WSRC-TR-98-00279

Request for One-Time Shipment of 32 Watt PU-328 Source in 9968 Packaging

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WSRC-TR-98-00279
Equipment Engineering and Systems Department

REQUEST FOR ONE TIME SHIPMENT OF 32 WATT PU-238 SOURCE IN 9968 PACKAGING

Supplement To

Safety Analysis Report - Packages

USA/9965/B(U)F (DOE-SR)
USA/9966/B(U)F (DOE-SR)
USA/9967/B(U)F (DOE-SR)
USA/9968/B(U)F (DOE-SR)

(Packaging of Fissile and Other Radioactive Materials) DPSPU 83-124-1

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WSRC-TR-98-00279
Engineered Equipment and Systems Department

KEYWORDS: Packaging
Transportation

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ABSTRACT

The 9968 package is designed for surface shipment of fissile and other radioactive materials where a high degree of double containment is required. The use of the 9968 radioactive material package for a one time shipment of a 32 watt heat source versus the SARP approved maximum 30 watt heat source is addressed in this report. The analyses show that the small increase in heat load from 30 watts to 32 watts does not substantially increase internal temperatures or pressures that would approach limits for the package. Also, the weight of the content is within the current 9968 package limits. It is concluded that the 32-watt heat source can be safely shipped in the 9968 package and therefore a waiver to ship the source is justified.

ABBREVIAITIONS

CFR	Code of Federal Regulations
HAC	Hypothetical Accident Conditions
MNOP	Maximum Normal Operating Pressure
NCT	Normal Conditions of Transport
PCV	Primary Containment Vessel
QA	Quality Assurance
SARP	Safety Analysis Report - Packaging
SCV	Secondary Containment Vessel
SST	Safe, Secure Trailer
TSD	Transportation Safeguards Division
WSRC	Westinghouse Savannah River Company
WSMS	Westinghouse Safety Management Solutions

INTRODUCTION AND BACKGROUND

The 9968 package is designed for surface shipment of fissile and other radioactive materials where a high degree of double containment is required. This report contains information and analyses to support shipment of a 32-watt heat source from the Mound Laboratory in Miamisburg, Ohio to the Los Alamos National Laboratory in Los Alamos, New Mexico. The 9968 radioactive material package will be used to ship the heat source. However, the current Safety Analysis Report for Packaging (SARP, Ref. 1) has validated the shipment of heat sources only up to 30 watts. Justification for shipping a 32-watt heat source in the 9968 package is presented in this report. This report is subdivided into the ten chapters corresponding to the 9968 SARP with each chapter describing justification and/or analysis appropriate to confirm that the 9968 is suitable for the 32 watt heat source. Additional thermal and shielding analyses were performed to support the conclusion that the 9968 package could be safely used to transport the encapsulated Pu-238 heat source.

Chapter 1 General Information

This supplement to the current 9968 SARP [Ref. 1] evaluates the 9968 package with a 32 W encapsulated plutonium oxide heat source as contents subject to the regulatory requirements in 10 CFR 71. The 9968 package and the 32 W Pu-238 contents will be shipped in the Safe Secure Trailer (SST).

The 9968 package is a Type B double containment and lead shielded drum package (35 gallons). The approved contents for the 9968 (based on criticality considerations) are up to 4.4 kg of plutonium metal or oxides where the Pu-240 content is equal to or greater than the Pu-241 content. The approved contents are limited to 30 Watts (based on thermal analysis) and must weigh less than 53 lbs (based on structural analysis).

The Pu-238 source generates 32 Watts of power, is 2 in. in diameter by 1.5 in. high and weighs 497.8 grams. This information was supplied by Mound Laboratory by the correspondence given in Appendix 1. The isotopic distribution is provided in Table 1.1. The source is primarily Pu-238, and the Pu-240 mass is greater than the Pu-241 mass. The source is completely sealed in a metallic alloy. The source is 22 years old and does not contain any organics internally. The source contains less than 1 gram of moisture (see Appendix 1).

Table 1.1: Isotopic Composition of 32-Watt Source [App. 1]

Isotope	Mass Fraction (%) (see note)
Pu-238	79.5
Pu-239	17.2
Pu-240	2.59
Pu-241	0.54
Pu-242	0.14
Am-241	3413 ppm
Pu-236	0.28 ppm

Note: The mass fractions do not sum to 100%, the remaining 0.03% is other materials including the Am-241 and Pu-236.

The exact mass of the Pu isotopes is computed in Table 1.2 based on the total power output of the source. The PuO_2 mass is approximately 80.6 grams [(238+32)/238 × 71.01g Pu]. (238 is the molecular weight of Pu and 32 is the O_2 molecular weight)

Table 1.2: Mass of Pu Isotopes

(1) Isotope	(2) Mass Fraction, g isotope/g total × 100 (%)	(3) Specific Power Isotope (W/g of isotope) (Ref. 2)	(4) Specific Power Source (W/g total mass) Col. 2 × Col. 3	(5) Mass Isotope, g (Based on 32 W source/0.450518w/g), i.e., 71.03g × Col. 2
Pu-238	79.5	0.56602	0.449986	56.47
Pu-239	17.2	0.00193	0.000332	12.22
Pu-240	2.59	0.00707	0.000183	1.84
Pu-241	0.54	0.00313	0.000017	0.38
Pu-242	0.14	0.000113	------------	0.10
Total Pu	99.97		0.450518	71.01 see note

Note: The total mass of heat generating material is determined by (32w/0.450518 w/g) = 71.03 g of which 99.97% is Pu and 0.03% is Am-241, Pu-236 and other material. Notice though that 0.28 ppm Pu-236 is equivalent to ~ 0.00002g and 3413 ppm Am-241 is equivalent to ~ 0.245 g which is greater than the the 0.0213 g allowed by the 0.03% (0.0003×71.03g). This is probably attributable to round-off in the analyses. For the shielding analysis, the Am-241 was assumed to be 1% of the total to bound the contribution to dose.

The source will be placed in a 7 in. food can (7 in. high by 4.25 in. diameter) during shipment (App. 1). The 7 in. can will be placed on top of the honeycomb, which rests at the bottom of the primary containment vessel. An additional empty 7 in. can will be placed on top of the 7 in. can containing the source. Both cans will be sealed, however the can lids will have a small hole to ensure equal pressure within the cans and the primary containment vessel. No plastics or other organic materials will be allowed within the primary or secondary containment vessels during shipment. As already mentioned, the Pu-238 contents have 1 gram of moisture or less which is in accordance with the 9968 SARP. Both containment vessels will be closed normally (i.e. no purging or backfilling of any gas will be performed).

Chapter 2 Structural Evaluation

The contents and its shipment in the 9968 package do not require any exemption from limitations described in the structural chapter [Ref. 1]. The MNOP for this shipment is 28.2 psig which is well below the 1,000 psig primary and secondary containment vessel design pressures. The internal gas temperature of the primary containment vessel during NCT is 411°F (see Chapter 3) which is below the 500°F design temperature for both containment vessels. The peak primary containment vessel temperature during HAC is 436°F (Chapter 3), which is also below the 500°F design temperature. The total mass of the contents including the encapsulated source (497.8 grams), honeycomb (less than 200 grams), and two 7 in. cans (150 grams each) is roughly 1.87 lbs which is well below the 53 lbs limit.

Chapter 3 Thermal Evaluation

The primary issue in this supplement is to evaluate the 9968 package (currently certified for 30 Watts) with a 32 Watt content. The Pu-238 source exceeds the certified content power limit by 6.67% which impacts package temperatures and containment vessel pressures modestly.

The impact on critical packaging component temperatures was determined by conservatively extrapolating package temperatures from the SARP for a 30 Watt content up to the proposed 32 Watt content. These temperatures are well below acceptance criteria. Details of the extrapolation are documented in Appendix 2. Details of the containment vessel pressure analysis are given below.

The free volume within the containment vessels (primary and secondary) are required to determine the operating pressures of the package. The vessel volumes in column 2 of Table 3.1 are taken directly from the 9968 SARP [Ref. 1, pgs. 3-25,26]. The SARP uses conservatively low values for this volume to overestimate the vessel pressure. The actual total free volume was estimated and is provided in column 3, and the actual net free volume (column 5) subtracts the volume of the sealed Pu source. Note that the SCV free volume is based on the PCV being within the SCV (the SCV total free volume is the sum of the PCV free volume and the volume between the PCV and SCV). The values in Table 3.1 illustrate the conservative (i.e. small) free volume used in the SARP. These conservative volumes for the containment vessels are used in this supplement to maintain consistency.

Table 3.1: Vessel volumes

Vessel	SARP Vol. ($ft.^3$)	Total Free Vol. ($ft.^3$)	Content Vol. ($ft.^3$)	Actual Net Free Vol. ($ft.^3$)
PCV	0.1227[1]	0.1814[2]	.00273[3]	0.1787
SCV	0.2231[4]	0.2817[5]	.00273[3]	0.2790

1 Conservative volume used in Reference 1 to calculate maximum pressure in PCV (3475 cc ≡ 0.1227 ft^3)
2 Actual PCV volume from Reference 1 (313.4 in^3 ≡ 0.1814 ft^3)
3 Calculated from dimensions in Appendix 1 ($\pi \times (2/12)^2/4 \times 1.5/12 = 0.00273$ ft^3)
4 Calculated from Reference 1 PCV volume + SCV volume with PCV inside SCV (3475 cc + 2842 cc = 6317 cc or 0.2231 ft^3)
5 Calculated from total SCV volume (604.4 in^3 ≡ 0.3498 ft^3, Ref.1) less metal volume of PCV. Metal volume of PCV determined approximately from weight of PCV (33.6 lbs, Ref. 1) and density of 304 SS (Ref. 5, 493.3 lb/ft^3) to be 0.0681 ft^3. Total free volume = 0.3498 – 0.0681 = 0.2817 ft^3.

The only gas species within the package containment vessels is air. However, assuming the sealed source ruptures during shipment, helium and hydrogen (from complete radiolysis of water) would also be present in the containment vessels. Total number of moles of gas in the vessels is provided in Table 3.2. These values are determined using the ideal gas law as follows (Ref. 2):

$$M = \frac{P \times V}{R \times T}$$

where:

M = number of lb-moles

P = pressure in psia

R = 10.73, universal gas constant, psia-ft^3/°R lb-mole (Ref. 2)

T = Temperature in °R

V = Volume in ft^3

Table 3.2: Gas Species In Containment Vessels (assuming Pu source ruptures)

Vessel	Air (lb.-moles) (based on SARP free volumes and 70°F ambient)	Helium (lb.-moles) (based on 32 Watts for 30 yrs. vs. actual 22 yrs.)	Hydrogen (lb.-moles) (based on 1 gram moisture and 81 g PuO_2)	Total Gas (lb.-moles)
PCV	0.000317	0.000123[1]	0.000121[2]	0.000562
SCV	0.000577	0.000123[1]	0.000121[2]	0.000821 (assuming PCV leakage)

1 Based on generation of 0.0035 g-mole helium in 2 yrs. scaled up to 30 yrs. from Ref. 1 (pg. 3-25) and for increased heat load (32/30) and conversion to lbs. (0.0035*32/30*15/453.6 = 0.000123 lb-moles)

2 Based on 0.055 g-mole from Ref. 1, pg. 3-25 converted to lb-mole (0.055/453.6 = lb-moles)

The pressures during NCT are computed and presented in Table 3.3. The temperature is based on linear extrapolation of the 9965 PCV gas temperature (395°F for 30 watts of contents) up to a 32 watt content [pg. 3-25, Ref. 1]. (The 9965 gas temperature is higher than the 9968 and therefore is used here for conservatism as was done in Reference 1.) The extrapolated temperature is conservatively used for the SCV pressures, too. The pressures are well below the 1000 psig design pressure. The gas species include air, helium and hydrogen as presented in Table 3.2. The Maximum Normal Operating Pressure listed in the SARP is 34 psia (shown as 34 psig by typographical error). The PCV pressure in Table 3.3 is 42.9 psia which is above the SARP MNOP of 34 psia but well below the design pressure. These pressures are calculated using the ideal gas law as follows:

$$P = \frac{M \times R \times T}{V}$$

where the symbols are as defined above and the parameters are given in the table.

Table 3.3: NCT Pressures

Vessel	Temperature (°F)	Volume (ft.^{3})	Gas (lb.-moles)	Gas Constant (psi-ft.^{3}/°R-lb.-moles)	Pressure (psia)
PCV	411[1]	0.1227[2]	0.000562[3]	10.73[4]	42.8
SCV	411[1]	0.2231[2]	0.000821[3]	10.73[4]	34.4

1 Temperature calculated via linear extrapolation from 395°F using ratio of source powers (395-150)*32/30 + 150 = 411°F

2 Table 3.1

3 Table 3.2

4 Reference 3

The pressures during HAC are computed and presented in Table 3.4. The temperature is based on linear extrapolation of the 9966 PCV gas temperature (478°F for 30 watts of contents, 100°F ambient temperature) up to a 32 watt content [pg. 3-34, Ref. 1]. (The 9966 gas temperature is higher than the 9968 and therefore is used here for conservatism as was done in Reference 1.) The extrapolated temperature is conservatively used for the SCV pressures, too. The peak containment vessel pressures during the hypothetical accident fire are well below the 1000 psig design pressure for the containment vessels. The gas species include air, helium and hydrogen as presented in Table 3.2.

Table 3.4: HAC Pressures

Vessel	Temperature (°F)	Volume ($ft.^3$)	Total Gas (lb.-moles)	Gas Constant (psi-$ft.^3$/°R-lb.-moles)	Pressure (psia)
PCV	503[1]	0.1227[2]	0.000562[3]	10.73[4]	47.3
SCV	503[1]	0.2231[2]	0.000821[3]	10.73[4]	38.0

1 Temperature calculated via linear extrapolation from 478°F using ratio of source powers (478-100)*32/30 + 100 = 503°F
2 Table 3.1
3 Table 3.2
4 Reference 3

During HAC the SARP reports a primary containment vessel peak metal temperature of 415°F and a peak internal gas temperature of 478°F [pg. 3-34,35, Ref. 1]. Assuming a similar temperature gradient exists with the 32 W contents, the peak primary containment vessel (metal) temperature during HAC is 436°F [(415-100)*32/30 + 100], which is well below the 500°F containment vessel design temperature.

Chapter 4 Containment

The containment section of the SARP is not impacted by the Pu-238 source as contents. The "Viton" GLT O-rings are serviceable up to 500°F [Ref. 1] which is well above the 411°F internal temperature of the primary containment vessel during NCT and the peak primary containment vessel temperature of 436°F during HAC.

As already mentioned, the contents are confined in a single 7 in. tall food can. The lid of the food can will be punctured prior to sealing the can to ensure no pressurization within the food can. An empty 7 in. tall food can will be stacked above and its lid will also be punctured. No plastics or organics will be in the primary or secondary containment vessel during shipment other than the "Viton" GLC O-rings used to seal the 9968 containment vessels.

Chapter 5 Shielding

The shielding chapter in the 9968 SARP contains an evaluation of weapons grade Pu metal only. The gamma and neutron source from the Pu-238 oxide contents is sufficiently different to require further evaluation. A very detailed shielding analysis, including a Pu-238 oxide content, was performed [Ref. 4, included as Appendix 3]. These results are summarized in this chapter.

The Pu-238 oxide content considered for shielding purposes is defined in Table 5.1.

Table 5.1 : Content Analyzed In Detailed Shielding Analyses

Isotopes	Weight Percent
Am-241	1.00000
Am-243	0.00010
Cm-244	0.00010
Np-237	0.50000
Pu-236	0.00010
Pu-238	100.000
Pu-239	40.0000
Pu-240	13.0000
Pu-241	1.00000
Pu-242	1.50000
Th-232	10.0000
U	1.00000

The restricting limit for this content is 100 grams. That is, the maximum mass of each isotope as defined by this content is equal to its permitted weight percentage in grams where the total content mass of the isotopes defined in Table 5.1 is no greater than 100 grams.

For conservatism decay transmutations were evaluated over 100 years beginning with the content distribution. The maximum isotopic activities calculated during the 100 years of decay were then used to calculate the source distribution to determine the most conservative doses.

