metal sphere in a 6CV,
- a fissile metal sphere closely surrounded by 100 g of polyethylene in a 6CV,
- a fissile metal sphere closely surrounded by 50 g of Be inside a SGQ-SC2 polyethylene container,
- a fissile metal sphere intimately mixed with 50 g of Be inside a SGQ-SC2 polyethylene container.

- In all cases, the 6CV and the interior of the SGQ-SC2 container were flooded with water.

Addendum Figure A.6.3 depicts the SP model with a single fissile metal sphere surrounded by 50 grams of beryllium inside the SGQ-SC2[3].

The results are summarized in Addendum Table A.6.12. Examination of the results in Addendum Table A.6.12 indicates that 100 g of plutonium or uranium remain subcritical if the material remains as a metal.

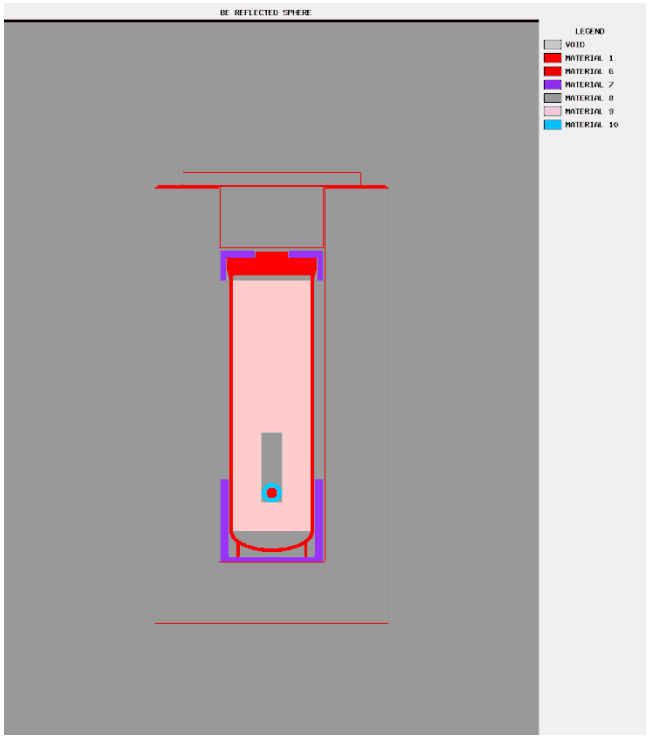

Figure A.6.3 - SP Model with Beryllium Reflected Metal Sphere in SGQ-SC2 Container

[3] The SGQ-SC2 Shielded Container was conservatively modeled as filling the CV with the fissile material centered in the container.

Table A.6.12 - Single Package Analysis for Intact Fissile Units

Input File Name	k_{eff}	σ	$k_{eff} + 2\sigma$
Bare Fissile Material Sphere in SGC-SC2 Container			
pu239sph.in	0.2859	0.0008	0.2874
pu241sph.in	0.2729	0.0009	0.2747
u233sph.in	0.2742	0.0008	0.2758
u235sph.in	0.1955	0.0006	0.1967
Bare Fissile Material Sphere in 6CV			
pu239_nopig.in	0.2743	0.0008	0.2759
pu241_nopig.in	0.2633	0.0008	0.2649
u233_nopig.in	0.2632	0.0008	0.2647
u235_nopig.in	0.1838	0.0006	0.1849
Polyethylene Wrapped Fissile Material Sphere in 6CV			
pu239_polynopig.in	0.2824	0.0009	0.2842
pu241_polynopig.in	0.2723	0.0008	0.2739
u233_polynopig.in	0.2722	0.0010	0.2741
u235_polynopig.in	0.1919	0.0006	0.1931
Beryllium Reflected Fissile Material Sphere in SGC-SC2 Container			
pu239be.in	0.2960	0.0010	0.2980
pu241be.in	0.2834	0.0008	0.2851
u233be.in	0.2835	0.0009	0.2852
u235be.in	0.2001	0.0006	0.2014
Beryllium Mixed With Fissile Material Sphere in SGC-SC2 Container			
pu239mxdbe.in	0.1992	0.0007	0.2005
pu241mxdbe.in	0.2208	0.0009	0.2227
u233mxdbe.in	0.2229	0.0008	0.2245
u235mxdbe.in	0.1788	0.0007	0.1803

6.4.2 Solution

Addendum Figure A.6.4 shows the single package model with the fissile material mixed with intruding water forming a fissile solution. As the modeled solution height increases, the fissile concentration in the solution decreases. Solutions modeled in the 6CV include 100 grams of ^{239}Pu, ^{241}Pu, ^{233}U, or ^{235}U. Addendum Tables A.6.13 and A.6.14 summarize the results of the calculations.

An additional case with 110 grams of ^{239}Pu or ^{241}Pu was analyzed to model the effect of 1000 ppm of special actinides included with the plutonium.[4] The results are reported in Addendum Table A.6.15.

The tables indicate the nominal fissile mass considered, the fissile concentration, and the solution height in the 6CV.

Examination of the results in Addendum Tables A.6.13, A.6.14, and A.6.15 indicate that 100 g of plutonium or uranium in a 6CV remain subcritical even if the material were dissolved in water.

[4] 1000 ppm of special actinides in 100 grams of plutonium would be 0.1 grams. If all of this were ^{251}Cf (the most reactive) that would correspond to 9 grams of ^{239}Pu (0.1 grams*450 g [subcritical limit of ^{239}Pu]/5 g [subcritical limit of ^{251}Cf].

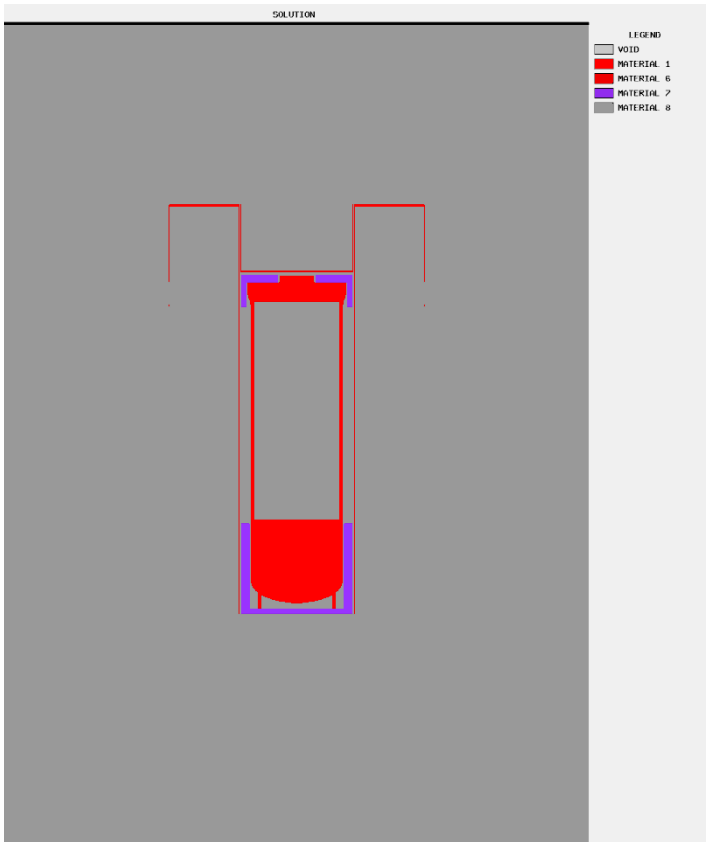

Figure A.6.4 - SP Model with Fissile Solution in 6CV

Table A.6.13 - Single Package – Solution – 100 g Plutonium

Input File Name	Plutonium Concentration (g/cc)	Height in 6CV (cm)	k_{eff}	σ	$k_{eff} + 2\sigma$
^{239}Pu					
pu239sol.12.in	0.0150	37.6398	0.5086	0.00110	0.5108
pu239sol.13.in	0.0200	28.6989	0.5465	0.00100	0.5485
pu239sol.14.in	0.0300	19.7580	0.5627	0.00130	0.5653
pu239sol.15.in	0.0400	15.2876	0.5516	0.00110	0.5538
pu239sol.16.in	0.0500	12.6054	0.5301	0.00120	0.5325
pu239sol.17.in	0.0600	10.8172	0.5072	0.00120	0.5096
pu239sol.18.in	0.0800	8.5820	0.4677	0.00110	0.4699
pu239sol.19.in	0.1000	7.2408	0.4306	0.00120	0.4330
pu239sol.20.in	0.2000	4.5586	0.3392	0.00110	0.3414
^{241}Pu					
pu241sol.11.in	0.0102	54.2785	0.5313	0.00120	0.5337
pu241sol.12.in	0.0150	37.6398	0.6046	0.00120	0.6070
pu241sol.13.in	0.0200	28.6989	0.6424	0.00130	0.6450
pu241sol.14.in	0.0300	19.7580	0.6553	0.00140	0.6581
pu241sol.15.in	0.0400	15.2876	0.6420	0.00120	0.6444
pu241sol.16.in	0.0500	12.6054	0.6164	0.00140	0.6192
pu241sol.17.in	0.0600	10.8172	0.5902	0.00120	0.5926
pu241sol.18.in	0.0800	8.5820	0.5449	0.00150	0.5479
pu241sol.19.in	0.1000	7.2408	0.5056	0.00150	0.5086
pu241sol.20.in	0.2000	4.5586	0.4023	0.00120	0.4047
Note: Specified fissile mass at listed concentration in water occupies 6CV (full radius) to the indicated height					

Table A.6.14 - Single Package – Solution – 100 g Uranium

Input File	Plutonium Concentration (g/cc)	Height in 6CV (cm)	k_{eff}	σ	$k_{eff} + 2\sigma$
^{233}U					
u233sol.11.in	0.0102	54.2785	0.3225	0.00073	0.3239
u233sol.12.in	0.0150	37.6398	0.3970	0.00075	0.3985
u233sol.13.in	0.0200	28.6989	0.4420	0.00110	0.4442
u233sol.14.in	0.0300	19.7580	0.4864	0.00098	0.4883
u233sol.15.in	0.0400	15.2876	0.4935	0.00110	0.4957
u233sol.16.in	0.0500	12.6054	0.4873	0.00130	0.4899
u233sol.17.in	0.0600	10.8172	0.4768	0.00130	0.4794
u233sol.18.in	0.0800	8.5820	0.4506	0.00130	0.4532
u233sol.19.in	0.1000	7.2408	0.4231	0.00130	0.4257
u233sol.20.in	0.2000	4.5586	0.3479	0.00120	0.3503
^{235}U					
u235sol.11.in	0.0102	54.2785	0.3157	0.0007	0.3170
u235sol.12.in	0.0150	37.6398	0.3850	0.0008	0.3867
u235sol.13.in	0.0200	28.6989	0.4252	0.0010	0.4271
u235sol.14.in	0.0300	19.7580	0.4606	0.0010	0.4626
u235sol.15.in	0.0400	15.2876	0.4637	0.0010	0.4657
u235sol.16.in	0.0500	12.6054	0.4539	0.0011	0.4561
u235sol.17.in	0.0600	10.8172	0.4382	0.0011	0.4404
u235sol.18.in	0.0800	8.5820	0.4121	0.0012	0.4145
u235sol.19.in	0.1000	7.2408	0.3872	0.0011	0.3894
u235sol.20.in	0.2000	4.5586	0.3114	0.0010	0.3134
Note: Specified fissile mass at listed concentration in water occupies 6CV (full radius) to the indicated height					

Table A.6.15 - Single Package – Solution – 110 g Plutonium

Input File Name	Plutonium Concentration (g/cc)	Height in 6CV (cm)	k_{eff}	σ	$k_{eff} + 2\sigma$
^{239}Pu					
pu239hvy.11.in	0.0113	54.2783	0.4630	0.0009	0.4648
pu239hvy.12.in	0.0150	41.2161	0.5186	0.0010	0.5206
pu239hvy.13.in	0.0200	31.3812	0.5602	0.0011	0.5624
pu239hvy.14.in	0.0300	21.5462	0.5807	0.0012	0.5831
pu239hvy.15.in	0.0400	16.6287	0.5722	0.0014	0.5750
pu239hvy.16.in	0.0500	13.6783	0.5521	0.0014	0.5549
pu239hvy.17.in	0.0600	11.7113	0.5331	0.0012	0.5355
pu239hvy.18.in	0.0800	9.2525	0.4906	0.0011	0.4928
pu239hvy.19.in	0.1000	7.7773	0.4555	0.0012	0.4579
pu239hvy.20.in	0.2000	4.8268	0.3561	0.0013	0.3587
^{241}Pu					
pu241hvy.11.in	0.0113	54.2783	0.5587	0.0011	0.5609
pu241hvy.12.in	0.0150	41.2161	0.6151	0.0014	0.6179
pu241hvy.13.in	0.0200	31.3812	0.6562	0.0013	0.6588
pu241hvy.14.in	0.0300	21.5462	0.6766	0.0013	0.6792
pu241hvy.15.in	0.0400	16.6287	0.6656	0.0015	0.6686
pu241hvy.16.in	0.0500	13.6783	0.6408	0.0018	0.6444
pu241hvy.17.in	0.0600	11.7113	0.6169	0.0015	0.6199
pu241hvy.18.in	0.0800	9.2525	0.5706	0.0015	0.5736
pu241hvy.19.in	0.1000	7.7773	0.5313	0.0013	0.5339
pu241hvy.20.in	0.2000	4.8268	0.4240	0.0014	0.4268
Note: Specified fissile mass at listed concentration in water occupies 6CV (full radius) to the indicated height					

6.5 NORMAL CONDITIONS OF TRANSPORT ARRAY ANALYSES

10 CFR §71.55 contains the following requirements for NCT criticality safety analyses:

(d) A package used for the shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in § 71.71 ("Normal conditions of transport") --

(1) The contents would be subcritical;

(2) The geometric form of the package contents would not be substantially altered;

(3) There would be no leakage of water into the containment system unless, in the evaluation of undamaged packages under § 71.59(a)(1), it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material; and

(4) There will be no substantial reduction in the effectiveness of the packaging, including:

(i) No more than 5 percent reduction in the total effective volume of the packaging on which nuclear safety is assessed;

(ii) No more than 5 percent reduction in the effective spacing between the fissile contents and the outer surface of the packaging;

6.5.1 Configuration

In the NCT undamaged package array model, the package was modeled with the dimensions specified in Addendum Reference A.6.1. The fissile material was modeled as a bare sphere, a sphere surrounded by 100 g of polyethylene, or a sphere surrounded by 50 g of beryllium. An infinite square pitch array of stacked packages both dry and flooded with water in all regions including the liner and insulation regions was modeled. The infinite square pitch array was simulated by modeling a single package in a cuboid. This outer region was assigned mirror reflection boundaries in the x and y directions, and periodic boundary conditions in the z direction.

6.5.2 Results

Addendum Table A.6.16 shows the k_{eff} results. Addendum Table A.6.16 indicates that masses of 100 g of fissile isotopes other than the special actinide isotopes are acceptable. Therefore, the 10 CFR § 71.55(d) and § 71.59(a)(1) requirements related to NCT analyses are satisfied for these fissile masses.

The evaluations in Addendum Table A.6.16 demonstrate that k_{eff} for NCT arrays is lower than k_{eff} for Single Packages containing solutions (Addendum Section 6.4.2). This is confirmed by un-validated analysis results presented in the NCSE.