A summary of the shielding results is presented in Table 5.2 along with the regulatory limits. The objective of this evaluation is to demonstrate compliance with the performance requirements specified in 10 CFR 71.47, 10 CFR 71.57, 49 CFR 173.403, and 49 CFR 173.441 for each package and its contents. According to these regulations, dose rate limits are 200 mrem/h at the accessible surface of the package, 10 mrem/h at 1 m from the accessible surface of the package, and 1000 mrem/h at 1 m from the surface of a damaged package after a hypothetical accident. The shielding analysis results indicate that the 9968 package complies (with a significant margin of safety) with the federal regulations for nonexclusive use.

Table 5.2: Shielding Results

NCT Surface	Dose (mrem/hr)	10 CFR 71 Limits (mrem/hr)
SIDE		
Neutrons	73.3	
Photons	13.6	
Total	86.9	200.0
TOP		
Neutrons	21.3	
Photons	2.47	
Total	23.8	200.0
BOTTOM		
Neutrons	55.9	
Photons	25.5	
Total	81.4	200.0
NCT 1 m Away		
SIDE		
Neutrons	1.75	
Photons	0.431	
Total	2.18	10.0
TOP		
Neutrons	0.754	
Photons	0.115	
Total	0.869	10.0
BOTTOM		
Neutrons	1.47	
Photons	0.715	
Total	2.19	10.0
HAC 1 m Away		
SIDE		
Neutrons	2.29	
Photons	4.54	
Total	3.0	1000.0
TOP		
Neutrons	0.713	
Photons	0.168	
Total	0.881	1000.0
BOTTOM		
Neutrons	1.89	
Photons	3.35	
Total	5.24	1000.0

Chapter 6 Criticality

The 32W source term contains ~ 71 grams of Plutonium and the Pu-240 contents are greater than the Pu-241 contents (see Ch. 1). The SARP establishes an approved contents of 4.4 kg of Pu (where Pu-240 contents are equal to or greater than Pu-241 contents) based on criticality considerations which envelopes the 32W source term. Therefore no further evaluation is required.

Chapter 7 Operating Procedures

The operating procedures chapter in the 9968 SARP are applicable to the operations of the 32W source with the following modifications and additions.

1. The 32W source will not be placed in a plastic bag.

2. The 32W source will not be enclosed in a inner product can.

3. The 32W source will be shipped in the DOE Transportation Safeguards Division (TSD) Safe, Secure Trailer (SST).

4. Two 7 inch tall food cans will be shipped in the PCV. The cans will be stacked and the lids of both will be punctured. The top can will be empty and the 32 watt source will be shipped within the bottom can.

5. No filler or other materials will be allowed in the PCV or SCV during shipment except the honeycomb specified on drawings.

Chapter 8 Acceptance Test and Maintenance Program

In chapters 1-7 the use of a 32W heat source has been shown to fit well within the safety envelope of the 9968 packaging as originally conceived, designed and built. Therefore, the acceptance test and maintenance program established for the 9968 packaging requires no modifications or additions to accommodate the 32W source.

Chapter 9 Quality Assurance Requirements

The 32W heat source presents no additional hazard or usage restrictions as demonstrated in chapters 1-8 that would alter the safety related or "Q" items for the 9968 packaging. No changes to Chapter 9 are required except to note that current QA site related administrative requirements are to be implemented as required.

Chapter 10 Detail Engineering Drawings

There are no design changes associated with using the 32W heat source and therefore there are no revisions or additions to the engineering drawings.

CONCLUSIONS AND RECOMMENDATIONS

The 9968 radioactive material package is shown to be capable for transporting a 32 watt heat source. The additional thermal load does not increase the internal temperatures or pressures significantly. These parameters are well below the package limits as described in Reference 1 under NCT or HAC. The shielding is also shown to adequate to meet regulatory guidelines.

It is recommended that the 9968 package be used for transportation of the 32 watt heat source.

REFERENCES

1. Safety Analysis Report - Packages, USA/9965B(U)F (DOE-SR), USA/9966B(U)F (DOE-SR), USA/9967B(U)F (DOE-SR), USA/9968B(U)F (DOE-SR), Packaging of Fissile and Other Radioactive Materials, Final Report, DPSPU 83-124-1, DuPont, June, 1984.

2. "Fission Product Production at SRS", EPD-CTG-94-0039, R. L. Webb, WSRC, Dec. 1994.

3. "Thermodynamics", 5th edition, Kenneth Wark, McGraw-Hill, Inc.

4. "Dose Calculation for Pu-238 Oxide Payload in 9968 Shipping Container", N-CLC-G-00067, R. L. Webb, WSMS, July, 1998.

5. "Fundamentals of Heat and Mass Transfer", 4th edition, Incropera and DeWitt, John Wiley & Sons.

APPENDICES

1. **32 Watt Source Information Communication from Mound Laboratory**
2. **Thermal Calculations for 9968 Package with 32 Watt Heat Source**
3. **Dose Calculation for Pu-238 Oxide Payload in 9968 Shipping Container**

APPENDIX 1
32 Watt Source Information Communication from Mound Laboratory

BWX Technologies, Inc.
Babcock & Wilcox, a McDermott company

Babcock & Wilcox of Ohio, Inc.
1 Mound Road
P.O. Box 3030
Miamisburg, Ohio 45343-3030
(937) 865-4020

WM-112/98
July 28, 1998

Mr. William Massey
Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29801

SUBJECT: Contract No. DE-AC24-97OH20044
9968 Exemption Request

Dear Mr. Massey:

In support of Mound's request for a one time shipment of the 32 watt heat source, the following information provided is a summary of data previously supplied to SRS via e-mail:

- the power of the source is 32 watts
- the dimensions of the source are 2" dia. X 1.5" high
- gross weight of the source is 497.8 grams
- the isotopic distribution is:

Pu-238	79.5%	(Weight %)
Pu-239	17.2	
Pu-240	2.59	
Pu-241	0.54	
Pu-242	0.14	
Pu-236	0.28 ppm	
Am-241	3413 ppm	

- the materials of encapsulation are unknown
- the source is approximately 22 years old
- based upon process knowledge, the moisture content of the source is less than one gram

If you need additional information, please call Jerry Crawford at (937) 865-3172.

Sincerely,

John W. Krueger
Manager, Waste Management

cc: Jerry Crawford
Ray Finney

APPENDIX 2

Thermal Calculations for 9968 Package with 32 Watt Heat Source

Calculation Cover Sheet

Project	Calculation Number	Project Number
Exemption Request For 9968 Packaging Of 32W Pu-238 Source	M-CLC-F-00481	Special Request 98-107
Title Thermal Considerations Of 32 Watts Of Plutonium Oxide In The 9968 Package (U)	**Functional Classification** SC	Sheet 1 of 6
	Discipline Mechanical	

☐ Preliminary ☐ Committed ☒ Confirmed

Computer Program No.	Version/Release No.
☒ N/A	

Purpose and Objective

To evaluate the 9968 shipping package with a content payload of 32 watts.

Summary of Conclusion

A simplified analysis of the 9968 package with 32 watts of Pu oxide contents subjected to the Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) defined in 10 CFR 71 demonstrates that the package temperatures and pressures are well within the predefined acceptance criteria in the 9968 SARP.

Revisions

Rev No.	Revision Description
0	Original issue

Sign Off

Rev No.	Originator (Print) Sign/Date	Verification/ Checking Method	Verifier/Checker (Print) Sign/Date	Manager (Print) Sign//Date
0	Steve Hensel Steve Hensel 5/20/98	Individual	J. STEIMKE 5/28/98 John Steimke	C.P. Holding-Smith C.P. Holding-Smith 5/28/98

Classification
Unclassified

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Thermal Considerations Of 32 Watts Of Plutonium Oxide In The 9968 Package

1.0 Conclusions

A simplified analysis of the 9968 package with 32 watts of Pu oxide contents subjected to the Normal Conditions Of Transport (NCT) and Hypothetical Accident Conditions (HAC) defined in 10 CFR 71 demonstrates that the package temperatures and pressures are well within the predefined acceptance criteria in the SARP [1].

2.0 Input

The thermal chapter (Chapter 3) of the 9968 SARP provides temperatures and pressure within the packaging for a 30 watt plutonium payload during NCT [1]. These values are provided in Table 1.

Table 1: Current Performance Of The 9968 Package During NCT (30 watt payload)

Location	Temperature (°F)/Pressure (psig)
ambient temperature	150
outside drum temperature	150
midpoint of insulation temperature	179
lead shield temperature	201
SCV temperature	223
PCV temperature	260
upper button temperature	438
lower button temperature	419
Maximum Normal Operating Pressure (based on 9965)	34 (based on 395°F gas temperature)

Similarly, Table 2 contains the 9968 SARP temperatures and pressure for the HAC with 30 watts of plutonium contents. The temperature and pressure acceptance criteria in the 9968 SARP for each component are provided in Table 3. These acceptance criteria must be satisfied to ensure package safety and demonstrate compliance with 10 CFR 71 requirements.

Table 2: Current Performance Of The 9968 Package During HAC (30 watt payload)

Location	Temperature (°F)/Pressure (psig)
ambient temperature before and after fire	100
ambient temperature during fire	1475
peak lead shield temperature	318
peak SCV temperature	330
peak PCV temperature	362
peak PCV pressure (based on 9966)	37 (based on 478°F gas temperature)

Table 3: Acceptance Criteria From 9968 SARP For Critical Components

Component	NCT Temp. (°F)/Pressure (psig)	HAC Temp. (°F)/Pressure (psig)
O-rings	500 / 1000	500 / 1000
PCV	500 / 1000	500 / 1000
SCV	500 / 1000	500 / 1000
Fiberboard	325 / NA	NA / NA
Lead	621/ NA	621 / NA

3.0 Analytical Methods and Computations

The temperatures and pressures in Tables 1 and 2, which are based on 30 watt contents, can be readily scaled up to account for a 32 watt content. The scaling is a linear extrapolation based on the generic steady-state heat conduction equation below.

$$T_i = T_o + QR_i$$

where:

T_i is the temperature at i (°F)

T_o is the reference temperature with zero watts contents

Q is internal heat generation in watts

R_i is the thermal resistance from location i to the ambient

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The 150°F ambient NCT temperature is described in the SARP as the non-solar ambient equivalent to the NCT solar conditions, and this temperature is used as the reference temperature in the extrapolation equation.

During HAC, the temperature rise in the package is attributable to both the 30 minute fire and decay heat from the contents. In scaling the temperatures during HAC due to increased content heat generation, a reasonable approach would be to add the increase in steady-state NCT temperatures at each location i in going from 30 to 32 watts to the peak HAC temperatures for 30 watts. As shown in Figure 1, thermal analyses of drum overpack designs have shown that the temperature rise of the containment vessel during the HAC fire is virtually independent of content heat generation for contents generating between 25 and 50 watts [2]. The peak temperatures during HAC are essentially the initial temperature (NCT without solar) plus a rise due to the fire. The HAC temperatures for 32 watts are computed by adding the increase in NCT temperatures in going from 30 to 32 watts to the 30 watt HAC values. This approach is especially valid when dealing with small wattage changes (less than 10%).

4.0 Results

The temperatures and pressures for NCT and HAC are scaled upward for a 32 watt content and presented in Tables 4 and 5. Extrapolated temperatures and pressures during NCT and HAC for the critical packaging components are well below the acceptance criteria listed in Table 3. Therefore, the 9968 package can safely transport 32 watts of plutonium contents while satisfying the requirements of 10 CFR 71.

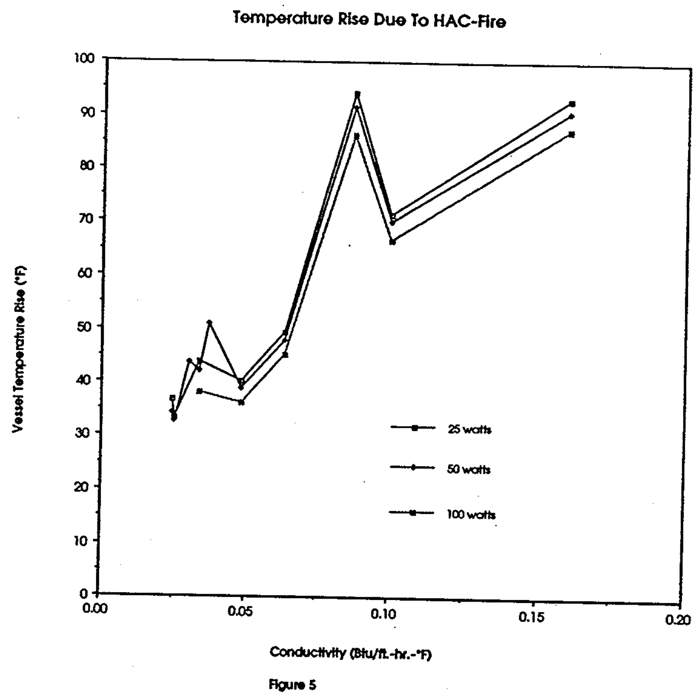

Figure 1 (taken directly from ref. 2)

Table 4: Extrapolated Performance Of The 9968 Package During NCT (32 watt payload)

Location	Temperature (°F)/Pressure (psig)
ambient temperature	150
outside drum temperature	150
midpoint of insulation temperature	181
lead shield temperature	204
SCV temperature	228
PCV temperature	267
upper button temperature	457
lower button temperature	437
Maximum Normal Operating Pressure (based on 9965)	35 (based on 411°F gas temperature)

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Table 5: Extrapolated Performance Of The 9968 Package During HAC (32 watt payload)

Location	Temperature (°F)/Pressure (psig)
ambient temperature before and after fire	100
ambient temperature during fire	1475
peak lead shield temperature	332
peak SCV temperature	345
peak PCV temperature	379
peak PCV pressure (based on 9966)	37 (based on 503°F gas temperature)

5.0 References

1. Chalfant, G. G., Safety Analysis Report - Packages USA/9965/B(U)F (DOE-SR) USA/9966/B(U)F (DOE-SR) USA/9967/B(U)F (DOE-SR) USA/9968/B(U)F (DOE-SR) (Packaging of Fissile and Other Radioactive Materials), DPSPU 83-124-1, June 1984.

2. Gromada, R. J., and Hensel, S. J., "Thermal Considerations For Overpack Designs In Drum Packages", WSRC-MS-97-0193.

APPENDIX 3

Dose Calculation for Pu-238 Oxide Payload in 9968 Shipping Container

Calculation Cover Sheet

Project	Calculation Number	Project Number
Project	N-CLC-G-00067	
Title DOSE CALCULATION FOR Pu-238 OXIDE PAYLOAD IN 9968 SHIPPING CONTAINER	Functional Classification N/A Discipline Nuclear	Sheet 1 of 40

☐ Preliminary ☑ Confirmed

Computer Program No. (s) 1) MCNP 2) ORIGEN-S 3) RASTA ☐ N/A	Version/Release No. 1) 4B 2) Revision 5 3) Revision 0

Purpose and Objective

Calculate dose rates for a ^{238}Pu oxide payload (100 gram actinide limit) in a 9968 shipping package.

Summary of Conclusion Dose rates for the specified payload satisfy 10 CFR 71 requirements for a non-exclusive use package. Surface dose rates (Normal Conditions of Transport) are 87 mrem/h @ side, 82 mrem/h @ bottom, 24 mrem/h @ top. Dose rates in mrem/h @ 1 meter are: for NCT, 2.2 @ side, 2.2 @ bottom, and 0.87 @ top; for Hypothetical Accident Conditions 6.9 @ side, 5.3 @ bottom, and 0.88 @ top.

Revisions

Rev. No.	Revision Description
0	Original Issue

Sign Off

Rev No.	Originator (Print) Sign / Date	Verification / Checking Method	Verifier / Checker (Print) Sign / Date	Manager (Print) Sign / Date
0	Roger L. Webb 7/20/98 Roger L. Webb Charles T. Kelsey 7/20/98 [signature]	Detailed Technical review per E-7 Manual.	Steven J. Nathan Steven J Nathan 7/20/98	Joye Brotherton J. Brotherton 7/24/98

Classification **UNCLASSIFIED**

Does Not Contain Unclassified Controlled Nuclear Information

ADC & Reviewing Official: Roger L. Webb 7/20/98

Roger L. Webb

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INTRODUCTION

The purpose of this work is to demonstrate that the 9968 shipping container meets Federal regulations for maximum radiation dose rates when loaded with the intended plutonium oxide payload. The dose calculations analyzed a ^{238}Pu-oxide payload in a 9968 shipping container. The plutonium mass limit for the payload is 100 grams. The envelope for the payload contents is shown in Table 1. The particle transport calculations were performed using MCNP 4B (Ref. 1) on the WSMS workstation cluster. Flux-to-dose conversion factors from ANSI/ANS-6.1.1-1977 (Ref. 2) were used to convert computed fluxes to doses. The source term characterization was performed using ORIGIN-S (Ref. 3) and RASTA (Ref. 4).

TABLE 1. 9968 Payload Envelope for ^{238}Pu-Oxide Payload

ISOTOPES[a]	Weight Percent
^{241}Am	1.00000
^{243}Am	0.00010
^{244}Cm	0.00010
^{237}Np	0.50000
^{236}Pu	0.00010
^{238}Pu	100.00000
^{239}Pu	40.00000
^{240}Pu	13.00000
^{241}Pu	1.00000
^{242}Pu	1.50000
^{232}Th	10.00000
U	1.00000
Inert material	100.00000
Mass Limit	100 grams

[a] In addition to the isotopes listed in the table, small concentrations of other actinides, fission products, decay products, and neutron activation products are also permitted.

SUMMARY OF RESULTS

Table 2 summarizes results of the dose calculations. The computed doses are all well below the guidelines for non-exclusive use shipments as specified and defined in 10 CFR 71.

Details of the calculations are presented later in this report.

This work has been done for an off-site shipper, so the neutron doses reported in Table 2 (and elsewhere throughout this report) are the "as-calculated" values and <u>have not</u> been multiplied by a factor of two as required by SRS' 5Q Manual.

TABLE 2. Radiation Dose Rates for the 9968 Shipping Container

		NORMAL CONDITIONS OF TRANSPORT		HYPOTHETICAL ACCIDENT CONDITIONS
		Dose (mrem/h) @ Surface	Dose (mrem/h) @ 1 m	Dose (mrem/h) @ 1 m
Side	Neutrons	73.3	1.75	2.29
	Gammas	13.6	0.431	4.54
	Total	86.9	2.18	6.83
Bottom	Neutrons	55.9	1.47	1.89
	Gammas	25.5	0.715	3.35
	Total	81.4	2.19	5.24
Top	Neutrons	21.3	0.754	0.713
	Gammas	2.47	0.115	0.168
	Total	23.8	0.869	0.881

REGULATORY REQUIREMENTS

The Federal regulatory requirements applicable to the shielding requirements are given in 10 CFR 71.47 and 10 CFR 71.51. 10 CFR 71.4 also defines two terms: *Exclusive Use* and *Transport Index.* Exclusive use is defined as *the sole use of a conveyance by a single consignor and for which all initial, intermediate, and final loading and unloading are carried out in accordance with the direction of the consignor or consignee.* Packages must meet more stringent requirements to qualify as a non-exclusive use package. The 9968 cask, with the payload of Table 1, satisfies the shielding requirements for a non-exclusive use package. The transport index is a *dimensionless number (rounded up to the next tenth) placed on the label of a package, to designate the degree of control to be exercised by the carrier during transportation.* It is determined as either the maximum radiation level in mrem/hr at 1 meter, or by the criticality control provisions of §71.59.

10 CFR 71.47 states that for non-exclusive use the radiation dose rate at the surface of a package cannot exceed 200 mrem/hr at any point on the surface of the package. Furthermore, the transport index must not exceed 10. (Hence, the radiation level at 1 meter from the package cannot exceed 10 mrem/hr.) In addition, 10 CFR 71.51 requires the radiation dose rate to not exceed 1000 mrem/hr at a distance of one meter from the external surface of the package under hypothetical accident conditions.

GEOMETRY

Details of the 9968 shipping container were taken from drawings S5-2-13101 (9968 Shipping Package Assembly), S5-2-13100 (9968 Stretched Double Containment Assembly), S5-2-13097 (9968 Stretched Primary Containment Vessel), S5-2-13098 (9968 Stretched Secondary Containment Vessel), and S4-2-767 (35 Gallon Full-Removable Head Drum).

A schematic of the package is shown in Figure 1. The 9968 consists of double stainless steel containment vessels, a lead shield, and cane fiberboard (Celotex™) insulation inside a 35-gallon steel drum. The 0.5-inch thick lead sheath is open at top and bottom. There is a 0.5-inch stainless steel anti-rotation plate at the bottom of the shield, and a 0.5-inch aluminum plate at the top. Content separation is provided by aluminum honeycomb spacers in the bottom of the primary and secondary contain vessels (PCV and SCV) and on top of the PCV. The fissile payload is shown in Figure 1 as a 1.277 cm radius sphere at the bottom of the PCV. Details of the PCV/SCV closures are shown in Figures 2 and 3. Additional dimensions for the package are shown in Table 3. Though dimensional tolerances were expected to have a negligible impact on the calculated doses, minimum and maximum pipe dimensions (for the PCV and SCV) were taken from ASTM A 530/A 530M –91a and used instead of nominal pipe dimensions.

TABLE 3. Radial Components of the 9968 Container Assembly

Region Description	IR (cm)	OR (cm)	Material
Primary Containment	6.57098	7.02564	304L SS
Secondary Containment	7.87019	8.37438	304L SS
Shield Liner	9.3846	9.5377	Void
Lead Shield	9.5377	10.7823	Lead
Fiberboard Packing	10.922	22.86	Celotex
Drum	23.1775	23.2989	304L SS

Table 4 shows specifications for the various components.

TABLE 4. 9968 Component Materials

Component	Material	Density
PCV	304L - SS	7.895
SCV	304L - SS	7.895
Drum	304L - SS	7.895
Cone Seal Nut	Nitronic-60 SST	7.895
Cone Seal Plug	304L - SS	7.895
Vent Plug	316-SS	7.895
Gland Nut	410-SS	7.895
Aluminum Honeycomb	Aluminum	0.28
Aluminum Plate	Aluminum	2.7
Celotex	Cellulose	0.20
Shield	Lead	11.29
Shield Liner	Void	0.0

Simplifications made to the package geometry include:

- uniform PCV and SCV wall thickness (ignoring the flaring and, hence, the increased thickness at the vessel closures),
- simplified PCV and SCV vessel bottoms (PCV bottom approximated as a 10.97534 cm IR sphere; SCV by a 14.732 cm IR sphere),
- ignoring any product cans, plastic, or other inert materials that could be present inside the PCV,
- ignoring the 'legs' on the bottom of the PCV and SCV,
- modeling the gland nut's hexagonal outer surface as a cylinder having the equivalent cross-sectional area,
- modeling the Celotex as a single component, ignoring seams that exist between the different pieces of Celotex, and
- ignoring the rolling hoops and the drum lid closure.

Dimensions of the various components are given below. (The geometric model used in this analysis was adapted from that used for a 9975 analysis. The packages are very similar, with only minor differences. For example, the 9975 lead shield has a stainless steel liner that was changed to be void material for this analysis.)

- PCV – 6.57098 cm Inner Radius, 7.02564 cm Outer Radius, 41.5925 cm height from outer (bottom) surface of the PCV to the bottom of the primary cone seal plug; outer (bottom) surface is 17.4027 cm above the outer (bottom) surface of the 35 gallon drum.
- SCV – 7.87019 cm Inner Radius, 8.37438 cm Outer Radius, 55.2323 cm height from outer (bottom) surface of the PCV to the bottom of the primary cone seal plug; outer (bottom) surface is 13.3929 cm above the outer (bottom) surface of the 35 gallon drum.
- Aluminum honeycomb above PCV – 4.572 cm high, 4.6725 cm Inner Radius, 7.46125 cm Outer Radius.
- Shield liner (void) – 9.3846 cm Inner Radius and 9.5377 cm Outer Radius.
- Lead shield – 9.5377 cm Inner Radius and 10.7823 cm Outer Radius; 62.3824 cm high (outer dimensions) – bottom is 12.2753 cm above the outer (bottom) surface of the 35 gallon drum.
- Stainless steel anti-rotation plate – 14.288 cm radius, 1.016 cm thick; bottom is 11.2593 cm above the outer (bottom) surface of the 35 gallon drum.
- Upper aluminum plate – 14.288 cm radius, 1.2446 cm thick; bottom rests on top of the lead shield and is 73.6417 cm above the outer (bottom) surface of the 35 gallon drum.

- Celotex – 10.922 cm Inner Radius for bottom Celotex sections, 11.049 cm Inner Radius for top section; 22.86 cm Outer Radius for bottom Celotex sections, 22.479 cm Outer Radius for top section; the change in inner radii between top and bottom sections occurs at 62.1863 cm above the drum's outer (bottom) surface, and the change in outer radii occurs at 67.5203 cm above the drum's outer surface; top of Celotex at 85.0463 cm above the drum's outer (bottom) surface.
- Drum – 23.1775 cm Inner Radius and 23.2989 cm Outer Radius; 0.1087 cm bottom thickness; inner height 84.9376 cm; external height 85.167712 cm. (Differences between carbon steel and 304 stainless steel were ignored and the drum was assumed to be 304 stainless steel.)

Several different assumptions were made regarding the payload contents. Differing contents, as well as content locations, were used in order to maximize doses for the various dose locations. Specifically:

- for neutron and (n,γ) calculations, a 1.277151 cm sphere at 11.46 g/cm^3 was assumed with 59 wt-% ^{238}Pu, 40 wt-% ^{239}Pu, and 1 wt-% ^{241}Pu. The contents and the spherical geometry were assumed in order to maximize the system's subcritical multiplication. The assumed density (11.46 g/cm^3) is the theoretical density of plutonium oxide – the oxygen content was ignored. For dose locations on the side or below the package, the fissile sphere was placed at the bottom of the PCV, touching the PCV side (see Figure 1). For dose locations above the package, the fissile sphere was placed at the top of the PCV, again touching the PCV side.

- for gamma source calculations, 52.020 wt-% ^{238}Pu, 35.268 wt-% ^{239}Pu, 0.882 wt-% ^{241}Pu, and 11.830 wt-% oxygen was assumed at 0.70 g/cm^3 (PuO_2 bulk density). For dose locations on the side, a 20-cm high, 0.734 cm thick, quarter-annulus (IR = 5.83698 cm) was assumed (see Figure 4). For dose locations above and below the package, a 1.0532-cm thick disc source was assumed at the bottom or top (respectively) of the PCV.

For hypothetical accident conditions, all material outside of the SCV was ignored. Figure 5 is a schematic of the geometry used when computing the source gamma dose 1 meter above the package. Note that for that scenario, a disc gamma source at the top of the PCV was used.

MATERIALS

Composition of the various steels used in the calculations are given in Table 5. The lead shield was modeled as 100% lead at 11.29 g/cc. The aluminum honeycomb spacers and aluminum plate were modeled as 100% aluminum at 0.28 and 2.7 g/cm^3, respectively. The Celotex™ was modeled as cellulose, $C_6H_{10}O_5$, at 0.20 g/cm^3 (Ref. 6). (The cane fiberboard (Celotex™) insulation has a nominal density of 16 ± 2 lb/ft^3, resulting in a minimum density of 0.224 g/cm^3. For conservatism, 0.20 g/cm^3 was used.) Payload isotopics assumed for the transport calculations are shown in Table 6.

TABLE 5. Elemental Composition (in weight fractions) of Steels[5]

	316-SS	304L-SS	410-SS	Nitronic-60
Iron	0.6917	0.7117	0.8603	0.655
Nickel	0.1	0.08	0.005	0.08
Molybdenum	0.02	0	0	0
Chromium	0.16	0.18	0.115	0.16
Silicon	0.0075	0.0075	0.0075	0.035
Carbon	0.0008	0.0008	0.0015	0.001
Manganese	0.02	0.02	0.01	0.07
Phosphorus	0	0	0.0004	0
Sulfur	0	0	0.0003	0

TABLE 6. Payload Isotopics Assumed for Transport Calculations

	Material Composition -- Weight %	
	Neutron and (n,γ) Calculations	Gamma Source Calculations
^{238}Pu	59	52.020
^{239}Pu	40	35.268
^{241}Pu	1	0.882
O	0	11.830
density (g/cm^3)	11.46	0.70

SOURCE GENERATION

The source specifications for the Table 1 contents were assessed using the ORIGEN-S[3] and RASTA[4] codes. The approach taken in this evaluation uses ORIGEN-S to perform decay transmutations over 100 years beginning with the Table 1 content description. The source distributions as a function of time are generated for the BUGLE-80 group structure. The maximum source strengths reported for each group during 100 years of decay are used to conservatively establish the ORIGEN-S source distribution. The maximum isotopic activities reported by ORIGEN-S during 100 years of decay are then supplied as input to calculate the source distribution with RASTA. The final source distributions, one for photons and one for neutrons, include the larger of each group source strength as calculated with ORIGEN-S and RASTA.

The isotopic composition of Table 1 is a list of allowable weight percentages that totals to 168 percent (ignoring, of course, inert materials since they do not contribute to the source term). In order to generate bounding source distributions, calculations of source strengths use a basis of 1.68 grams. The calculation assumed isotopic masses equivalent to the weight fractions of the Table 1 envelope.

The form of the actinides in the certified contents is oxide. For the source term calculations, two oxygen atoms are assumed present for each actinide atom. The total oxygen mass is calculated as the sum of the quotients of actinide masses and mass numbers multiplied by 32, the oxide mass number. Naturally occurring oxygen isotopic abundances from the fifteen edition of the Chart of the Nuclides are used to calculate masses of each oxygen isotope. These are listed below.

Element	Mass Number	Naturally Occuring Percentages	Oxygen Masses (grams)
O	16	99.76	2.25E-01
O	17	0.04	9.03E-05
O	18	0.20	4.52E-04
Totals	-	1.0E+02	2.26E-01

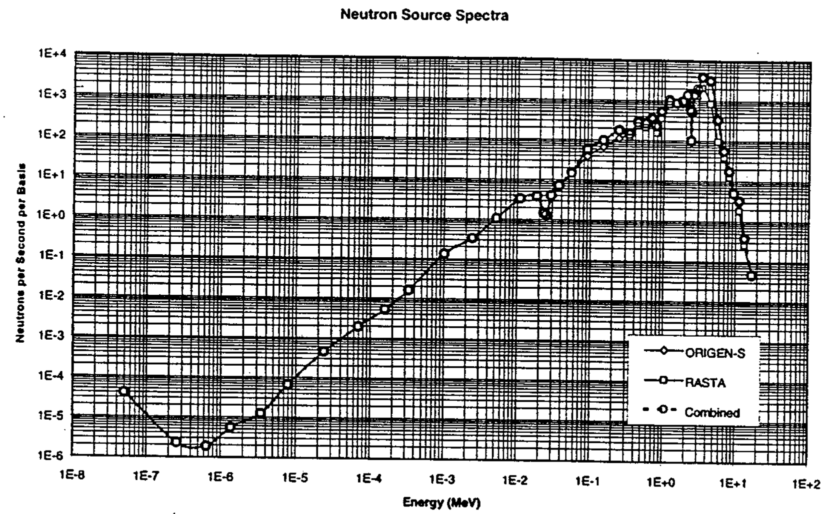
The composition described was used to prepare an ORIGEN-S input deck with the ORIGINATE interface. The deck is given in Appendix A.1. Isotopic activities and energy group source magnitudes were both investigated as a function of decay time up to 100 years. The activities are listed in Table 7. The maximum activities and the decay time required to reach the maximum are also indicated. The maximum activities were used to prepare the RASTA input deck which is also given in Appendix A. Note that Bi-212 and Po-216 have decay alphas at energies higher than those allowed in RASTA execution.