Table A.6.16 - NCT Array Configuration Results

Input File Name	k_{eff}	σ	$k_{eff} + 2\sigma$
Polyethylene Wrapped Sphere in 6CV[a]			
pu239_cvfl.in	0.2835	0.0008	0.2851
pu241_cvfl.in	0.2735	0.0009	0.2752
u233_cvfl.in	0.2733	0.0008	0.2749
u235_cvfl.in	0.1838	0.0006	0.1850
Beryllium Wrapped Sphere in SGQ-SC2[a]			
pu239nctbe.in	0.2942	0.0008	0.2968
pu241nctbe.in	0.2830	0.0008	0.2848
u233nctbe.in	0.2834	0.0009	0.2851
u235nctbe.in	0.2002	0.0006	0.2015
Bare Sphere in SGQ-SC2[a]			
pu239nctpig.in	0.2839	0.0008	0.2855
pu241nctpig.in	0.2750	0.0009	0.2767
u233nctpig.in	0.2742	0.0008	0.2759
u235nctpig.in	0.1946	0.0006	0.1958
Bare Sphere in 6CV no Water in Drum			
pu239_dry.in	0.2383	0.0008	0.2399
pu241_dry.in	0.2156	0.0007	0.2169
u233_dry.in	0.2123	0.0007	0.2136
u235_dry.in	0.1389	0.0005	0.1399
Bare Sphere in Dry 6CV Drum Flooded			
pu239_fdrm.in	0.2355	0.0008	0.2371
pu241_fdrm.in	0.2133	0.0007	0.2148
u233_fdrm.in	0.2125	0.0007	0.2138
u235_fdrm.in	0.1374	0.0004	0.1383
Bare Sphere in 6CV[a]			
pu239_nct.in	0.2740	0.0008	0.2756
pu241_nct.in	0.2629	0.0008	0.2645
u233_nct.in	0.2641	0.0008	0.2657
u235_nct.in	0.1846	0.0006	0.1858

a: Drum and 6CV flooded; Foam, Vermiculite, Fiberfrax®, and Min K® 2000 replaced with water

6.6 HYPOTHETICAL ACCIDENT CONDITIONS ANALYSES

10 CFR 71.55 contains the following requirements for HAC criticality safety analyses:

(e) A package used for the shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in § 71.73 (Hypothetical accident conditions), the package would be subcritical. For this determination, it must be assumed that:

(1) The fissile material is in the most reactive credible configuration consistent with the damaged condition of the package and the chemical and physical form of the contents;

(2) Water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents; and

(3) There is full reflection by water on all sides, as close as is consistent with the damaged condition of the package.

6.6.1 Configuration

The HAC models were also taken from Addendum Reference A.6.1 and satisfy these prescribed requirements of 10 CFR 71.55. The 2-cluster model from Reference A.6.2 was used as Addendum Reference A.6.1 demonstrated it was the most reactive configuration for HAC. This modeling selection is consistent with 10 CFR § 71.55(e)(1). The most reactive conditions from the Addendum Reference A.6.1 models were used. This most reactive configuration did not include interspersed moderation within the drum and the array.

The 6 × 6 × 3 square pitch array of 9977 packages was reflected by 30 cm of water in all six directions. This model has no water in the 6CV. This is based on test results that indicate no damage occurred to the 6CV as a result of the required test conditions. Additional cases modeled an infinite square pitched array of 9977 packages with and without water in the 6CV. All cases modeled the fissile material as a sphere surrounded by 100 g of polyethylene. The 9977 packages were modeled under the prescribed accident conditions (e.g., reduced package dimensions and absence of foam to represent damage, as discussed in Addendum Section 6.3.1).

Addendum Figure A.6.5 depicts a top view of the 2-cluster 6 × 6 × 3 square pitch array used in the HAC analysis and depicts a systematic shift in the interior contents where the distance between the fissile content in every pair of packages was minimized. The shift of contents in one direction allowed for mass and volume of the insulating material to be conserved because it was simply displaced in the opposite direction of the shift.

6.6.2 Results

Addendum Table A.6.17 summarizes the HAC results and shows that masses 100 g of fissile isotopes other than the special actinide isotopes are acceptable. Therefore, the 10 CFR § 71.55(e) and § 71.59(a)(2) requirements related to HAC analyses for those masses are satisfied.

The evaluations in Addendum Table A.6.17 demonstrate that k_{eff} for HAC arrays is lower than k_{eff} for Single Packages containing solutions (Addendum Section 6.4.2. This is confirmed by un-validated analysis results presented in the NCSE.

Therefore, the 10 CFR § 71.55(e) and § 71.59(a)(2) requirements related to HAC analyses for those masses are satisfied.

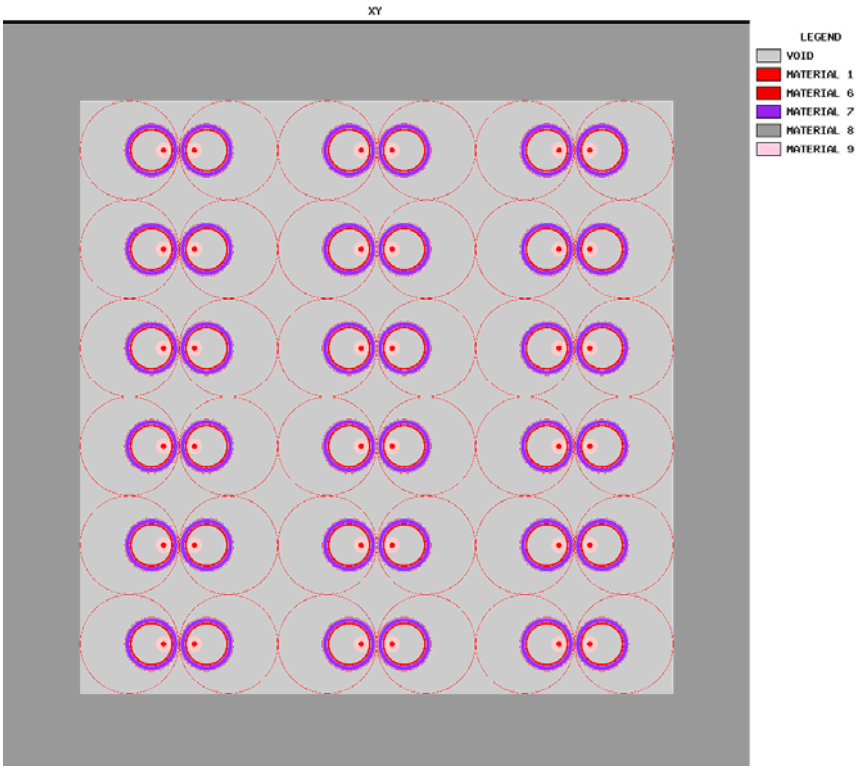

Figure A.6.5 – Two-Cluster HAC Model

Table A.6.17 - HAC Analysis Results

File Name	Isotope	Mass (g)	k_{eff}	σ	$k_{eff} + 2\sigma$
6 × 6 × 3 Array Dry					
pu239_2clus.in	pu-239	100	0.2610	0.0008	0.2625
pu241_2clus.in	pu-241	100	0.2460	0.0008	0.2476
u233_2clus.in	u-233	100	0.2447	0.0007	0.2461
u235_2clus.in	u-235	100	0.1400	0.0004	0.1409
Infinite Array Dry Polyethylene Wrapped Sphere					
pu239_2inf.in	pu-239	100	0.3534	0.0009	0.3552
pu241_2inf.in	pu-241	100	0.3652	0.0009	0.3670
u233_2inf.in	u-233	100	0.3691	0.0010	0.3711
u235_2inf.in	u-235	100	0.2101	0.0006	0.2112
Infinite Array Dry Beryllium Wrapped Sphere					
pu239_2infbe.in	pu-239	100	0.3201	0.0009	0.3218
pu241_2infbe.in	pu-241	100	0.3280	0.0008	0.3296
u233_2infbe.in	u-233	100	0.3273	0.0008	0.3289
u235_2infbe.in	u-235	100	0.2220	0.0006	0.2232
Infinite Array Flooded					
pu239_2fld.in	pu-239	100	0.2849	0.0008	0.2864
pu241_2fld.in	pu-241	100	0.2724	0.0008	0.2740
u233_2fld.in	u-233	100	0.2741	0.0008	0.2757
u235_2fld.in	u-235	100	0.1751	0.0006	0.1764

6.7 FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

This section is not applicable because the 9977 Shipping Package will not be used for Air Transport.

6.8 BENCHMARK EVALUATIONS

This section provides the validation of the CSAS26 criticality analysis sequence contained in Version 5 of the SCALE package. Validation is required by the criticality safety standard ANSI/ANS-8.1. The section describes the method, computer program and cross-section libraries used, experimental data, areas of applicability, and bias and uncertainty. A description of the benchmarks, and calculation of k_{safe}, is provided. [Ref A.6.11]

The criticality safety method is CSAS26 embedded in SCALE Version 5. CSAS26 includes the SCALE Material Information Processor, BONAMI, CENTRM, and KENO-VI. The Material Information Processor generates atom densities for standard compositions, prepares geometry data for resonance self-shielding, and creates data input files for the cross-section processing codes. The BONAMI and CENTRM codes are used to prepare a resonance-corrected cross-section library in AMPX working format. The KENO-VI code uses Monte Carlo techniques to calculate k_{eff}.

6.8.1 Code Validation and Bias for Pu and U Metal and Oxide Contents

SCALE 5 (KENO-VI) using the 238-group ENDF/B-V neutron cross-section library has been validated for Pu metal and oxide, Pu solution, highly enriched uranium (HEU) metal, HEU oxide, and HEU solution systems on the WSMS Linux system. [Ref A.6.11] The values reported for the biased k_{eff}, k_B, in Addendum Table A.6.18 were taken from their respective reference document. [Ref A.6.11] No critical experiments similar to the 9977 shipping package systems with Pu/U metal are available. Therefore, a wide range of validation experiments was chosen for this study. Addendum Table A.6.18 shows the biased k_{eff} and k_{safe} values for different systems. The NUREG document [Ref A.6.12] specifies a minimum required Minimum Subcritical Margin (MSM) of 0.05 for packaging applications. Based on the fact that a large MSM has been used for the 9977 analysis using common fissile material (i.e., ^{239}Pu and ^{235}U) and drum components, no additional margin due to 'areas of applicability' is necessary.

The results of the validation report [Ref A.6.11] were evaluated to determine the k_{safe} value applicable to this analysis. It is seen from Addendum Table A.6.18 that the lowest k_{safe} value derived from the validations is 0.931. Therefore, a k_{safe} value of 0.931 is used in this evaluation.

Table A.6.18 - Validation Values, SCALE 5 (KENO-VI), 238-group ENDF/B-V

System	Biased k_{eff} Value k_B	Minimum Subcritical Margin (MSM) $- \sigma_M$	$= k_{safe}$
Plutonium Metal	0.981	0.05	0.931
Highly Enriched Uranium (HEU) Metal	0.983	0.05	0.933
Uranium 233 Metal	0.990	0.05	0.940
Plutonium Solution	0.997	0.05	0.947
HEU Solution	0.990	0.05	0.940
Uranium 233 Solution	0.985	0.05	0.935

ADDENDUM CHAPTER 6 REFERENCES

A.6.1 Kerr, B. R., *Nuclear Criticality Safety Evaluation: 9977 Shipping Package Analysis for SARP*, N-NCS-A-00014, Revision 0 (March 2006)

A.6.2 ANSI/ANS-8.15-1981 (R 2007), *Nuclear Criticality Control of Special Actinide Elements*, American Nuclear Society

A.6.3 ANSI/ANS-8.1-1998 (R 2007), *Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*, American Nuclear Society

A.6.4 R-R3-G-00042, Revision 2, *9977 – Six Inch Containment Vessel Subassembly (U)* (May 2007).

A.6.5 NUREG/CR-5661, ORNL/TM-11936, *Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages* (April 1997)

A.6.6 Malloy, J., *SRNL Package Burn Test Report*, NT-TDR-06-101, Revision 0, NovaTech Innovative Technologies International, Lynchburg, VA (February 2006).

A.6.7 Gelder, L. F., May, C.M., *9977 General Purpose Fissile Packaging Prototype Testing*, M-TRT-A-00007, Revision 0 (February 2006)

A.6.8 Abramczyk, G. A., *RE: Material Properties for Components of the 9977*, SRNL-IES-2006-00007 (February 10, 2006)

A.6.9 Petrie, L. M., Fox, P. B., and Lucius, K., *Standard Composition Library*, NUREG/CR-0200, Revision 6, SCALE Computer System, Volume 3, Section M8, Oak Ridge National Laboratory, Oak Ridge, TN (September 1998)

A.6.10 *CRC Handbook of Chemistry & Physics 77th Edition*, CRC Press, Boca Raton, FL (1996).

A.6.11 Abney, L. M., et. al., *SCALE 5.0 Validation for SRNS Personal Computers (U)*, SRNS-RP-2008-00153, Revision 0 (January 2009)

A.6.12 NUREG/CR-0095, ORNL/NUREG/CSD-6, *Nuclear Safety Guide* TID-7016 Revision 2 (May 1978)

ADDENDUM CHAPTER 6 APPENDIX

Appendix	Description
A.6.1	*Nuclear Criticality Safety Evaluation 9977 Shipping Package Analysis for Small Gram Quantity SARP Addendum*, N-NCS-A-00021, Revision 0 Note: Input and output files associated with this chapter are listed in Addendum Appendix A.6.1 and are available on CD.

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Chapter 7 -- Package Operations

The addition of SGQ Content envelopes to the 9977 SARP Revision 2 will affect the operating procedures of the package slightly because of the likely need to use of one of the SGQ Shielded Containers for high dose-rate materials.

Payload: Everything that is contained within the 6CV (e.g., radioactive material, containers, associated handling conveniences, the Sleeve and Plug component, SGQ-EC1, SGQ-SC1, SGQ-SC2, or SGQ-SC3 Shielded Container, materials used for contamination control, dunnage or packing components that secure the radioactive material within the 6CV).

7.1.1.1 Packaging Preparation

28. Verify that the correct spacer materials for the payload (Addendum Section 1.2.2) are available for use.

7.1.1.2 **CONTENTS/PAYLOAD PREPARATION**

1. Verify that the radioactive contents and the total decay heat load are both in compliance with the CoC.

2. Prior to placement of SGQ material inside a Shielded Container or 6CV, verify that the radioactive material product container(s) do not show signs of degradation (e.g., pitting, cracking, bulging, buckling, or corrosion).

3. Determine if a Shielded Container is required for the content to meet radiation dose-rate requirements.

   NOTE-1: For SGQ Contents Type 2 or 3, the Shipper shall evaluate the contents per the *Methodology for Determining Dose Rate* (MDDR) calculation to determine if the Content will meet the dose rate limits an approved Content Configuration. If the MDDR results are not favorable, the dose rate of their proposed content at the surface and at 1-meter from the surface of the Content Container (including the SGQ Shielded Containers) shall be measured. Measurements dose-rates shall not exceed administrative limits of 170 mrem/hr at any surface of the content container (contact) or 8.5 mrem/hr at 1-meter from any surface of the content container. The dose rate measurements of the loaded SGQ Shielded Container will confirm the acceptability of the content configuration.

   NOTE-2: For SGQ Contents Type 4, the dose rate at any location shall be established by taking gamma measurements using at least two independent meter/gamma probe combinations and by taking neutron measurements using a meter with an NRD probe. The dose rate shall be the sum of the highest gamma reading and the neutron reading. The measurements shall be taken by qualified Technicians using calibrated and certified equipment.

   NOTE-3: SGQ Type 4 in the SGQ-EC1 configuration may consist of more than one item (each sealed in a separate capsule or Convenience Container) provided the administrative dose-rate limits of 180 mRem/hr (on contact) and 9 mRem/hr (at 1-meter) are met. These limits apply to the dose rates of each individual item and to the sum of the dose rates for the combined items.

4. If an Engineered Container Type 1 is to be used, inspect the Container Body, Bottom, Nut, Plug, and threads for signs of degradation which would reduce confinement functionality and inspect welds for signs of cracking. Replace or repair the Engineered Container if such damage is found.

5. If a Shielded Container Type 1 or Type 2 is to be used, verify that the content decay heat rate is acceptable for the Shielded Container used.