The source spectra calculated using both RASTA and ORIGEN-S are plotted below, first for neutrons and then for photons. The group source magnitudes are plotted versus the mean group energies. The ORIGEN-S spectra uses the peak magnitude of each individual group over the decay time studied. For photons, all maxima occur at 50 years or less. All neutron group maxima occur initially. The RATSA spectra is that generated using the peak isotopic activities tabulated above. The plots include the combined distribution which is obtained by conservatively taking the larger of the two values, the one from ORIGEN-S and the one from RASTA, for each group. Following the plots is Table 8, listing the combined source distributions.

The source specifications of Table 8 conservatively describe radiations that could be emitted from contents of a 9968 package bounded by the envelope of Table 1. The basis for the magnitudes calculated is 1.68 grams of envelope actinide. This represents 168 percent of unit mass limit, implying that for envelope dose calculations the source strengths should be interpreted as particles per second per gram of contained actinide.

TABLE 7. Payload Isotopic Activity (from ORIGEN-S)

Isotope	Activities (Curies per basis) at Decay Time Indicated									Maximum Activity	Maximum Time
	initial	0.3 yr	1.0 yr	3.0 yr	10.0 yr	25.0 yr	50.0 yr	75.0 yr	100.0 yr		
tl208	0.00E+00	2.86E-08	2.77E-07	1.69E-06	5.81E-06	6.47E-06	5.10E-06	3.98E-06	3.11E-06	6.47E-06	25.0 yr
pb212	0.00E+00	7.96E-08	7.69E-07	4.71E-06	1.62E-05	1.80E-05	1.42E-05	1.11E-05	8.64E-06	1.80E-05	25.0 yr
bi212	0.00E+00	7.96E-08	7.69E-07	4.71E-06	1.62E-05	1.80E-05	1.42E-05	1.11E-05	8.64E-06	1.80E-05	25.0 yr
po212	0.00E+00	5.10E-08	4.93E-07	3.02E-06	1.03E-05	1.15E-05	9.09E-06	7.09E-06	5.53E-06	1.15E-05	25.0 yr
po216	0.00E+00	7.96E-08	7.69E-07	4.71E-06	1.62E-05	1.80E-05	1.42E-05	1.11E-05	8.64E-06	1.80E-05	25.0 yr
rn220	0.00E+00	7.96E-08	7.69E-07	4.71E-06	1.52E-05	1.80E-05	1.42E-05	1.11E-05	8.64E-06	1.80E-05	25.0 yr
ra224	0.00E+00	7.96E-08	7.69E-07	4.71E-06	1.62E-05	1.80E-05	1.42E-05	1.11E-05	8.64E-06	1.80E-05	25.0 yr
ra228	0.00E+00	3.90E-10	1.25E-09	3.33E-09	7.69E-09	1.04E-08	1.09E-08	1.10E-08	1.10E-08	1.10E-08	75.0 yr
ac228	0.00E+00	3.90E-10	1.25E-09	3.33E-09	7.69E-09	1.04E-08	1.09E-08	1.10E-08	1.10E-08	1.10E-08	75.0 yr
th228	0.00E+00	7.96E-08	7.69E-07	4.71E-06	1.62E-05	1.80E-05	1.42E-05	1.11E-05	8.64E-06	1.80E-05	25.0 yr
th230	0.00E+00	2.00E-11	2.22E-10	1.98E-09	2.16E-08	1.30E-07	4.89E-07	1.04E-06	1.74E-06	1.74E-06	100.0 yr
th231	0.00E+00	1.08E-08	1.08E-08	1.09E-08	1.11E-08	1.14E-08	1.20E-08	1.26E-08	1.33E-08	1.33E-08	100.0 yr
th232	1.10E-08	1.10E-08	1.10E-08	1.10E-08	1,10E-08	1.10E-08	1.10E-08	1.10E-08	1.10E-08	1.10E-08	initial
th234	0.00E+00	1.61E-09	1.68E-09	1.68E-09	1.68E-09	1.68E-09	1.68E-09	1.68E-09	1.68E-09	1.68E-09	1.0 yr
pa233	0.00E+00	3.32E-06	3.54E-06	3.56E-06	3.66E-06	3.91E-06	4.40E-06	4.89E-06	5.38E-06	5.38E-06	100.0 yr
pa234m	0.00E+00	1.61E-09	1.68E-09	1.68E-09	1.68E-09	1.68E-09	1.68E-09	1.68E-09	1.68E-09	1.68E-09	1.0 yr
pa234	0.00E+00	2.09E-12	2.19E-12	2.19E-12	2.19E-12	2.19E-12	2.19E-12	2.19E-12	2.19E-12	2.19E-12	1.0 yr
u232	0.00E+00	1.50E-06	4.59E-06	1.09E-05	1.84E-05	1.76E-05	1.38E-05	1.08E-05	8.39E-06	1.84E-05	10.0 yr
u233	0.00E+00	3.07E-12	1.37E-11	4.63E-11	1.56E-10	4.03E-10	8.55E-10	1.36E-09	1.92E-09	1.92E-09	100.0 yr
u234	0.00E+00	1.45E-05	4.81E-05	1.43E-04	4.65E-04	1.10E-03	2.00E-03	2.73E-03	3.34E-03	3.34E-03	100.0 yr
u235	1.08E-08	1.08E-08	1.08E-08	1.09E-08	1.11E-08	1.14E-08	1.20E-08	1.26E-08	1.33E-08	1.33E-08	100.0 yr
u236	0.00E+00	2.62E-10	8.74E-10	2.62E-09	8.73E-09	2.18E-08	4.36E-08	6.53E-08	8.69E-08	8.69E-08	100.0 yr
u237	0.00E+00	2.44E-05	2.36E-05	2.14E-05	1.53E-05	7.40E-06	2.21E-06	6.61E-07	1.97E-07	2.44E-05	0.3 yr
u238	1.68E-09	1.68E-09	1.68E-09	1.68E-09	1.68E-09	1.68E-09	1.68E-09	1.68E-09	1.68E-09	1.68E-09	initial
np237	3.53E-06	3.53E-06	3.54E-06	3.56E-06	3.66E-06	3.91E-06	4.40E-06	4.89E-06	5.38E-06	5.38E-06	100.0 yr
np239	0.00E+00	2.00E-07	2.00E-07	2.00E-07	1.99E-07	1.99E-07	1.99E-07	1.98E-07	1.98E-07	2.00E-07	0.3 yr
pu236	5.23E-04	4.86E-04	4.11E-04	2.55E-04	4.79E-05	1.33E-06	3.37E-09	8.56E-12	2.17E-14	5.23E-04	initial
pu238	1.71E+01	1.71E+01	1.70E+01	1.67E+01	1.58E+01	1.41E+01	1.15E+01	9.47E+00	7.77E+00	1.71E+01	initial
pu239	2.48E-02	2.48E-02	2.48E-02	2.48E-02	2.48E-02	2.48E-02	2.48E-02	2.48E-02	2.48E-02	2.48E-02	initial
pu240	2.95E-02	2.95E-02	2.95E-02	2.95E-02	2.95E-02	2.94E-02	2.94E-02	2.93E-02	2.92E-02	2.95E-02	initial
pu241	1.03E+00	1.02E+00	9.85E-01	8.95E-01	6.38E-01	3.09E-01	9.24E-02	2.76E-02	8.25E-03	1.03E+00	initial
pu242	5.93E-05	5.93E-05	5.93E-05	5.93E-05	5.93E-05	5.93E-05	5.93E-05	5.93E-05	5.93E-05	5.93E-05	initial
am241	3.43E-02	3.48E-02	3.59E-02	3.88E-02	4.68E-02	5.64E-02	6.13E-02	6.09E-02	5.92E-02	6.13E-02	50.0 yr
am243	2.00E-07	2.00E-07	2.00E-07	2.00E-07	1.99E-07	1.99E-07	1.99E-07	1.98E-07	1.98E-07	2.00E-07	initial
cm244	8.10E-05	8.01E-05	7.79E-05	7.22E-05	5.52E-05	3.11E-05	1.19E-05	4.58E-06	1.76E-06	8.10E-05	initial
totals	1.83E+01	1.82E+01	1.81E+01	1.77E+01	1.66E+01	1.45E+01	1.17E+01	9.62E+00	7.90E+00	1.82E+01	NA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Neutrons per Second per Basis
1E+4
1E+3
1E+2
1E+1
1E+0
1E-1
1E-2
1E-3
1E-4
1E-5
1E-6
1E-8
1E-7
1E-6
1E-5
1E-4
1E-3
1E-2
1E-1
1E+0
1E+1
1E+2
Energy (MeV)
ORIGEN-S
RASTA
Combined

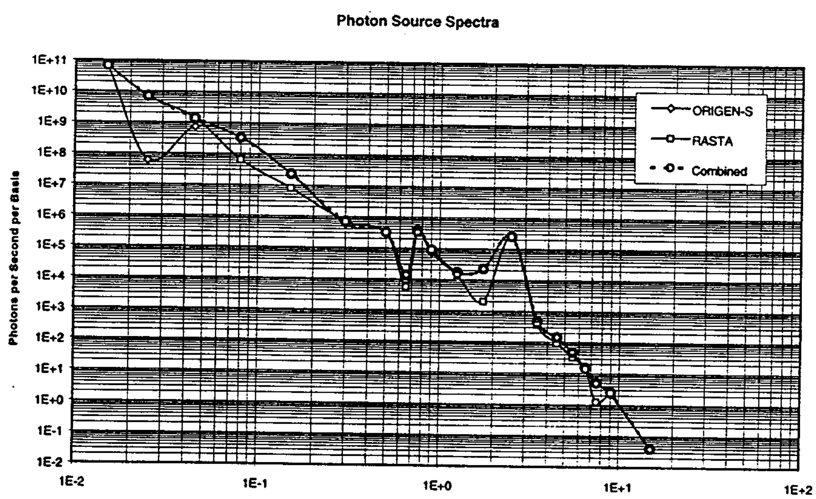

Photon Source Spectra
Photons per Second per Basis
1E+11
1E+10
1E+9
1E+8
1E+7
1E+6
1E+5
1E+4
1E+3
1E+2
1E+1
1E+0
1E-1
1E-2
1E-2
1E-1
1E+0
1E+1
1E+2
Energy (MeV)
ORIGEN-S
RASTA
Combined

TABLE 8. Neutron and Photon Source Distributions

BUGLE Neutron Group Number	Energy Group Lower Bound (MeV)	Energy Group Upper Bound (MeV)	Neutron Source (n/s per g actinide)
47	1.0000E-11	1.0000E-07	3.97E-05
46	1.0000E-07	4.1400E-07	2.26E-06
45	4.1400E-07	8.7642E-07	1.87E-06
44	8.7642E-07	1.8554E-06	5.53E-06
43	1.8554E-06	5.0435E-06	1.26E-05
42	5.0435E-06	1.0667E-05	6.76E-05
41	1.0667E-05	3.7267E-05	4.58E-04
40	3.7267E-05	1.0130E-04	1.94E-03
39	1.0130E-04	2.1445E-04	5.26E-03
38	2.1445E-04	4.5400E-04	1.61E-02
37	4.5400E-04	1.5846E-03	1.32E-01
36	1.5846E-03	3.3546E-03	3.32E-01
35	3.3546E-03	7.1017E-03	1.05E+00
34	7.1017E-03	1.5034E-02	3.36E+00
33	1.5034E-02	2.1875E-02	3.92E+00
32	2.1875E-02	2.4176E-02	1.48E+00
31	2.4176E-02	2.6058E-02	1.28E+00
30	2.6058E-02	3.1828E-02	4.08E+00
29	3.1828E-02	4.0868E-02	7.21E+00
28	4.0868E-02	6.7379E-02	1.55E+01
27	6.7379E-02	1.1109E-01	5.80E+01
26	1.1109E-01	1.8316E-01	9.99E+01
25	1.8316E-01	2.9720E-01	1.78E+02
24	2.9720E-01	3.6883E-01	1.51E+02
23	3.6883E-01	4.9787E-01	2.97E+02
22	4.9787E-01	6.0810E-01	2.79E+02
21	6.0810E-01	7.4274E-01	3.65E+02
20	7.4274E-01	8.2085E-01	2.32E+02
19	8.2085E-01	1.0026E+00	5.37E+02
18	1.0026E+00	1.3534E+00	1.04E+03
17	1.3534E+00	1.6530E+00	8.77E+02
16	1.6530E+00	1.9205E+00	9.88E+02
15	1.9205E+00	2.2313E+00	1.40E+03
14	2.2313E+00	2.3457E+00	6.06E+02
13	2.3457E+00	2.3653E+00	1.03E+02
12	2.3653E+00	2.4660E+00	5.21E+02
11	2.4660E+00	2.7253E+00	1.53E+03
10	2.7253E+00	3.0119E+00	1.94E+03
9	3.0119E+00	3.6788E+00	3.86E+03
8	3.6788E+00	4.9659E+00	3.18E+03
7	4.9659E+00	6.0653E+00	3.43E+02
6	6.0653E+00	7.4082E+00	5.64E+01
5	7.4082E+00	8.6071E+00	1.78E+01
4	8.6071E+00	1.0000E+01	5.14E+00
3	1.0000E+01	1.2214E+01	3.33E+00
2	1.2214E+01	1.4191E+01	3.82E-01
1	1.4191E+01	1.9600E+01	4.73E-02

BUGLE Photon Group Number	Energy Group Lower Bound (MeV)	Energy Group Upper Bound (MeV)	Photon Source (γ/s per g actinide)
20	1.00E-02	2.00E-02	6.67E+10
19	2.00E-02	3.00E-02	6.79E+09
18	3.00E-02	6.00E-02	1.32E+09
17	6.00E-02	1.00E-01	3.24E+08
16	1.00E-01	2.00E-01	2.27E+07
15	2.00E-01	4.00E-01	6.96E+05
14	4.00E-01	6.00E-01	3.21E+05
13	6.00E-01	7.00E-01	1.36E+04
12	7.00E-01	8.00E-01	3.72E+05
11	8.00E-01	1.00E+00	8.76E+04
10	1.00E+00	1.50E+00	1.69E+04
9	1.50E+00	2.00E+00	2.24E+04
8	2.00E+00	3.00E+00	2.52E+05
7	3.00E+00	4.00E+00	4.61E+02
6	4.00E+00	5.00E+00	1.46E+02
5	5.00E+00	6.00E+00	4.68E+01
4	6.00E+00	7.00E+00	1.52E+01
3	7.00E+00	8.00E+00	4.96E+00
2	8.00E+00	1.00E+01	2.46E+00
1	1.00E+01	2.00E+01	3.90E-02

The most significant contributor to the neutron source magnitude is the alpha,n component for Pu-238. This component is approximately 75 percent of the total specific neutron source magnitude, 1.87E+4 neutrons per second. From the photon dose rates perspective, the most significant isotope in the envelope is Pu-236. The isotope Tl-208 in the Pu-236 decay chain emits a 2.6 MeV gamma-ray with a yield of nearly one. The source distribution of Table 8 was computed assuming the maximum activity of Tl-208 is present (which occurs after approximately 25 years of decay). The Tl-208 photons comprise essentially all of the photons in the 2 to 3 MeV group. The total specific photon source magnitude is 7.51E+10 photons per second.

RESULTS – COMPUTED DOSE RATES

The discussion of the MCNP transport calculations is presented in two sections – one for Hypothetical Accident Conditions (HAC) and one for Normal Conditions of Transport NCT). The package geometry is, of course, different between NCT and HAC, but as mentioned earlier, different assumptions were made regarding source location and configuration. Those assumptions are summarized in Table 9 below. Essentially, the source is placed as close to the receptor location(s) as possible. Neutron source calculations assume a 1.277 cm radius sphere at the theoretical pu-oxide density, with the intent of maximizing sub-critical multiplication. Photon source calculations assume thin source regions at bulk pu-oxide density, with the intent of maximizing leakage.

Appendix B gives the MCNP job names for the different calculations, and discusses the conversion factors needed to convert the MCNP results into units of mrem/h.