6. If a Shielded Container Type 1 is to be used, inspect the Cup for signs of material degradation and replace if found.

7. If a Shielded Container Type 1 or Type 3 is to be used, inspect the Container Body, Bottom, Nut, Plug, and threads for signs of degradation which would reduce confinement functionality and inspect the welds for signs of cracking. Replace or repair the Shielded Container if such damage is found.

8. If a Shielded Container Type 2 is to be used, inspect the Body, Plug, and Pin for signs of degradation which would reduce confinement functionality and replace or repair if found.

9. For SGQ Content Type 5, place the AGR-1 Compact into a Pipe Container, place the pipe Container into a Shielded Container Type 3, and torque the Container Plug to 50 ft-lb (± 5 ft-lb).

10. For SGQ Content Type 4 with no additional shielding required, an Engineering Container Type 1 is to be used and the following shall be performed:

    a) Measure (see Note-2) and record the maximum contact radiation dose rates (gamma and neutron) at all surfaces (top, sides, and bottom) of each item (capsules/Convenience Container).

    b) Sum the maximum contact radiation dose rates from each of the capsules/Convenience Containers comprising the Content (the maximum rates may be from different surfaces)

    c) The sum of the contact dose rates from the capsules/Convenience Containers comprising the Content shall be less than 180 mrem/hr (1.8 mSv/hr).

    d) Measure (see Note-2) and record the radiation dose rate (gamma and neutron) at 1-meter from all surfaces (top, sides, and bottom) of each content item (capsules/Convenience Container).

    e) Sum the maximum 1-meter radiation dose rates from each the capsules/Convenience Containers comprising the Content (the maximum rates may be from different surfaces)

    f) The sum of the 1-meter dose rates from the capsules/Convenience Containers comprising the Content shall be less than 9 mrem/hr.

    g) Place the Content and appropriate packing materials into an Engineered Container Type 1 and torque the Container Plug to 50 ft-lb (± 5 ft-lb).

    h) Measure the radiation dose rate at the surface (top, sides, and bottom) of the Engineered Container Type 1. The maximum dose shall be less than 180 mrem/hr (1.8 mSv/hr).

    i) Measure the radiation dose rate 1-meter from the surface (top, sides, and bottom) of the Engineered Container Type 1. The maximum dose shall be less than 9 mrem/hr.

11. If additional gamma shielding is required, place contents in a Shielded Container Type 1 or Type 3, as appropriate, and torque the Shielded Container Plug to 50 ft-lb (± 5 ft-lb).

12. If additional neutron shielding is required, place contents in a Shielded Container Type 2 (using the Sleeve if needed to maintain central spacing) and close by capturing the Plug with the Pin.

    NOTE-4: Surface dose rate measurements are not required of the Shielded Container Type 3 housing SGQ Type 5.

13. For SGQ Content Type 2 or Type 3, the Shipper must verify dose-rate acceptability:

    a) The shipper shall evaluate the proposed contents per *Methodology for Determining Dose Rate* (MDDR) calculations to determine dose rates in an approved Content Configuration.

    b) If the MDDR results are not favorable, the Shipper shall verify (see Note-1) that the dose rates of the proposed content at the surface and at 1-meter from the surface of the Content Container

(including the SGQ Shielded Containers if additional shielding is required). The dose rates shall not exceed 170 mrem/hr at any surface of the content container (contact) or 8.5 mrem/hr at 1-meter from any surface of the content container.

14. For SGQ Content Type 4, verify (see NOTE-2) that the surface radiation dose rate for the Shielded Container Types 1, 2, or 3, is less than 180 mrem/hr and the radiation dose rate 1-meter from the surface of the Shielded Container is less than 9 mrem/h.

15. Assemble the contents into a payload configuration as described in Addendum Section 1.2.2.

7.1.2 Loading of Contents

The operating procedures for loading the radioactive material into the 6CV and for closing the 6CV shall include, as a minimum, the operational elements listed below. Integration of these procedural elements with facility-specific requirements shall be completed in a manner specified by ALARA principles.

1. Verify that the weight of the payload (i.e., everything to be placed into the 6CV) shall not exceed 100 lb. Place the payload within the 6CV using payload lifting equipment, as required. The configurations for the contents are described in Addendum Section 1.2.2 and are illustrated in Addendum Section 1.2.2.1.

7.3 PREPARATION OF EMPTY PACKAGE FOR TRANSPORT

An empty packaging shall be shipped per 49 CFR 173.428,[10] *Empty Class 7 (Radioactive) Materials Packaging*. A non-empty packaging is packaging that is internally contaminated as specified in 49 CFR 173.421,[11] *Limited Quantities of Radioactive Materials*, and shall be prepared for transport as specified in 49 CFR 173.421. The level of non-fixed contamination on the external surfaces of the packaging must be kept As Low As Reasonably Achievable and may not exceed the limits set forth in 49 CFR 173.443 *Contamination Control*[12] or 10 CFR 835, Appendix D, Occupational Radiation Protection,[Ref A.7.1] as applicable.

7.3.2 SHIPPING A NON-EMPTY PACKAGE

1. The packaging shall be prepared for shipment per Section 7.1.1.1, *Packaging Preparation* and Section 7.1.2, Loading of Contents, Steps 2 through 6.

2. The packaging shall be closed per Section 7.1.3, *Preparation for Transport*.

ADDENDUM CHAPTER 7 REFERENCES

A.7.1 *Occupational Radiation Protection*, Code of Federal Regulations, Title 10, Part 835, Washington, DC (November 2006).

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CHAPTER 8 -- ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

The addition of the SGQ Content envelopes to the 9977 SARP Revision 2 will not affect packaging acceptance testing and its maintenance program.

The SGQ Shielded Containers perform a function integral to the Package Safety performance and to its compliance with the Code of Federal Regulations. As such, dimensional inspections of the Shielded Containers require Quality ("Q") as listed in Appendix A.8.2 and documented per SARP Table 9.7 with the documentation issued to the Design Authority for retention.

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CHAPTER 9 -- QUALITY ASSURANCE

The addition of SGQ Content envelopes does not affect the quality assurance of the package design. However, as the SGQ-SC1, SGQ–SC2 and SGQ–SC3 components are credited with maintaining package dose-rates within the 10 CFR 71 Non-Exclusive Use limits, quality assurance requirements are imposed on the SGQ-SC1, SGQ-SC2, and SGQ-SC3 Containers as noted in Addendum Table A.9.1. Therefore, the quality assurance program documented in the 9977 SARP Revision 2 is valid for the SGQ Content envelopes.

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Table A.9.1 - Safety Assessment of Packaging Features

Feature	Q Category	Function	Component Name	Drawing Number	Part Number	Item Number
Containment Vessel	A	Provides containment	Stayed Head Pipe Cap Pipe (6” dia.)	R-R2-G-00042 R-R2-G-00042 R-R2-G-00042	-E -F -G	4 5 6
	C	Provides base for CV	Pipe Skirt (5” dia.)	R-R2-G-00042	-H	7
Cone-Seal Plug	A	Provides containment	Cone-Seal Plug	R-R2-G-00042	-C	2
Cone-Seal Nut	A	Provides containment	Cone-Seal Nut	R-R2-G-00042	-D	3
Cone-Seal Nut C-ring	C	Joins cone-seal Plug to cone-seal nut	Retaining Ring	R-R2-G-00042	Com. (1)	9
Leak-Test Port Plug	A	Provides containment	Plug	R-R2-G-00042	Com.	10
Leak-Test Port Gland Nut	A	Provides containment	Gland Nut	R-R2-G-00042	Com.	11
Outer O-ring	A	Provides containment	O-Ring	R-R2-G-00042	Com.	8
Inner O-ring (2)	A	Provides means for post-load leak rate test and redundancy for Inner O-ring	O-Ring	R-R2-G-00042	Com.	8
Load Distribution Fixtures	A	Provides additional load bearing surface against the drum liner for the CV	Bottom LDF Top LDF	R-R4-G-00032 R-R4-G-00032	-A -B	1 2
BeRP Ball Heat Sink Fixture	A	Maintains subcritical configuration	Heat Sink Fixture	128Y271403 128Y271369 128Y271370	- - -	3 - -
6CV Sleeve and Plug	A	Consumes volume within the 6CV to maintain subcriticality and provides distance for shielding.	Sleeve and Plug	R-R4-G-00053	-A	-
SGQ Shielded Container Type 1	A	Provides shielding for gamma source material.	Container Bottom Container Plug Container Nut Lead Plug Lead Body Container Body	R-R1-G-00037 R-R1-G-00037 R-R1-G-00037 R-R1-G-00037 R-R1-G-00037 R-R1-G-00037	-B -C -D -E -F -G	1 2 3 4 5 6
	B	Provides a corrosion barrier between Contents and the Lead Body	Cup	R-R1-G-00037	-H	7