TABLE 9. Summary of Neutron and Photon Source Configurations

Dose Receptor Location	Neutron Source Configuration	Photon Source Configuration
Side	11.46 g/cm^3 sphere; bottom, side PCV	0.70 g/cm^3, ¼-annulus, side of PCV
Bottom	11.46 g/cm^3 sphere; bottom, side PCV	0.70 g/cm^3 disc, bottom of PCV
Top	11.46 g/cm^3 sphere; top, side PCV	0.70 g/cm^3 disc, top of PCV

Hypothetical Accident Conditions – Neutron Sources

The neutron source distribution used for these calculations is shown in Table 8. Scoping calculations indicated that of the 47 groups, neutrons in Groups 7 – 25 contributed > 99% of the total neutron dose, and neutrons in Groups 5 – 25 contributed > 99% of the total (n,γ) gamma dose. Consequently, neutron dose calculations typically used neutrons from

Groups 7 – 25 only; gamma doses from (n,γ) reactions were based on neutrons from Groups 5 – 25 only.

Results from the neutron source calculations for HAC are shown in Table 10. Shown in columns 3 and 4 are the computed mean and 1-sigma uncertainty (derived from the MCNP calculations). The last column is the computed mean plus 3σ. Table 10 shows that the gamma dose from neutron induced events is negligible relative to the neutron dose.

TABLE 10. Neutron Source Calculations – HAC

	Receptor Location	DOSE (mrem/h)		
		Mean	1-sigma	Mean + 3σ
Neutron	side @ 1 m	2.286	9.14E-04	2.289
	bottom @ 1 m	1.887	7.55E-04	1.890
	top @ 1 m	0.708	1.42E-03	0.713
(n,γ)	side @ 1 m	7.461E-03	1.34E-05	7.502E-03
	bottom @ 1 m	5.109E-03	8.17E-06	5.134E-03
	top @ 1 m	1.904E-03	1.07E-05	1.936E-03

Hypothetical Accident Conditions – Photon Sources

The photon source distribution used for these calculations is shown in Table 8. Scoping calculations indicated that of the 20 groups, photons in Groups 8 – 18 contributed > 99% of the total photon dose. Consequently, photon source calculations used photons from Groups 8 – 18 only. To ensure proper sampling of the photon source, two blocks of photon transport calculations were performed – one block with photon source of Groups 16 – 18, and one block with the photons source of Groups 8 – 15. Results from the photon source calculations for HAC are shown in Table 11.

TABLE 11. Photon Source Calculations – HAC

Receptor Location	Photon Source	DOSE (mrem/h)		
		Mean	1-sigma	Mean + 3σ
Side @ 1 m	Groups 16 -18	2.814	1.52E-02	2.860
	Groups 8 - 15	1.665	8.33E-04	1.668
Bottom @ 1 m	Groups 16 -18	1.928	1.29E-02	1.967
	Groups 8 - 15	1.374	8.24E-04	1.377
Top @ 1 m	Groups 16 -18	0.0008	6.60E-05	0.00100
	Groups 8 - 15	0.1534	3.91E-03	0.166

Hypothetical Accident Conditions – SUMMARY

Table 12 summarizes results for the HAC cases. The 1σ uncertainties on the total gamma dose in Table 12 are calculated using the square-root-sum-of-squares method for the three components (Groups 8 – 15, Groups 16 – 18, and the (n,γ) events). One can note that the contribution from (n,γ) events is negligible since it is less than the uncertainty associated with the photon source calculations.

TABLE 12. HAC Summary

	Receptor Location	DOSE (mrem/h)		
		Mean	1-sigma	Mean + 3σ
Neutron	side @ 1 m	2.286	9.14E-04	2.289
	bottom @ 1 m	1.887	7.55E-04	1.890
	top @ 1 m	0.708	1.42E-03	0.713
Photon	side @ 1 m	4.486	1.52E-02	4.532
	bottom @ 1 m	3.307	1.29E-02	3.346
	top @ 1 m	0.1561	3.91E-03	0.168

Normal Conditions of Transport – Neutron Sources

The NCT calculations used the same abbreviated neutron source as the HAC calculations. Neutron dose calculations used neutrons from Groups 7 – 25 only; gamma doses from (n,γ) reactions were based on neutrons from Groups 5 – 25 only. Results from the neutron source calculations for NCT are shown in Table 13.

An unusual result was noted when comparing Tables 10 and 13. Neutron doses at 1 meter are higher for NCT (0.754 mrem/hr) than for HAC (0.713 mrem/h) even though there is more shielding present under NCT, and the distance between the payload and the (1 meter) dose receptor location is greater for NCT than HAC. The explantion lies in the fact that the additional shielding materials present under NCT serve as a neutron scattering source – a source that is not present for HAC. This scattering source is large enough to offset the effect of the additional shielding. Additional information on this phenomena can be obtained from a review of the MCNP detector tally edits. Those edits show how each individual cell's contribution to the dose changes between NCT and HAC.

TABLE 13. Neutron Source Calculations – NCT

		DOSE (mrem/h)		
		Mean	**1-sigma**	**Mean + 3σ**
Neutron	side @ surface	72.48	0.2682	73.29
	bottom @ surface	54.64	0.4153	55.89
	top @ surface	21.03	0.07783	21.27
	side @ 1 m	1.740	0.0006962	1.743
	bottom @ 1 m	1.463	0.0007314	1.466
	top @ 1 m	0.7525	0.0003762	0.7537
(n,γ)	side @ surface	0.1745	0.003611	0.1853
	bottom @ surface	0.1949	0.002398	0.2022
	top @ surface	6.825E-02	3.412E-04	6.927E-02
	side @ 1 m	4.030E-03	9.672E-06	4.060E-03
	bottom @ 1 m	4.395E-03	1.846E-05	4.451E-03
	top @ 1 m	2.033E-03	2.439E-06	2.041E-03

Normal Conditions of Transport – Photon Sources

The photon source calculations for NCT used photons from only Groups 8 – 15. HAC conditions assumed significantly less shielding materials than will be present under NCT. For HAC, the low energy photons in Groups 16 –18 were numerous enough that the small fraction that did manage to penetrate the PCV and SCV make a significant contribution to the dose. The additional intervening materials present for NCT effectively eliminates the contribution from those energy groups. (Evidence of this is seen in Table 11 where the contribution to the dose above the package from Groups 16 – 18 is negligible. Due to the PCV and SCV closures (see, for example, Figure 3) there is more shielding above the package than on its side or bottom.) Results from the photon source calculations for HAC are shown in Table 14.

TABLE 14. Photon Source Calculations – NCT

		DOSE (mrem/h)		
		Mean	**1-sigma**	**Mean + 3σ**
Photon Source	side @ surface	12.52	0.2816	13.37
	bottom @ surface	24.61	0.2141	25.26
	top @ surface	2.318	2.457E-02	2.392
	side @ 1 m	0.4226	1.268E-03	0.4264
	bottom @ 1 m	0.7084	6.376E-04	0.7104
	top @ 1 m	0.1097	9.872E-04	0.1127

Normal Conditions of Transport – SUMMARY

Table 15 summarizes results for the NCT cases. The 1σ uncertainties on the total gamma dose in Table 15 are calculated using the square-root-sum-of-squares method for the two components (Groups 8 – 15 and the (n,γ) events). As noted with the HAC cases, the contribution from (n,γ) events is negligible.

TABLE 15. NCT Summary

		DOSE (mrem/h)		
		Mean	1-sigma	Mean + 3σ
Neutron	side @ surface	72.48	0.2682	73.29
	bottom @ surface	54.64	0.4153	55.89
	top @ surface	21.03	0.07783	21.27
	side @ 1 m	1.740	0.0006962	1.743
	bottom @ 1 m	1.463	0.0007314	1.466
	top @ 1 m	0.7525	0.0003762	0.7537
Photon	side @ surface	12.69	0.2817	13.54
	bottom @ surface	24.80	0.2141	25.45
	top @ surface	2.318	2.457E-02	2.460
	side @ 1 m	0.4226	1.268E-03	0.4305
	bottom @ 1 m	0.7128	6.378E-04	0.7148
	top @ 1 m	0.1117	9.872E-04	0.1147

CONCLUSIONS

The results from Tables 12 and 15 are combined and appear in Table 2. They show that the payload contents of Table 1 (100 gram actinide limit) in the 9968 package satisfy the regulatory requirements for a non-exclusive use package. A substantial margin is noted between the regulatory limit and the computed results even though the source term was assumed to be 168% of the nominal source.

The transport index based upon shielding considerations (the maximum radiation level in mrem/hr at 1 meter, rounded up to the next tenth) for this payload in the 9968 package is 2.2 (see Table 2).

Figure 1. Schematic of 9968 Shipping Package

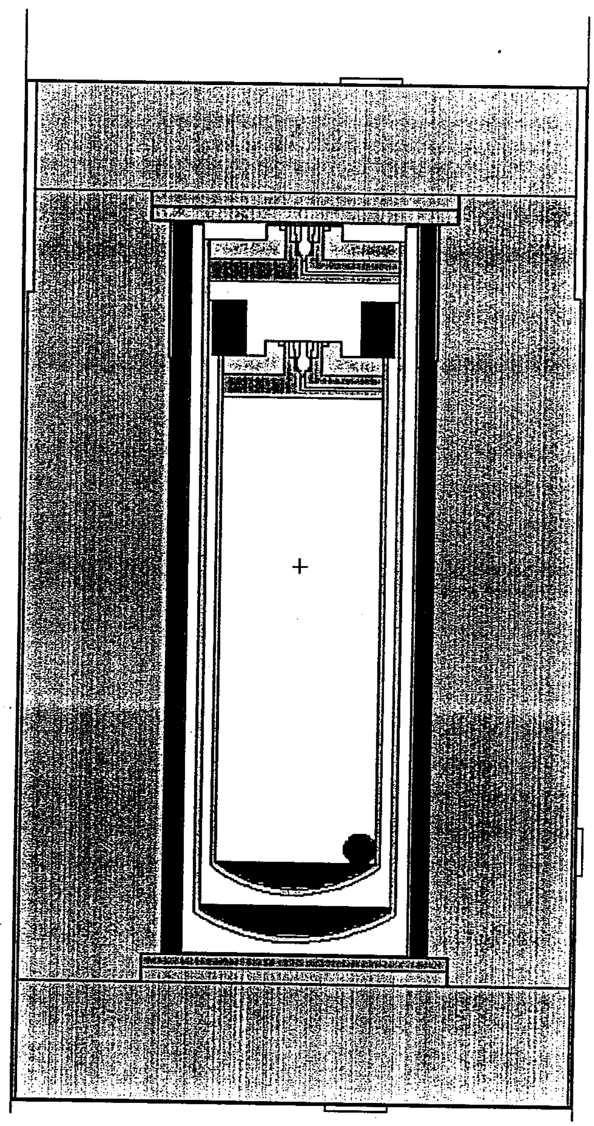


Figure 2. Detail of PCV and SCV Closures

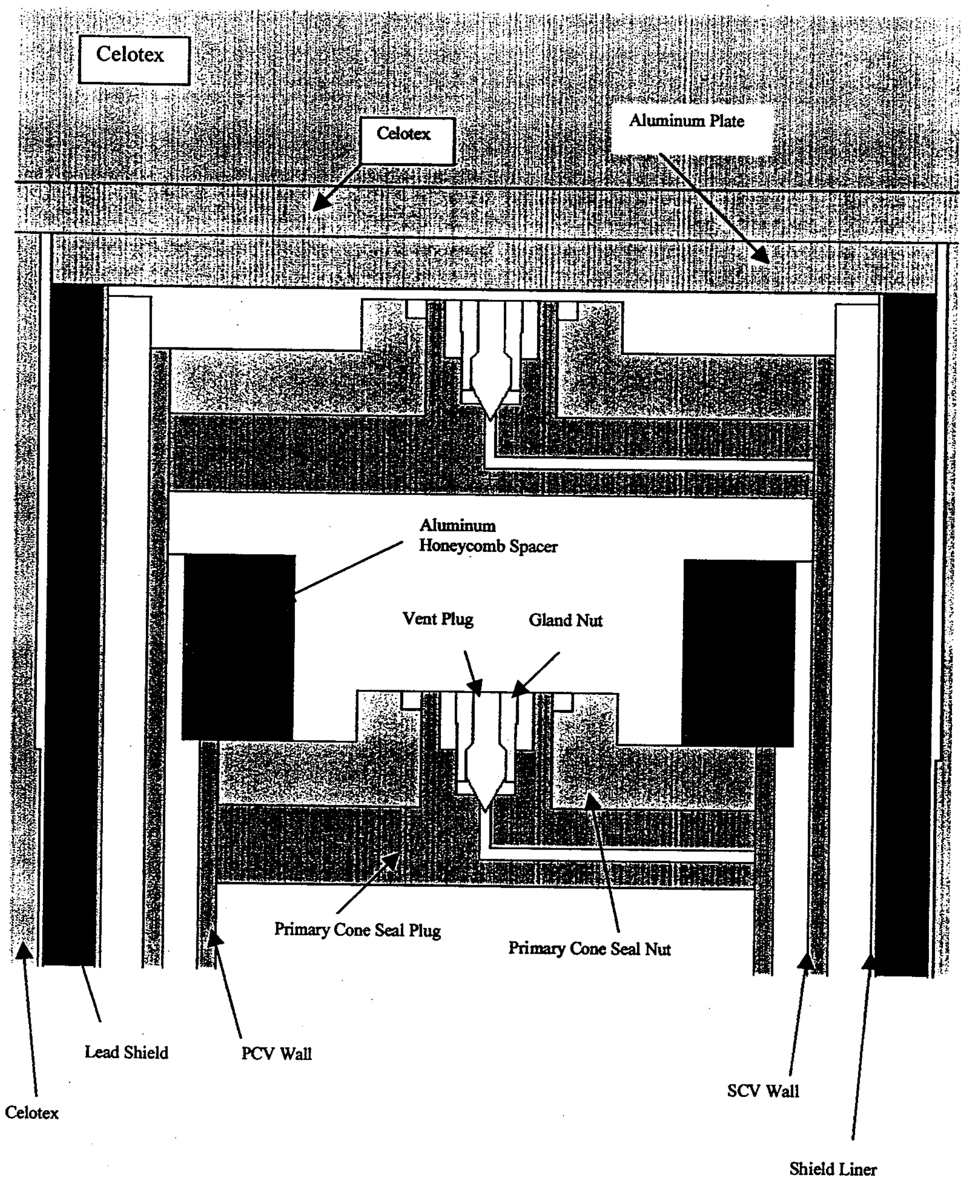


FIGURE 3

PCV/SCV CLOSURE GEOMETRY (Dimensions in cm)

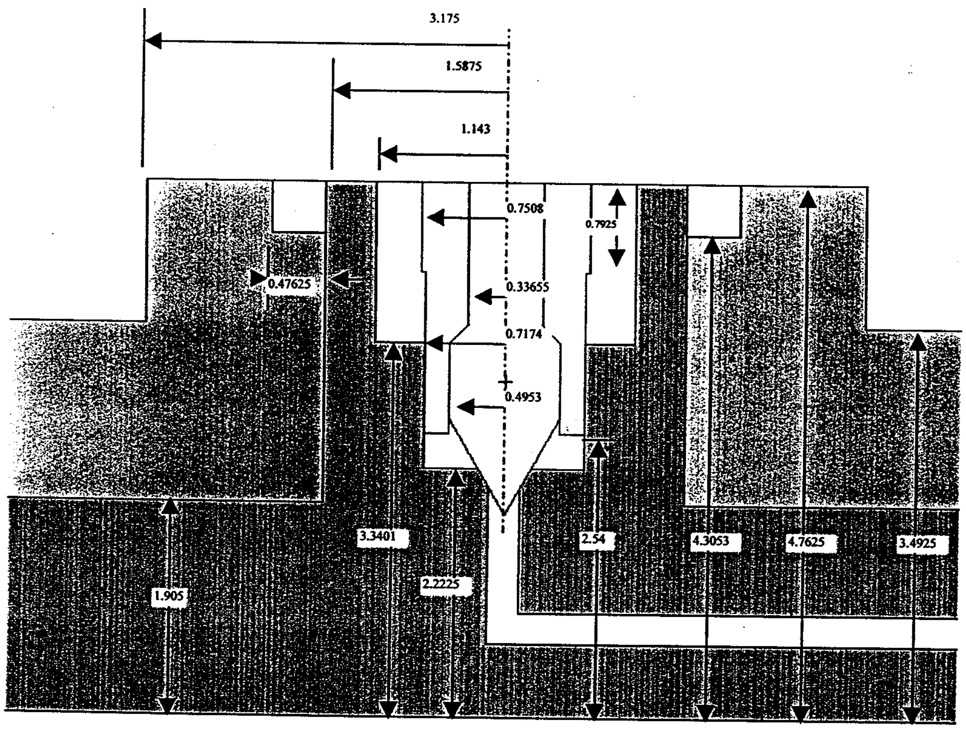


Figure 4. Geometry for Gamma Source Calculations, Dose Locations on Side

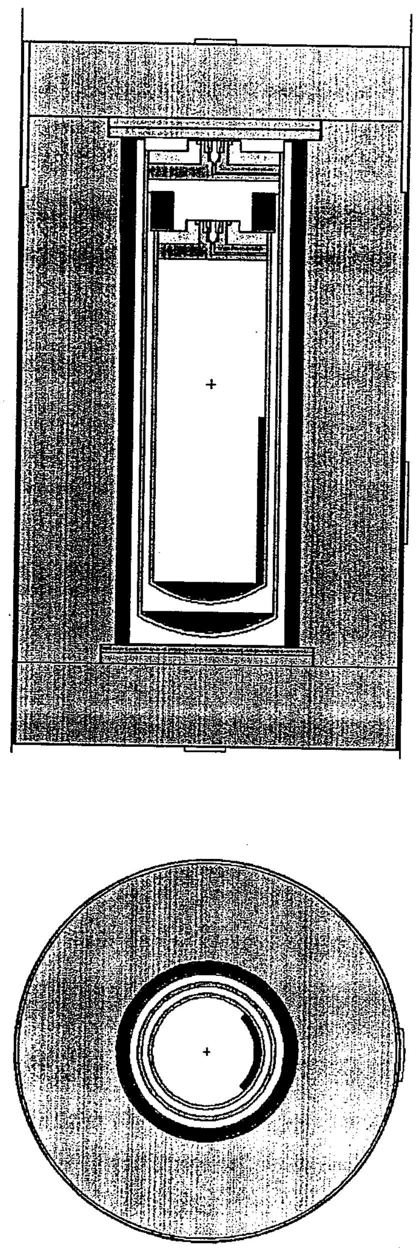
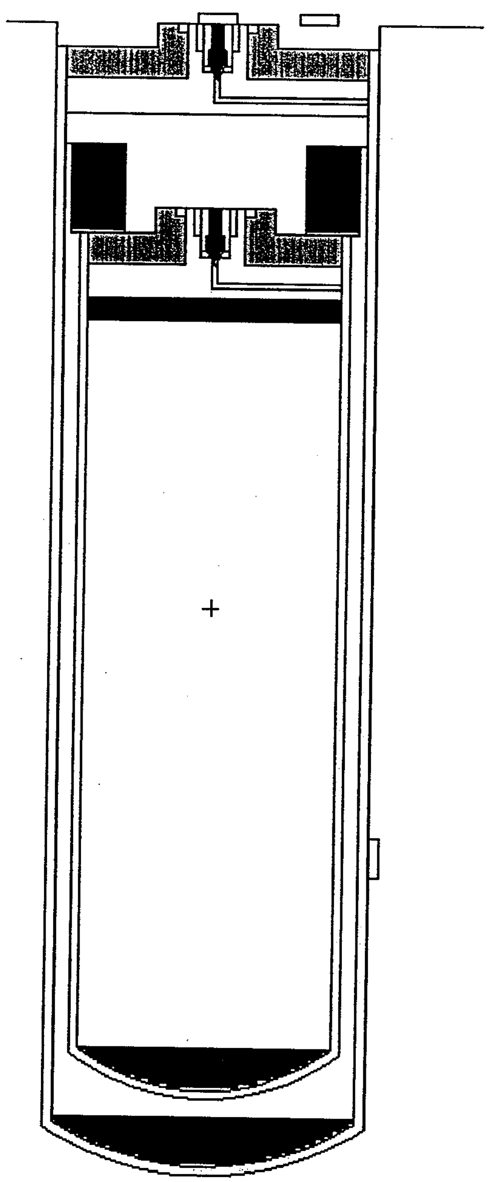


Figure 5. Geometry Used for Hypothetical Accident Conditions (Disc Gamma Source at Top of PCV)



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APPENDIX A

SAMPLE INPUT DECKS

A.1. ORIGEN-S Input Deck:

```
#ORIGENS
0$$   E T
DECAY CASE
3$$ 21 1 1 47  A16 2  A33 20  E T
35$$ 0 T
54$$ A8 1 A11 1  E
56$$ A2 8  A6 1  A10  0  A13 16  A14 5  A15 3 E
57** 0 E T
ENVELOPE D OXIDE SOURCE TERM CALCULATION
1.68 GRAMS ENVELOPE D ACTINIDE
60** .3 1 3 10 25 50 75 100
61** F.000000000000001
65$$
'GRAM-ATOMS   GRAMS    CURIES      WATTS-ALL  WATTS-GAMMA
     3Z      1  1  0    1  1  0       3Z          3Z          6Z
     3Z      1  1  0    1  1  0       3Z          3Z          6Z
     3Z      1  1  0    1  1  0       3Z          3Z          6Z
81$$ 2 0 26 1  E
82$$  2  2  2  2  2  2  2  2
83**  2.E+7        1.E+7        8.E+6        7.E+6        6.E+6
 5.E+6        4.E+6        3.E+6        2.E+6        1.5E+6
 1.E+6        8.E+5        7.E+5        6.E+5        4.E+5
 2.E+5        1.E+5        6.E+4        3.E+4        2.E+4
 1.E+4
84**  1.96403E+7   1.41907E+7   1.2214E+7    1.E+7        8.60708E+6
 7.40818E+6   6.06531E+6   4.96585E+6   3.67879E+6   3.01194E+6
 2.72532E+6   2.46597E+6   2.36525E+6   2.3457E+6    2.2313E+6
 1.9205E+6    1.65299E+6   1.35335E+6   1.00259E+6   8.2085E+5
 7.42736E+5   6.08101E+5   4.97871E+5   3.68832E+5   2.97211E+5
 1.83156E+5   1.1109E+5    6.737937E+4  4.08677E+4   3.18278E+4
 2.60584E+4   2.41755E+4   2.18749E+4   1.50344E+4   7.101738E+3
 3.35463E+3   1.58461E+3   4.53999E+2   2.14454E+2   1.01301E+2
 3.726649E+1  1.0677E+1    5.04348E+0   1.85539E+0   8.76425E-1
 4.13994E-1   1.00001E-1   1.00001E-5
73$$  952410  952430  962440  932370  942360  942380  942390  942400
 942410  942420  902320  922350  922380  80160  80170  80180
74** 1.00E-02 1.00E-06 1.00E-06 5.00E-03 1.00E-06 1.00E+00 4.00E-01
1.30E-01 1.00E-02 1.50E-02 1.00E-01 5.00E-03 5.00E-03 2.25E-01 9.03E-05
4.52E-04
75$$  2  2  2  2  2  2  2  2  2  2  2  2  2  1  1  1  T
ENVELOPE D OXIDE SOURCE TERM CALCULATION TIMESTEP 1
ENVELOPE D OXIDE SOURCE TERM CALCULATION TIMESTEP 2
ENVELOPE D OXIDE SOURCE TERM CALCULATION TIMESTEP 3
ENVELOPE D OXIDE SOURCE TERM CALCULATION TIMESTEP 4
ENVELOPE D OXIDE SOURCE TERM CALCULATION TIMESTEP 5
ENVELOPE D OXIDE SOURCE TERM CALCULATION TIMESTEP 6
ENVELOPE D OXIDE SOURCE TERM CALCULATION TIMESTEP 7
ENVELOPE D OXIDE SOURCE TERM CALCULATION TIMESTEP 8
56$$ F0 T
END
```

A.2. RASTA Input Deck:

```
OXIDE SOURCE TERM CALCULATION
1.68 GRAMS ENVELOPE D ACTINIDE
-1 -1 1 0 0 0 0
33 1
812080 6.47E-06
822120 1.80E-05
/ 832120 1.80E-05
842121 1.15E-05
/ 842160 1.80E-05
862200 1.80E-05
882240 1.80E-05
882280 1.10E-08
892280 1.10E-08
902280 1.80E-05
902300 1.74E-06
902310 1.33E-08
902320 1.10E-08
902340 1.68E-09
912330 5.38E-06
912341 1.68E-09
912340 2.19E-12
922320 1.84E-05
922330 1.92E-09
922340 3.34E-03
922350 1.33E-08
922360 8.69E-08
922370 2.44E-05
922380 1.68E-09
932370 5.38E-06
932390 2.00E-07
942360 5.23E-04
942380 1.71E+01
942390 2.48E-02
942400 2.95E-02
942410 1.03E+00
942420 5.93E-05
952410 6.13E-02
952430 2.00E-07
962440 8.10E-05
3 2
80160 2.25E-01
80170 9.03E-05
80180 4.52E-04
```

A.3. MCNP Input (HAC, Gamma Source Groups 16 – 18, Bottom Dose) Deck:

```
message:     outp=gkb2a.o runtpe=gkb2a.r

Photon calc with Kelsey's source.  Groups 16 - 18.
c
c  This is 9968 drum modified from my 9975 drum.
c  HAC conditions.  Looking at bottom.
c  Disc    source region on bottom.
c
c 9968 Primary containment vessel.
c    Gland Plug (316-SS)
1    5    -7.895      (-29 -4 -49 32):(-3 20 -23):(-50 49 -20)        u=1
c    Gland Nut  (410-SS)
2    6    -7.895      (4 -5  17 -49):(50 -5 49 -20):(3 -5  20 -19):
                                             (3 -6  19 -23)           u=1
c    Cone Seal Plug (304L-SS)
3    7    -7.895      (7 -8  18 -23):(5 -8  16 -18):
                     ((29 1 -8 32 -16):(1 -10 32 -15)):
                     ((14 -32 -10) (1:-30) (28:-31))                  u=1
4    0                (29 16 -17 -5):(29 -4 17)                       u=1
5    0               ((-1 29  32):(-1 30 -32)):(-28 31 -10)           u=1
c    Cone Seal Nut (Nitronic-60 SST)
6    8    -7.895      (15 -21  8 -10):(21 -22 8 24 -25 26 -27):
                                 (22 -23 9 24 -25 26 -27)             u=1
7    0               22 -23 8 -9                                      u=1
8    0                (18 -19 5 -7):(19 -23 6 -7)                     u=1
c    PCV wall (304L-SS)
9    7    -7.895      (10 -11 35 -21):(-33 34 -35):(-10 34 35 -36)    u=1
c    Contents of PCV
10   4    -0.70        -10                  36 -115                   u=1
11   0                (-10 115 -14)                                   u=1
c    Al honeycomb spacer @ bottom
12   2    -0.28        -10 -34 -36                                    u=1
13   0               ((21 -23 -46) (-24:25:-26:27)):(-46 23):48       u=1
c    Al honeycomb spacer @ top
14   2    -0.28        46 -47  21 -48                                 u=1
15   0                 (11 -21):(-11 33 -35):(21 47 -48)              u=1
16   5    -7.895      (-29 -4 -49 32):(-3 20 -23):(-50 49 -20)        u=2
17   6    -7.895      (4 -5  17 -49):(50 -5 49 -20):(3 -5  20 -19):
                                             (3 -6  19 -23)           u=2
18   7    -7.895      (7 -8  18 -23):(5 -8  16 -18):
                     ((29 1 -8 32 -16):(1 -40 32 -15)):
                     ((51 -32 -40) (1:-30) (28:-31))                  u=2
19   0                (29 16 -17 -5):(29 -4 17)                       u=2
20   0               ((-1 29  32):(-1 30 -32)):(-28 31 -40)           u=2
21   8    -7.895      (15 -21  8 -40):(21 -22 8 24 -25 26 -27):
                                 (22 -23 9 24 -25 26 -27)             u=2
22   0               22 -23 8 -9                                      u=2
23   0                (18 -19 5 -7):(19 -23 6 -7)                     u=2
24   7    -7.895      (40 -41 44 -21):(-42 43 -44):(-40 43 44 -45)    u=2
25   0                 -40  55 -51    fill=1 (0.0 0.0 -9.630)         u=2
26   2    -0.28        -40 -43 -55                                    u=2
27   0               ((21 -23 -41) (-24:25:-26:27)):23                u=2
28   0               -100 -102 103                                    u=2
29   0               -101 -102 103                                    u=2
30   0                104 -105 106 -107 -108 109                      u=2
31   0               -112                                             u=2
32   0               -116                                             u=2
33   0               ((-41 42 -44):(41 -23)) (100:-103:102) 112 116
                     (101:-103:102) (-104:105:-106:107:-109:108)      u=2
34   0               -52 53 -54     fill=2 (0.0 0.0 28.30270)
35   0                52:-53:54

1    cz    0.13891          $Vertical leak test port
2    cz    0.23749          $Leak test port plug closure hole
3    cz    0.33655          $Top inner component of leak test port plug
4    cz    0.49530          $Lower inner piece  of leak test port plug
5    cz    0.714375         $9/32" bottom hole, leak test port plug
6    cz    0.750814         $Top outer component of leak test port plug
7    cz    1.14300          $0.45" topp   hole, leak test port plug
8    cz    1.58750          $0.625" top OR cone seal
9    cz    2.06375          $0.8125" top IR cone seal nut
10   cz    6.57098          $Max PCV IR (5.047" ID nor, 5.174" max)
11   cz    7.02564          $Min PCV OR (5.563" OD nor, 5.532" min)
12   pz   -1.27000          $Outer Surface - Bottom of PCV  (-0.5")
13   pz   -0.81534          $Inner Surface - Bottom of PCV
14   pz   40.32250          $Lower surface of male cone seal PCV
15   pz   42.22750          $Top surface of male cone seal PCV
```

```
16    pz    42.54500                 $Lowest surface of leak test port plug
17    pz    42.86250                 $Lowest tip of outer plug   (0.875" from top)
18    pz    43.66260                 $Outer top lip on cone seal (0.56" from top)
19    pz    44.29252                 $Extent of top inner component of port plug
20    pz    43.81627                 $Extent of leak test port plug
21    pz    43.81500                 $Top surface of cone seal nut  (17.25")
22    pz    44.62780                 $Lip on cone seal nut of PCV
23    pz    45.08500                 $Top Surface of PCV
24    px    -3.175                   $Cone seal nut left
25    px    3.175                    $Cone seal nut right
26    py    -3.175                   $Cone seal nut left
27    py    3.175                    $Cone seal nut right
28    c/x    0.0  41.1099  0.13891       $Horiz. Leak test port
29    kz    42.1336553   0.33333333333    $Plug inner tip
30    pz    40.970993                $Bottom of vertical leak test port.
31    px    0.00                     $Left tip of horizontal leak test port.
32    pz    42.1336553               $Plug inner tip
33    sz    10.16  11.43             $Cask Bottom Outer
34    sz    10.16  10.97534          $Cask bottom Inner
35    pz     1.1441649
36    pz     1.37
40    cz     7.87019                 $Max SCV IR (6.065" ID nor, 6.197" max)
41    cz     8.37438                 $Min SCV OR (6.625" OD nor, 6.594" min)
42    sz     0.32639   15.23619       $SCV Cask Bottom Outer Surface
43    sz     0.32639   14.732         $SCV Cask Bottom Inner Surface
44    pz    -12.40197
45    pz    -12.12720
46    cz     4.7625                  $IR top honeycomb spacer (3-3/4" ID)
47    cz     7.46125                 $OR top honeycomb spacer (5-7/8" OD)
48    pz    48.387                   $Top of top spacer on PCV (1.8" tall)
49    pz    43.65752                 $Bottom plane plug upper cone
50    kz    44.15282     1.00        $Plug upper cone
51    pz    40.32250                 $Same as surface 14 (for SCV)
52    cz    523.0
53    pz   -500.0
54    pz    590.0
55    pz    -11.86561                $Top surface of SCV honeycomb
60    cz     9.3846                  $IR SS liner of Pb shield
61    cz     9.5377                  $IR Pb shield
62    cz    10.7823                  $OR Pb shield
63    cz    10.922                   $IR cane fiberboard (bottom @ 8.6" ID)
81    cz    11.049                   $IR cane fiberboard (top    @ 8.7" ID)
64    cz    12.70                    $End rotation plate
65    cz    22.479                   $OR cane fiberboard top     (17.7" OD)
66    cz    22.86                    $OR cane fiberboard bottom  (18"   OD)
67    cz    23.1775                  $IR drum
68    cz    23.2989                  $OR drum (18 gauge, 0.0478")
69    pz     0.0                     $Bottom outside surface drum
70    pz     0.1087                  $bottom inside  surface drum
71    pz    10.0147                  $To bottom of rotation plate (+3.9")
72    pz    11.2593                  $To bottom of lead plate (+0.49")
73    pz    12.2753                  $To bottom of lead shield liner (+0.49")
74    pz    12.4277                  $To top of SS liner of lead shield (+0.06")
75    pz    67.5203                  $Top/Bottom Celotex division  (6.9" below top)
82    pz    62.1863                  $Top/bottom Celotex division  (9" below top)
76    pz    73.6417                  $Bottom of top Al rotation plate (24.1" IH)
77    pz    74.8863                  $To top of 1st (top) rotation plate (+0.49")
78    pz    76.1309                  $To top of 2nd (top) rotation plate (+0.49")
79    pz    85.0463                  $To top of Celotex (+3.51")
80    pz    85.167712                $Top outer surface of drum  (+0.0478")
83    pz    19.7590                  $Top of PuO2 powder (2 g/cc) (+18.3890 cm)
99    s     5.293 0.0   2.6472  1.277151      $Radius of sphere 100 g @ 11.46 g/c
100   c/z   5.293  0.0   1.0
101   cz                 1.0
102   pz    -14.9107
103   pz    -15.4107
104   cz     8.375
105   cz     8.875
106   pz     0.74
107   pz     2.74
108   p     0.0 0.0 0.0 0.0 0.0 1.0 9.288162   1.273 0.0
109   p     0.0 0.0 0.0 0.0 0.0 1.0 9.288162  -1.273 0.0
110   p     0.0 0.0 0.0 0.0 0.0 1.0 0.707107   0.707107 0.0
111   p     0.0 0.0 0.0 0.0 0.0 1.0 0.707107  -0.707107 0.0
112   s     108.375 0.0   1.74    4.0
113   pz    21.37                    $Top PuO2 @ 0.7 g/cc
114   cz     5.83698                 $Inner radius source cell
115   pz     2.4232                  $Top of fissile PuO2 layer at bottom of PCV.
116   sz    -114.9107 4.0

m1    82000            1.0         $Lead @ 11.29
```

```
m2     13027          1.00          $Al honeycomb @ 0.28
m3      8016         -0.1180261180  $PuO2 @ 2.0
       94238         -0.0000879154
       94239         -0.8277515472
       94240         -0.0506931354
       94241         -0.0031727522
       94242         -0.0002685318
m4     94238         -0.52020       $9968 PuO2 contents @ 0.70 g/cc
       94239         -0.35268
       94241         -0.00882
        8016         -0.11830
m5     26000         -0.6917        $316-SS @ 7.895
       28000         -0.10
       42000         -0.02
       24000         -0.16
       14000         -0.0075
        6000         -0.0008
       25055         -0.02
m6     26000         -0.8603        $410-SS @ 7.895
        6000         -0.0015
       25055         -0.01
       15031         -0.0004
       16032         -0.0003
       14000         -0.0075
       24000         -0.115
       28000         -0.005
m7     26000         -0.7117        $304L-SS @ 7.895
       25055         -0.02
       24000         -0.18
       14000         -0.0075
        6000         -0.0008
       28000         -0.08
m8     26000         -0.655       $Nitronic-60 @ 7.895
       28000         -0.08
       24000         -0.16
       14000         -0.035
       25055         -0.07
        6000         -0.001
m9     13027          1.0         $Aluminum @ 2.7
m10     6000          6.0         $Celotex @ 0.20
        1001         10.0
        8016          5.0
mode   p
sdef    erg=d1  pos=0.0 0.0 20.5693 rad=d2 ext=d3
        axs=0 0 1
nps     2e+7
si1     3.0000e-02  6.0000e-02   0.100      0.200
sp1     0.0         1.32e+09     3.24e+08   2.27e+07
si2     0.0       6.57098
si3     0.5266
wwg    105  10  0.5     5.293 0.0 13.142
f105:p       5.293    0.0   13.142     0.0
f115:p       0.0      0.0   13.142     0.0
f125:p       0.0      0.0  -86.608             0.0
f204:p       28
f214:p       29
f224:p       32
prdmp        3j   2
imp:p   1.5 1.5 1.0 1.5 1.0 1.5 1.5 1.5 1.0 1.0 1.0 1.0 2.0 2.0 1.0
        3.0 3.0 2.0 3.0 1.0 3.0 3.0 3.0 1.0 1.0 1.0 4.0 1.0 1.0 1.0
        1.0 1.0 1.0 1.0 0.0
ft105    scx 1
de0     0.01 0.03 0.05 0.07 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50
        0.55 0.60 0.65 0.70 0.80 1.00 1.40 1.80 2.20 2.60 2.80 3.25 3.75
        4.25 4.75 5.00 5.25 5.75 6.25 6.75 7.50 9.00 11.0 13.0 15.0
df0     3.96e-06 5.82e-07 2.90e-07 2.58e-07 2.83e-07 3.79e-07 5.01e-07
        6.31e-07 7.59e-07 8.78e-07 9.85e-07 1.08e-06 1.17e-06 1.27e-06
        1.36e-06 1.44e-06 1.52e-06 1.68e-06 1.98e-06 2.51e-06 2.99e-06
        3.42e-06 3.82e-06 4.01e-06 4.41e-06 4.83e-06 5.23e-06 5.60e-06
        5.80e-06 6.01e-06 6.37e-06 6.74e-06 7.11e-06 7.66e-06 8.77e-06
        1.03e-05 1.18e-05 1.33e-05
```