Feature	Q Category	Function	Component Name	Drawing Number	Part Number	Item Number
SGQ Shielded Container Type 2	A	Provides shielding for neutron source material	Body	R-R1-G-00038	-B	1
			Sleeve	R-R1-G-00038	-C	2
			Plug	R-R1-G-00038	-D	3
			Pin	R-R1-G-00038	-E	4
SGQ Shielded Container Type 3	A	Provides shielding for gamma source material.	Container Bottom	R-R1-G-00039	-B	1
			Container Plug	R-R1-G-00039	-C	2
			Container Nut	R-R1-G-00039	-D	3
			Tungsten Plug	R-R1-G-00039	-E	4
			Tungsten Body	R-R1-G-00038	-F	5
			Container Body	R-R1-G-00039	-G	6
SGQ Engineered Container Type 1	B	Provides confinement.	Container Bottom	R-R1-G-00045	-B	1
			Container Plug	R-R1-G-00045	-C	2
			Container Nut	R-R1-G-00045	-D	3
			Container Body	R-R1-G-00045	-E	4
SGQ-SC1 Spacers	B	Provides load bearing surface for SGQ-SC1	Top Spacer	R-R4-G-00073	-A	-
			Bottom Spacer	R-R4-G-00073	-B	-
SGQ-SC3 Spacers	B	Provides load bearing surface for SGQ-SC3	Top Spacer	R-R4-G-00074	-A	-
			Bottom Spacer	R-R4-G-00074	-B	-
Drum Weldment	B	Protects insulation and package components	Drum Bottom	R-R2-G-00017	-B	1
			Drum Side	R-R2-G-00017	-C	2
			Drum Top Plate	R-R2-G-00017	-F	5
			Drum Liner Ring	R-R2-G-00017	-G	6
			Drum Rim	R-R2-G-00017	-H	7
			Threaded Fitting	R-R2-G-00017	-I	8
			Wear Ring	R-R2-G-00017	-K	10

(1) "Com." signifies a Commercial item purchased as specified on the drawing.
(2) The inner O-ring is not needed for containment, but it is classified Category A because it has the same specifications as the outer O-ring. This will simplify O-ring procurement and will prevent mixing up replacement inner and outer O-rings.

ADDENDUM APPENDIX A.1.1

DRAWING LIST

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DRAWING LIST

Drawing Number	Rev	Title
R-R5-G-00002	1	9977 - Drawing Tree (U)
R-R1-G-00020	2	9977 - Assembly with 6-inch Diameter Containment Vessel (U)
R-R2-G-00017	1	9977 - Drum and Liner Subassembly (U)
R-R2-G-00018	2	9977 - Drum Lid Subassembly (U)
R-R2-G-00019	1	9977 - Insulating Blanket Subassembly (U)
R-R2-G-00042	2	9977 - Six Inch Diameter Containment Vessel Subassembly (U)
R-R4-G-00032	1	9977 - Load Distribution Fixtures Details (U)
R-R4-G-00053	1	9977 - Sleeve and Plug Details (U)
R-R1-G-00037	1	9977 Small Gram Quantity - Shielded Container 1
R-R1-G-00038	1	9977 Small Gram Quantity - Shielded Container 2
R-R1-G-00039	1	9977 Small Gram Quantity - Shielded Container 3
R-R1-G-00045	0	9977 Small Gram Quantity - Engineered Container 1
R-R4-G-00073	1	9977 Small Gram Quantity - Shielded Container 1 Spacers
R-R4-G-00074	1	9977 Small Gram Quantity - Shielded Container 3 Spacers

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ADDENDUM APPENDIX A.1.2

SGQ CONTENT TYPE 5

(ADVANCED GAS REACTOR (AGR-1) COMPACTS)

RADIONUCLIDE LIST

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Table A.App.1.2.1 Isotopic Composition of Individual AGR-1 Fuel Specimen (Compact)

Radioactive Isotopes			Isotopes with No Radioactivity	
Isotope	Activity (Ci/compact)	Mass (g/compact)	Isotope	Mass (g/compact)
PR144	5.34E+00	7.06E-08	C 12	4.05E+00
CE144	5.34E+00	1.67E-03	SI 28	4.33E-01
NB 95	3.07E+00	7.84E-05	O 16	8.48E-02
ZR 95	1.53E+00	7.13E-05	SI 29	2.28E-02
RH106	1.24E+00	3.48E-10	SI 30	1.56E-02
RU106	1.24E+00	3.70E-04	XE136	1.12E-02
Y 91	1.03E+00	4.19E-05	XE134	6.84E-03
PM147	7.41E-01	7.99E-04	BA138	6.11E-03
CS134	6.76E-01	5.22E-04	LA139	5.82E-03
SR 89	5.60E-01	1.93E-05	CE140	5.72E-03
CS137	4.77E-01	5.48E-03	PR141	5.39E-03
BA137M	4.51E-01	8.38E-10	CS133	5.29E-03
Y 90	4.05E-01	7.44E-07	ND143	4.98E-03
SR 90	4.05E-01	2.97E-03	ND146	4.82E-03
RU103	3.01E-01	9.31E-06	XE132	4.65E-03
RH103M	2.71E-01	8.33E-09	MO100	4.24E-03
PU241	2.00E-01	1.94E-03	ZR 96	3.88E-03
CE141	1.98E-01	6.95E-06	MO 98	3.82E-03
PR144M	6.41E-02	3.53E-10	MO 97	3.76E-03
KR 85	5.03E-02	1.28E-04	ZR 94	3.74E-03
EU154	4.02E-02	1.49E-04	MO 95	3.61E-03
EU155	3.75E-02	8.07E-05	ZR 92	3.43E-03
PM148M	3.55E-02	1.66E-06	RU101	3.40E-03
SB125	3.47E-02	3.35E-05	RU102	3.21E-03
CM242	2.53E-02	7.66E-06	ZR 91	3.15E-03
TE127M	2.08E-02	2.21E-06	Y 89	2.51E-03
TE127	2.04E-02	7.72E-09	RH103	1.97E-03
NB 95M	1.14E-02	2.98E-08	XE131	1.94E-03
TE125M	8.26E-03	4.58E-07	SR 88	1.92E-03
AG110M	7.00E-03	1.47E-06	RU104	1.81E-03
TE129M	5.28E-03	1.75E-07	ND148	1.69E-03
SN123	5.17E-03	6.29E-07	ND145	1.66E-03
PU238	5.05E-03	2.95E-04	TE130	1.43E-03
TE129	3.44E-03	1.64E-10	SM150	1.22E-03
H 3	2.18E-03	2.26E-07	PD105	1.18E-03
PM148	2.00E-03	1.22E-08	KR 86	1.03E-03
CM244	1.70E-03	2.10E-05	ND150	7.07E-04
PU240	9.30E-04	4.08E-03	KR 84	6.03E-04
PR143	8.91E-04	1.32E-08	PD104	5.96E-04
SB124	8.05E-04	4.60E-08	RB 85	5.23E-04
LA140	5.89E-04	1.06E-09	PD106	4.85E-04
TB160	5.49E-04	4.87E-08	EU153	4.84E-04
BA140	5.12E-04	7.02E-09	TE128	3.96E-04
PU239	4.89E-04	7.86E-03	SM152	3.95E-04
SN119M	3.68E-04	8.21E-08	RU100	3.41E-04
SM151	3.54E-04	1.35E-05	PD108	3.40E-04
CD115M	2.62E-04	1.03E-08	BA134	1.99E-04
AM241	2.61E-04	7.59E-05	KR 83	1.97E-04
EU156	1.18E-04	2.13E-09	SE 82	1.69E-04
CD113M	1.00E-04	4.61E-07	AG109	1.66E-04
AG110	9.31E-05	2.23E-14	I127	1.66E-04
TC 99	6.30E-05	3.71E-03	BA137	1.64E-04
ND147	4.08E-05	5.08E-10	SM154	1.22E-04
NP239	2.28E-05	9.82E-11	MO 96	1.18E-04
AM243	2.28E-05	1.14E-04	BR 81	1.07E-04
CM243	1.76E-05	3.41E-07	PD110	1.07E-04
GD153	1.74E-05	4.93E-09	GD156	9.92E-05
RB 86	1.41E-05	1.73E-10	ZR 90	9.78E-05
CS136	1.36E-05	1.86E-10	CD110	7.08E-05
TE123M	9.91E-06	1.12E-09	SE 80	6.47E-05
ZR 93	9.24E-06	3.68E-03	CD111	5.75E-05
U237	4.94E-06	6.05E-11	BA136	5.04E-05
XE131M	4.52E-06	5.39E-11	ND142	4.26E-05
PU242	4.26E-06	1.11E-03	XE130	4.04E-05
BA136M	2.24E-06	8.33E-18	GD158	3.95E-05
SB126M	2.21E-06	2.81E-14	CD114	3.87E-05
SN126	2.21E-06	7.78E-05	CD112	3.16E-05
AM242M	2.11E-06	2.17E-07	SN124	2.98E-05