A.4. MCNP Input (HAC, Gamma Source Groups 8 – 15, Side Dose) Deck:

```
message:     outp=gks3a.o runtpe=gks3a.r

Photon calc with Kelsey's source.  Groups  8 - 15.
c
c  This is 9968 drum modified from my 9975 drum.
c  HAC conditions.  Looking at side.
c  Annular source region on side.
c
c 9968 Primary containment vessel.
c    Gland Plug (316-SS)
1     5    -7.895        (-29 -4 -49 32):(-3 20 -23):(-50 49 -20)       u=1
c    Gland Nut  (410-SS)
2     6    -7.895        (4 -5  17 -49):(50 -5 49 -20):(3 -5  20 -19):
                                                (3 -6  19 -23)         u=1
c    Cone Seal Plug (304L-SS)
3     7    -7.895       (7 -8  18 -23):(5 -8  16 -18):
                       ((29 1 -8 32 -16):(1 -10 32 -15)):
                       ((14 -32 -10) (1:-30) (28:-31))                 u=1
4     0                  (29 16 -17 -5):(29 -4 17)                     u=1
5     0                 ((-1 29  32):(-1 30 -32)):(-28 31 -10)         u=1
c    Cone Seal Nut (Nitronic-60 SST)
6     8    -7.895        (15 -21  8 -10):(21 -22 8 24 -25 26 -27):
                                     (22 -23 9 24 -25 26 -27)          u=1
7     0                  22 -23 8 -9                                   u=1
8     0                  (18 -19 5 -7):(19 -23 6 -7)                   u=1
c    PCV wall (304L-SS)
9     7    -7.895        (10 -11 35 -21):(-33 34 -35):(-10 34 35 -36)  u=1
c    Contents of PCV
10    4    -0.70            -10 114 -110 111 36 -113                   u=1
11    0                  (-10 36 -14) (113:-114:110:-111)              u=1
c    Al honeycomb spacer @ bottom
12    2    -0.28          -10 -34 -36                                  u=1
13    0                 ((21 -23 -46) (-24:25:-26:27)):(-46 23):48     u=1
c    Al honeycomb spacer @ top
14    2    -0.28          46 -47  21 -48                               u=1
15    0                   (11 -21):(-11 33 -35):(21 47 -48)            u=1
16    5    -7.895        (-29 -4 -49 32):(-3 20 -23):(-50 49 -20)      u=2
17    6    -7.895        (4 -5  17 -49):(50 -5 49 -20):(3 -5  20 -19):
                                                (3 -6  19 -23)         u=2
18    7    -7.895       (7 -8  18 -23):(5 -8  16 -18):
                       ((29 1 -8 32 -16):(1 -40 32 -15)):
                       ((51 -32 -40) (1:-30) (28:-31))                 u=2
19    0                  (29 16 -17 -5):(29 -4 17)                     u=2
20    0                 ((-1 29  32):(-1 30 -32)):(-28 31 -40)         u=2
21    8    -7.895       (15 -21  8 -40):(21 -22 8 24 -25 26 -27):
                                     (22 -23 9 24 -25 26 -27)          u=2
22    0                  22 -23 8 -9                                   u=2
23    0                  (18 -19 5 -7):(19 -23 6 -7)                   u=2
24    7    -7.895        (40 -41 44 -21):(-42 43 -44):(-40 43 44 -45)  u=2
25    0                   -40  55 -51   fill=1 (0.0 0.0 -9.630)        u=2
26    2    -0.28          -40 -43 -55                                  u=2
27    0                 ((21 -23 -41) (-24:25:-26:27)):23              u=2
28    0                  -100 -102 103                                 u=2
29    0                  -101 -102 103                                 u=2
30    0                   104 -105 106 -107 -108 109                   u=2
31    0                  -112                                          u=2
32    0                 ((-41 42 -44):(41 -23)) (100:-103:102) 112
                        (101:-103:102) (-104:105:-106:107:-109:108)    u=2
33    0                  -52 53 -54     fill=2 (0.0 0.0 28.30270)
34    0                   52:-53:54

1     cz      0.13891             $Vertical leak test port
2     cz      0.23749             $Leak test port plug closure hole
3     cz      0.33655             $Top inner component of leak test port plug
4     cz      0.49530             $Lower inner piece   of leak test port plug
5     cz      0.714375            $9/32" bottom hole, leak test port plug
6     cz      0.750814            $Top outer component of leak test port plug
7     cz      1.14300             $0.45" topp   hole, leak test port plug
8     cz      1.58750             $0.625" top OR cone seal
9     cz      2.06375             $0.8125" top IR cone seal nut
10    cz      6.57098             $Max PCV IR (5.047" ID nor, 5.174" max)
11    cz      7.02564             $Min PCV OR (5.563" OD nor, 5.532" min)
12    pz     -1.27000             $Outer Surface - Bottom of PCV  (-0.5")
13    pz     -0.81534             $Inner Surface - Bottom of PCV
14    pz     40.32250             $Lower surface of male cone seal PCV
15    pz     42.22750             $Top surface of male cone seal PCV
```

```
16    pz    42.54500              $Lowest surface of leak test port plug
17    pz    42.86250              $Lowest tip of outer plug   (0.875" from top)
18    pz    43.66260              $Outer top lip on cone seal (0.56" from top)
19    pz    44.29252              $Extent of top inner component of port plug
20    pz    43.81627              $Extent of leak test port plug
21    pz    43.81500              $Top surface of cone seal nut  (17.25")
22    pz    44.62780              $Lip on cone seal nut of PCV
23    pz    45.08500              $Top Surface of PCV
24    px    -3.175                $Cone seal nut left
25    px    3.175                 $Cone seal nut right
26    py    -3.175                $Cone seal nut left
27    py    3.175                 $Cone seal nut right
28    c/x    0.0  41.1099  0.13891     $Horiz. Leak test port
29    kz    42.1336553   0.33333333333    $Plug inner tip
30    pz    40.970993             $Bottom of vertical leak test port.
31    px    0.00                  $Left tip of horizontal leak test port.
32    pz    42.1336553            $Plug inner tip
33    sz    10.16  11.43          $Cask Bottom Outer
34    sz    10.16  10.97534       $Cask bottom Inner
35    pz     1.1441649
36    pz     1.37
40    cz     7.87019              $Max SCV IR (6.065" ID nor, 6.197" max)
41    cz     8.37438              $Min SCV OR (6.625" OD nor, 6.594" min)
42    sz     0.32639  15.23619    $SCV Cask Bottom Outer Surface
43    sz     0.32639  14.732      $SCV Cask Bottom Inner Surface
44    pz   -12.40197
45    pz   -12.12720
46    cz     4.7625               $IR top honeycomb spacer (3-3/4" ID)
47    cz     7.46125              $OR top honeycomb spacer (5-7/8" OD)
48    pz    48.387                $Top of top spacer on PCV (1.8" tall)
49    pz    43.65752              $Bottom plane plug upper cone
50    kz    44.15282     1.00     $Plug upper cone
51    pz    40.32250              $Same as surface 14 (for SCV)
52    cz   523.0
53    pz  -500.0
54    pz   590.0
55    pz   -11.86561              $Top surface of SCV honeycomb
60    cz     9.3846               $IR SS liner of Pb shield
61    cz     9.5377               $IR Pb shield
62    cz    10.7823               $OR Pb shield
63    cz    10.922                $IR cane fiberboard (bottom @ 8.6" ID)
81    cz    11.049                $IR cane fiberboard (top    @ 8.7" ID)
64    cz    12.70                 $End rotation plate
65    cz    22.479                $OR cane fiberboard top      (17.7" OD)
66    cz    22.86                 $OR cane fiberboard bottom   (18"   OD)
67    cz    23.1775               $IR drum
68    cz    23.2989               $OR drum (18 gauge, 0.0478")
69    pz     0.0                  $Bottom outside surface drum
70    pz     0.1087               $bottom inside  surface drum
71    pz    10.0147               $To bottom of rotation plate (+3.9")
72    pz    11.2593               $To bottom of lead plate (+0.49")
73    pz    12.2753               $To bottom of lead shield liner (+0.49")
74    pz    12.4277               $To top of SS liner of lead shield (+0.06")
75    pz    67.5203               $Top/Bottom Celotex division  (6.9" below top)
82    pz    62.1863               $Top/bottom Celotex division  (9" below top)
76    pz    73.6417               $Bottom of top Al rotation plate (24.1" IH)
77    pz    74.8863               $To top of 1st (top) rotation plate (+0.49")
78    pz    76.1309               $To top of 2nd (top) rotation plate (+0.49")
79    pz    85.0463               $To top of Celotex (+3.51")
80    pz    85.167712             $Top outer surface of drum  (+0.0478")
83    pz    19.7590               $Top of PuO2 powder (2 g/cc) (+18.3890 cm)
99    s     5.293 0.0    2.6472   1.277151       $Radius of sphere 100 g @ 11.46 g/cc
100   c/z   5.293  0.0    1.0
101   cz                  1.0
102   pz    -14.9107
103   pz    -15.4107
104   cz     8.375
105   cz     8.875
106   pz     0.74
107   pz     2.74
108   p     0.0 0.0 0.0 0.0 0.0 1.0 9.288162  1.273 0.0
109   p     0.0 0.0 0.0 0.0 0.0 1.0 9.288162 -1.273 0.0
110   p     0.0 0.0 0.0 0.0 0.0 1.0 0.707107  0.707107 0.0
111   p     0.0 0.0 0.0 0.0 0.0 1.0 0.707107 -0.707107 0.0
112   s     108.375 0.0   1.74     4.0
113   pz    21.37                 $Top PuO2 @ 0.7 g/cc
114   cz     5.83698              $Inner radius source cell

m1   82000            1.0        $Lead @ 11.29
m2   13027            1.00       $Al honeycomb @ 0.28
m3    8016           -0.1180261180  $PuO2 @ 2.0
```