Radioactive Isotopes			Isotopes with No Radioactivity	
Isotope	Activity (Ci/compact)	Mass (g/compact)	Isotope	Mass (g/compact)
AM242	2.10E-06	2.59E-12	C 13	2.22E-05
SE 79	1.88E-06	2.70E-05	SB123	2.13E-05
PM146	1.72E-06	3.87E-09	SN122	1.96E-05
U236	1.57E-06	2.43E-02	SN120	1.76E-05
CS135	9.26E-07	8.04E-04	SN118	1.75E-05
PA233	8.91E-07	4.29E-11	SB121	1.74E-05
NP237	8.90E-07	1.26E-03	SN119	1.70E-05
I131	8.58E-07	6.92E-12	BE 9	1.69E-05
EU152	7.26E-07	4.20E-09	CD116	1.65E-05
SN121M	6.68E-07	1.13E-08	SN117	1.62E-05
NB 93M	5.66E-07	2.00E-09	GD154	1.16E-05
RH102	4.82E-07	3.98E-10	TE125	1.12E-05
SB126	4.79E-07	5.73E-12	SE 78	1.08E-05
PU236	2.78E-07	5.23E-10	SN116	9.58E-06
PD107	2.67E-07	5.18E-04	HE 4	9.01E-06
PA234M	2.36E-07	3.44E-16	XE128	6.24E-06
TH234	2.36E-07	1.02E-11	TB159	5.99E-06
U238	2.36E-07	7.02E-01	GD155	5.87E-06
IN114M	1.95E-07	8.42E-12	SE 77	4.95E-06
IN114	1.86E-07	1.35E-16	CD113	4.58E-06
CM245	1.67E-07	9.75E-07	GD160	2.76E-06
I129	1.19E-07	6.46E-04	P 31	2.63E-06
PU237	1.12E-07	9.25E-12	KR 82	2.62E-06
SN125	9.35E-08	8.62E-13	GE 76	2.20E-06
U235	5.78E-08	2.67E-02	TE126	2.12E-06
TH231	5.78E-08	1.09E-13	SR 86	1.55E-06
U234	1.94E-08	3.11E-06	TE124	1.27E-06
IN115M	1.84E-08	2.90E-15	MG 25	1.25E-06
SN117M	1.58E-08	1.98E-13	TE122	1.12E-06
AG111	1.22E-08	7.74E-14	DY161	1.06E-06
NP238	1.05E-08	4.06E-14	AS 75	7.48E-07
TM170	7.96E-09	1.33E-12	DY160	5.92E-07
CM246	5.63E-09	1.83E-08	SN115	5.85E-07
XE127	4.35E-09	1.54E-13	MG 26	5.73E-07
U232	3.90E-09	1.82E-10	DY162	5.37E-07
HO166M	3.16E-09	1.76E-09	BA135	5.15E-07
P 32	1.11E-09	3.90E-15	DY163	5.00E-07
BI212	8.38E-10	5.72E-17	XE129	3.46E-07
PB212	8.38E-10	6.03E-16	GE 74	3.23E-07
PO216	8.38E-10	2.40E-21	H 1	2.81E-07
RA224	8.38E-10	5.26E-15	HO165	2.24E-07
RN220	8.38E-10	9.08E-19	GE 73	1.24E-07
TH228	8.35E-10	1.02E-12	GD157	1.17E-07
NP235	7.63E-10	5.44E-13	ER166	6.49E-08
XE133	5.40E-10	2.88E-15	DY164	6.07E-08
C 14	5.40E-10	1.42E-10	EU151	5.64E-08
PO212	5.37E-10	3.02E-27	GE 72	4.39E-08
NB 94	3.61E-10	1.93E-09	IN113	2.54E-08
PA234	3.07E-10	1.54E-16	O 17	2.15E-08
TL208	3.01E-10	1.02E-18	SE 76	2.08E-08
TM171	1.58E-10	1.45E-13	RU 99	1.53E-08
AG109M	1.47E-10	5.63E-20	ER168	8.99E-09
CD109	1.47E-10	5.70E-14	AL 27	6.18E-09
CM241	1.32E-10	8.76E-15	SR 87	6.15E-09
CE142	1.30E-10	5.42E-03	ER167	4.59E-09
RB 87	1.17E-10	1.33E-03	LI 6	3.29E-09
BK249	6.77E-11	4.13E-14	SN114	7.23E-10
TB161	6.30E-11	5.37E-16	KR 80	6.73E-10
AG108M	6.03E-11	2.31E-12	BR 79	3.84E-10
XE129M	3.55E-11	2.80E-16	S 32	3.22E-10
BE 10	1.34E-11	8.10E-10	NB 93	2.08E-10
NP236	1.23E-11	9.33E-10	H 2	1.40E-10
SM147	8.10E-12	3.56E-04	BA132	1.06E-10
SI 32	7.91E-12	4.60E-13	CD108	8.91E-11
AG108	5.36E-12	7.30E-21	AG107	6.05E-11
U233	5.18E-12	5.35E-10	LI 7	4.66E-11
PA231	4.80E-12	1.02E-10	NE 22	4.12E-11
TC 98	2.90E-12	3.34E-09	TM169	3.68E-11
EU150	2.90E-12	4.38E-14	HE 3	1.61E-11

Radioactive Isotopes			Isotopes with No Radioactivity	
Isotope	Activity (Ci/compact)	Mass (g/compact)	Isotope	Mass (g/compact)
CF250	1.04E-12	9.51E-15	YB170	4.16E-12
KR 81	9.07E-13	4.31E-11	GA 71	3.35E-12
ER169	4.60E-13	5.59E-18	NA 23	3.34E-12
PU244	3.72E-13	2.10E-08	SF250	2.14E-12
U240	3.72E-13	4.01E-19	ZN 66	2.06E-13
NP240M	3.72E-13	3.51E-21	PB208	1.77E-13
CF252	2.13E-13	3.96E-16	YB171	8.06E-14
AC227	2.06E-13	2.84E-15	S 33	6.94E-14
TH227	1.92E-13	6.26E-18	MG 24	9.34E-15
BI211	1.89E-13	4.51E-22	ZN 67	9.31E-15
PB211	1.89E-13	7.65E-21	ER170	6.39E-15
PO215	1.89E-13	6.41E-27	YB172	2.67E-15
RA223	1.89E-13	3.69E-18	N 14	2.48E-15
RN219	1.89E-13	1.45E-23	ZN 68	1.32E-16
TL207	1.88E-13	9.89E-22	B 11	1.12E-16
TH230	1.58E-13	7.81E-12	HF176	6.80E-17
CS132	1.12E-13	7.32E-19	HF180	6.61E-17
CF249	1.02E-13	2.48E-14	PB207	6.57E-17
SM146	3.56E-14	1.02E-09	B 10	6.18E-17
CM248	2.08E-14	4.89E-12	HF179	5.28E-17
CM247	1.36E-14	1.46E-10	HF178	4.87E-17
PU243	1.36E-14	5.21E-21	SM144	4.07E-17
TH229	1.21E-14	5.69E-14	LU175	3.23E-17
AT217	1.21E-14	7.51E-27	GD160	3.16E-17
BI213	1.21E-14	6.26E-22	HF174	1.37E-17
FR221	1.21E-14	6.82E-23	BI209	1.28E-17
PB209	1.21E-14	2.66E-21	CD106	1.26E-17
AC225	1.21E-14	2.08E-19	HF177	8.99E-18
RA225	1.21E-14	3.08E-19	NE 20	2.39E-18
PO213	1.18E-14	9.38E-31	TA181	1.63E-18
CF251	6.44E-15	4.06E-15	GA 69	1.95E-19
AM246	5.84E-15	1.91E-22	W183	1.13E-19
PU246	5.83E-15	1.19E-19	W182	5.35E-20
ND144	4.38E-15	3.70E-03	PB206	5.35E-20
HF175	3.33E-15	3.13E-19	N 15	4.32E-20
SB127	3.28E-15	1.23E-20	NE 21	1.70E-20
FR223	2.84E-15	7.34E-23	W184	2.90E-21
AM245	9.82E-16	1.59E-22	GE 70	1.64E-22
LA138	7.45E-16	3.88E-08	YB173	7.15E-27
PO211	5.29E-16	5.54E-27	AG111	3.98E-32
BI210	3.61E-16	2.91E-21	**Total**	**4.73E+00**
PB210	3.61E-16	4.72E-18		
TL209	2.61E-16	6.39E-25		
PO210	2.59E-16	5.77E-20		
SM148	2.51E-16	8.33E-04		
HF181	1.97E-16	1.16E-20		
I132	1.57E-16	1.52E-23		
TE132	1.52E-16	5.01E-22		
ES253	1.44E-16	5.73E-21		
PO214	9.96E-17	3.10E-31		
TH232	9.08E-17	8.28E-10		
TA182	5.82E-17	9.33E-21		
RA222	5.19E-17	3.88E-26		
RN218	5.19E-17	3.51E-29		
TH226	5.19E-17	1.93E-24		
U230	5.09E-17	1.86E-21		
PO218	4.77E-17	1.69E-25		
RA226	4.77E-17	4.83E-17		
RN222	4.77E-17	3.10E-22		
BI214	4.77E-17	1.08E-24		
PB214	4.77E-17	1.46E-24		
IN115	4.61E-17	7.40E-06		
SM145	3.90E-17	1.47E-20		
BK250	3.79E-17	9.73E-24		
ES254	3.78E-17	2.03E-20		
CF253	1.36E-17	4.68E-22		
P 33	1.20E-17	7.56E-23		
CF254	1.17E-17	1.38E-21		
AC228	6.01E-18	2.68E-24		

Radioactive Isotopes			Isotopes with No Radioactivity	
Isotope	Activity (Ci/compact)	Mass (g/compact)	Isotope	Mass (g/compact)
RA228	6.01E-18	2.57E-20		
LU177M	4.05E-18	8.51E-22		
TE123	3.38E-18	1.16E-08		
PM145	2.71E-18	1.95E-20		
SM149	2.33E-18	9.70E-06		
LU177	9.31E-19	8.47E-24		
NB 92	3.53E-19	2.53E-24		
MO 99	1.71E-19	3.56E-25		
TC 99M	1.64E-19	3.12E-26		
GD152	6.59E-20	3.02E-09		
AG106	5.16E-20	3.56E-25		
CM249	4.21E-20	3.58E-27		
HO166	1.39E-20	1.97E-26		
ES255	1.06E-20	8.10E-25		
DY166	9.34E-21	4.03E-26		
CM250	1.62E-21	1.97E-20		
SB122	5.61E-23	1.41E-28		
U231	2.06E-24	1.53E-29		
HF182	1.58E-24	7.23E-21		
PM149	7.70E-25	1.94E-30		
XE133M	8.21E-26	1.83E-31		
LU176	6.79E-26	1.00E-18		
CD115	1.95E-26	3.82E-32		
W185	2.93E-27	3.12E-31		
SM153	3.26E-28	7.42E-34		
TM172	5.75E-32	2.01E-37		
GA 72	2.38E-32	7.70E-39		
ZN 72	1.66E-32	1.77E-38		
AM240	8.98E-34	3.49E-39		
AS 77	4.30E-36	4.10E-42		
RH105	7.55E-37	8.95E-43		
TA183	0.00E+00	0.00E+00		
CU 67	0.00E+00	0.00E+00		
Total	**2.39E+01**	**8.04E-01**		

ADDENDUM APPENDIX A.8.2

PACKAGING INDEPENDENT VERIFICATION ITEMS

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PACKAGING INDEPENDENT VERIFICATION ITEMS

Certain components and features of the 9977 packaging are defined as category A "Q" items (safety-related) in accordance with SARP Chapter 9, Section 9.2.3. These components and or features require documented evidence that the attributes have been satisfied during packaging fabrication. Addendum Table A.App.8.2.1 lists the "Q" items that require independent verification and the basis for designation of the items. The numbered items specifying dimensional, surface feature and material requirements are identified on the engineering drawings given in Addendum Chapter 1, Appendix A.1.1.

Table A.App.8.2.1 Dimensions/Materials Requiring Independent Verification Records

Number	Quality Item	Basis for Designation	Drawing Number
1	Cone seal face major diameter	Containment	R-R2-G-00042
2	Cone seal face angle	Containment	R-R2-G-00042
3	Cone seal face finish	Containment	R-R2-G-00042
4	Cone seal plug angle	Containment	R-R2-G-00042
5	Test port seat angle	Containment	R-R2-G-00042
6	Test port seat finish	Containment	R-R2-G-00042
7	Test port minor hole diameter	Containment	R-R2-G-00042
8	Lower O-ring gland depth	Containment	R-R2-G-00042
9	Upper O-ring gland depth	Containment	R-R2-G-00042
10	O-ring gland finish	Containment	R-R2-G-00042
11	Upper O-ring gland width	Containment	R-R2-G-00042
12	Lower O-ring gland width	Containment	R-R2-G-00042
13	Cone seal plug minor diameter	Containment	R-R2-G-00042
14	O-ring size and material	Containment	R-R2-G-00042
15	Leak-Test Port Plug size and material	Containment	R-R2-G-00042
16	Gland Nut size and material	Containment	R-R2-G-00042
17	SC3 - Tungsten Body Outside Diameter	Shielding	R-R1-G-00039
18	SC3 - Tungsten Body Inside Diameter	Shielding	R-R1-G-00039
19	SC3 - Tungsten Body Bottom Thickness	Shielding	R-R1-G-00039

20	SC3 - Tungsten Plug Thickness	Shielding	R-R1-G-00039
21	SC2 - Body Outside Diameter	Shielding	R-R1-G-00038
22	SC2 - Body Inside Diameter	Shielding	R-R1-G-00038
23	SC2 - Body Bottom Thickness	Shielding	R-R1-G-00038
24	SC2 - Plug Thickness	Shielding	R-R1-G-00038
25	SC2 – Sleeve Outside Diameter	Shielding	R-R1-G-00038
26	SC2 - Sleeve Inside Diameter	Shielding	R-R1-G-00038
27	SC1 – Lead Body Outside Diameter	Shielding	R-R1-G-00037
28	SC1 – Lead Body Inside Diameter	Shielding	R-R1-G-00037
29	SC1 – Lead Body Bottom Thickness	Shielding	R-R1-G-00037
30	SC1 – Lead Plug Thickness	Shielding	R-R1-G-00037