66

Dose Calculation for Pu-238 Oxide Payload
in 9968 Shipping Container

N-CLC-G-00067
WSMSC-98-0207
Revision 0

```
       94238          -0.0000879154
       94239          -0.8277515472
       94240          -0.0506931354
       94241          -0.0031727522
       94242          -0.0002685318
m4     94238          -0.52020     $9968 PuO2 contents @ 0.70 g/cc
       94239          -0.35268
       94241          -0.00882
        8016          -0.11830
m5     26000          -0.6917      $316-SS @ 7.895
       28000          -0.10
       42000          -0.02
       24000          -0.16
       14000          -0.0075
        6000          -0.0008
       25055          -0.02
m6     26000          -0.8603      $410-SS @ 7.895
        6000          -0.0015
       25055          -0.01
       15031          -0.0004
       16032          -0.0003
       14000          -0.0075
       24000          -0.115
       28000          -0.005
m7     26000          -0.7117      $304L-SS @ 7.895
       25055          -0.02
       24000          -0.18
       14000          -0.0075
        6000          -0.0008
       28000          -0.08
m8     26000          -0.655     $Nitronic-60 @ 7.895
       28000          -0.08
       24000          -0.16
       14000          -0.035
       25055          -0.07
        6000          -0.001
m9     13027           1.0         $Aluminum @ 2.7
m10     6000           6.0         $Celotex @ 0.20
        1001          10.0
        8016           5.0
mode   p
sdef    erg=d1  pos=0.0 0.0 30.0427 rad=d2 ext=d3 cel=33:25:10
        axs=0 0 1  eff=0.0001
nps     2e+7
si1     0.200 0.4 0.6 0.7 0.8 1.0 1.5 2.0 3.0
sp1     0.0  6.96e5 3.21e5 1.36e4 3.72e5 8.76e4 1.69e4 2.24e4 2.52e5
si2     5.83698 6.57098
si3     10
wwg    105  10  0.5     8.625 0 30.0427
f105:p      8.625     0.0    30.0427    0.0
f115:p    108.375     0.0    30.0427    0.0
f204:p      30
f214:p      31
sd204     2.34958
prdmp       3j   2
imp:p   1.5 1.5 1.0 1.5 1.0 1.5 1.5 1.5 1.0 1.0 1.0 1.0 2.0 2.0 1.0
        3.0 3.0 2.0 3.0 1.0 3.0 3.0 3.0 1.0 1.0 1.0 4.0 1.0 1.0 1.0
        1.0 1.0 1.0 0.0
ft105    scx 1
de0     0.01 0.03 0.05 0.07 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50
        0.55 0.60 0.65 0.70 0.80 1.00 1.40 1.80 2.20 2.60 2.80 3.25 3.75
        4.25 4.75 5.00 5.25 5.75 6.25 6.75 7.50 9.00 11.0 13.0 15.0
df0     3.96e-06 5.82e-07 2.90e-07 2.58e-07 2.83e-07 3.79e-07 5.01e-07
        6.31e-07 7.59e-07 8.78e-07 9.85e-07 1.08e-06 1.17e-06 1.27e-06
        1.36e-06 1.44e-06 1.52e-06 1.68e-06 1.98e-06 2.51e-06 2.99e-06
        3.42e-06 3.82e-06 4.01e-06 4.41e-06 4.83e-06 5.23e-06 5.60e-06
        5.80e-06 6.01e-06 6.37e-06 6.74e-06 7.11e-06 7.66e-06 8.77e-06
        1.03e-05 1.18e-05 1.33e-05
```

A.5. MCNP Input (NCT, Neutron Source Groups 7 - 25, Top Doses) Deck:

```
message:      outp=nnnkt1.o runtpe=nnnkt1.r

Kelsey's Neutron spectrum. Groups 7 - 25.
c
c  This is 9968 drum modified from my 9975 drum.
c
c   Groups 7 -25. Containment vessel.
c    Gland Plug (316-SS)
1     5     -7.895       (-29 -4 -49 32):(-3 20 -23):(-50 49 -20)       u=1
c    Gland Nut  (410-SS)
2     6     -7.895       (4 -5  17 -49):(50 -5 49 -20):(3 -5  20 -19):
                                                  (3 -6  19 -23)      u=1
c    Cone Seal Plug (304L-SS)
3     7     -7.895       (7 -8  18 -23):(5 -8  16 -18):
                        ((29 1 -8 32 -16):(1 -10 32 -15)):
                        ((14 -32 -10) (1:-30) (28:-31))
4     0                  (29 16 -17 -5):(29 -4 17)                      u=1
5     0                 ((-1 29  32):(-1 30 -32)):(-28 31 -10)          u=1
c    Cone Seal Nut (Nitronic-60 SST)                                    u=1
6     8     -7.895       (15 -21  8 -10):(21 -22 8 24 -25 26 -27):
                                     (22 -23 9 24 -25 26 -27)
7     0                  22 -23 8 -9                                    u=1
8     0                  (18 -19 5 -7):(19 -23 6 -7)                    u=1
c    PCV wall (304L-SS)                                                 u=1
9     7     -7.895       (10 -11 35 -21):(-33 34 -35):(-10 34 35 -36)   u=1
c    Contents of PCV
10    4    -11.46         -99                                           u=1
11    0                   -10  36 -14 99                                u=1
c    Al honeycomb spacer @ bottom
12    2     -0.28         -10 -34 -36                                   u=1
13    0                 ((21 -23 -46) (-24:25:-26:27)):(-46 23):48      u=1
c    Al honeycomb spacer @ top
14    2     -0.28         46 -47  21 -48                                u=1
15    0                   (11 -21):(-11 33 -35):(21 47 -48)             u=1
20    5     -7.895       (-29 -4 -49 32):(-3 20 -23):(-50 49 -20)       u=2
21    6     -7.895       (4 -5  17 -49):(50 -5 49 -20):(3 -5  20 -19):
                                                  (3 -6  19 -23)      u=2
22    7     -7.895       (7 -8  18 -23):(5 -8  16 -18):
                        ((29 1 -8 32 -16):(1 -40 32 -15)):
                        ((51 -32 -40) (1:-30) (28:-31))
23    0                  (29 16 -17 -5):(29 -4 17)                      u=2
24    0                 ((-1 29  32):(-1 30 -32)):(-28 31 -40)          u=2
25    8     -7.895       (15 -21  8 -40):(21 -22 8 24 -25 26 -27):      u=2
                                     (22 -23 9 24 -25 26 -27)
26    0                  22 -23 8 -9                                    u=2
27    0                  (18 -19 5 -7):(19 -23 6 -7)                    u=2
28    7     -7.895       (40 -41 44 -21):(-42 43 -44):(-40 43 44 -45)   u=2
29    0                   -40  55 -51   fill=1 (0.0 0.0 -9.630)         u=2
30    2     -0.28         -40 -43 -55                                   u=2
31    0                 ((21 -23 -41) (-24:25:-26:27)):23               u=2
32    0                  (-41 42 -44):(41 -23)                          u=2
40    0                   74 -76  -60   fill=2 (0.0 0.0 28.30270)       u=3
c    Shield liner - assumed void for 9968
41    0                  (60 -61 74 -76):(73 -74  -61)                  u=3
c    Lead Shield
42    1    -11.29        (61 -62 73 -76)                                u=3
c    Bottom SS304 anti-rotation plate
19    7    -7.895        (72 -73  -64)                                  u=3
c    Lower Al anti-rotation plate -- replace with Celotex
43    10    -0.20         -64  71 -72                                   u=3
c    1st of upper Al anti-rotation plate (Al 1100)
44    9     -2.7          -64  76 -77                                   u=3
c    2nd of upper Al anti-rotation plate -- replace with Celotex
45    10    -0.20         -64  77 -78                                   u=3
c    Celotex Bottom
46    10    -0.20        (70 -71 -66)                                   u=3
c    Celotex Sides
47    10    -0.20        (71 -73 64 -66):(73 -82  63 -66):
                         (82 -75 81 -66):(75 -76 81 -65):
                         (64 -65 76 -78)                                u=3
c    Celotex Top
48    10    -0.20        (-65 78 -79)                                   u=3
49    0                  (73 -82 62 -63):(82 -76 62 -81)                u=3
50    0                  (70 -75 -67 66):(75 -79 65 -67)                u=3
c    Drum Bottom
```

```
51    7    -7.895       69 -70 -68                              u=3
c     Drum Sides
52    7    -7.895       67 -68 70 -80                           u=3
c     Drum Top
53    7    -7.895       79 -80 -67                              u=3
54    0                -68  80 108 (109:111)                    u=3
55    0                -109 80 -111                             u=3
56    0                -108                                     u=3
57    0                -68 -69 107 (109:-110)                   u=3
58    0                -107                                     u=3
59    0                -109 110 -69                             u=3
60    0                 68 106 (103:-104:105:-101:102)          u=3
61    0                -106                                     u=3
62    0                 68 -105 -103 104 101 -102               u=3
100   0                -52 53 -54                   fill=3
101   0                 52:-53:54

1     cz      0.13891              $Vertical leak test port
2     cz      0.23749              $Leak test port plug closure hole
3     cz      0.33655              $Top inner component of leak test port plug
4     cz      0.49530              $Lower inner piece   of leak test port plug
5     cz      0.714375             $9/32" bottom hole, leak test port plug
6     cz      0.750814             $Top outer component of leak test port plug
7     cz      1.14300              $0.45" topp   hole, leak test port plug
8     cz      1.58750              $0.625" top OR cone seal
9     cz      2.06375              $0.8125" top IR cone seal nut
10    cz      6.57098              $Max PCV IR (5.047" ID nor, 5.174" max)
11    cz      7.02564              $Min PCV OR (5.563" OD nor, 5.532" min)
12    pz     -1.27000              $Outer Surface - Bottom of PCV  (-0.5")
13    pz     -0.81534              $Inner Surface - Bottom of PCV
14    pz     40.32250              $Lower surface of male cone seal PCV
15    pz     42.22750              $Top surface of male cone seal PCV
16    pz     42.54500              $Lowest surface of leak test port plug
17    pz     42.86250              $Lowest tip of outer plug    (0.875" from top)
18    pz     43.66260              $Outer top lip on cone seal (0.56" from top)
19    pz     44.29252              $Extent of top inner component of port plug
20    pz     43.81627              $Extent of leak test port plug
21    pz     43.81500              $Top surface of cone seal nut  (17.25")
22    pz     44.62780              $Lip on cone seal nut of PCV
23    pz     45.08500              $Top Surface of PCV
24    px     -3.175                $Cone seal nut left
25    px      3.175                $Cone seal nut right
26    py     -3.175                $Cone seal nut left
27    py      3.175                $Cone seal nut right
28    c/x     0.0  41.1099  0.13891     $Horiz. Leak test port
29    kz      42.1336553   0.33333333333    $Plug inner tip
30    pz      40.970993            $Bottom of vertical leak test port.
31    px      0.00                 $Left tip of horizontal leak test port.
32    pz      42.1336553           $Plug inner tip
33    sz      10.16  11.43         $Cask Bottom Outer
34    sz      10.16  10.97534      $Cask bottom Inner
35    pz      1.1441649
36    pz      1.37
40    cz      7.87019              $Max SCV IR (6.065" ID nor, 6.197" max)
41    cz      8.37438              $Min SCV OR (6.625" OD nor, 6.594" min)
42    sz      0.32639  15.23619    $SCV Cask Bottom Outer Surface
43    sz      0.32639  14.732      $SCV Cask Bottom Inner Surface
44    pz     -12.40197
45    pz     -12.12720
46    cz      4.7625               $IR top honeycomb spacer (3-3/4" ID)
47    cz      7.46125              $OR top honeycomb spacer (5-7/8" OD)
48    pz      48.387               $Top of top spacer on PCV (1.8" tall)
49    pz      43.65752             $Bottom plane plug upper cone
50    kz      44.15282     1.00    $Plug upper cone
51    pz      40.32250             $Same as surface 14 (for SCV)
52    cz     523.0
53    pz    -500.0
54    pz     590.0
55    pz     -11.86561             $Top surface of SCV honeycomb
60    cz      9.3846               $IR SS liner of Pb shield
61    cz      9.5377               $IR Pb shield
62    cz      10.7823              $OR Pb shield
63    cz      10.922               $IR cane fiberboard (bottom @ 8.6" ID)
81    cz      11.049               $IR cane fiberboard (top    @ 8.7" ID)
64    cz      12.70                $End rotation plate
65    cz      22.479               $OR cane fiberboard top      (17.7" OD)
66    cz      22.86                $OR cane fiberboard bottom  (18"    OD)
67    cz      23.1775              $IR drum
68    cz      23.2989              $OR drum (18 gauge, 0.0478")
69    pz      0.0                  $Bottom outside surface drum
70    pz      0.1087               $bottom inside surface drum
```

```
71    pz    10.0147              $To bottom of rotation plate (+3.9")
72    pz    11.2593              $To bottom of lead plate (+0.49")
73    pz    12.2753              $To bottom of lead shield liner (+0.49")
74    pz    12.4277              $To top of SS liner of lead shield (+0.06")
75    pz    67.5203              $Top/Bottom Celotex division  (6.9" below top)
82    pz    62.1863              $Top/bottom Celotex division  (9" below top)
76    pz    73.6417              $Bottom of top Al rotation plate (24.1" IH)
77    pz    74.8863              $To top of 1st (top) rotation plate (+0.49")
78    pz    76.1309              $To top of 2nd (top) rotation plate (+0.49")
79    pz    85.0463              $To top of Celotex (+3.51")
80    pz    85.167712            $Top outer surface of drum  (+0.0478")
83    pz    19.7590              $Top of PuO2 powder (2 g/cc) (+18.3890 cm)
99    s    5.293 0.0  39.0453  1.277151      $Radius of sphere 100 g @ 11.46 g/c
101   pz    19.3199
102   pz    23.3199
103   p    0.0 0.0 0.0 0.0 0.0 1.0 9.288162  1.273 0.0
104   p    0.0 0.0 0.0 0.0 0.0 1.0 9.288162 -1.273 0.0
105   cz    23.7989              $+0.5 cm thick Side tally region @ Surface.
106   s    123.2989 0.0 21.3199   5.0    $Side   tally region @ 1 m
107   sz             -100.0       5.0    $Bottom tally region @ 1 m
108   sz              185.1677    5.0    $Top    tally region @ 1 m
109   c/z    5.293  0.0   2.5            $Bottom/top tally region @ Surface
110   pz    -0.50                        $Bottom tally surface
111   pz    85.667712                    $Top tally surface

m1    82000.50c        1.0         $Lead @ 11.29
m2    13027.50c        1.00        $Al honeycomb @ 0.28
m3     8016.50c       -0.1180261180  $PuO2 @ 2.0
      94238.50c       -0.0000879154
      94239.55c       -0.8277515472
      94240.50c       -0.0506931354
      94241.50c       -0.0031727522
      94242.50c       -0.0002685318
m4    96244.50c       -1.0e-06     $9968 Pu contents @ 11.46 g/cc
      94238.50c       -0.589999
      94239.55c       -0.4000
      94241.50c       -0.01
m5    26000.55c       -0.6917      $316-SS @ 7.895
      28000.50c       -0.10
      42000.50c       -0.02
      24000.50c       -0.16
      14000.50c       -0.0075
       6000.50c       -0.0008
      25055.50c       -0.02
m6    26000.55c       -0.8603      $410-SS @ 7.895
       6000.50c       -0.0015
      25055.50c       -0.01
      15031.50c       -0.0004
      16032.50c       -0.0003
      14000.50c       -0.0075
      24000.50c       -0.115
      28000.50c       -0.005
m7    26000.55c       -0.7117      $304L-SS @ 7.895
      25055.50c       -0.02
      24000.50c       -0.18
      14000.50c       -0.0075
       6000.50c       -0.0008
      28000.50c       -0.08
m8    26000.55c       -0.655      $Nitronic-60 @ 7.895
      28000.50c       -0.08
      24000.50c       -0.16
      14000.50c       -0.035
      25055.50c       -0.07
       6000.50c       -0.001
m9    13027.50c        1.0        $Aluminum @ 2.7
m10    6000.50c        6.0        $Celotex @ 0.20
       1001.50c       10.0
       8016.50c        5.0
mt10  poly.01t
mode n
sdef    erg=d1  pos=5.293 0.0 57.7180 rad=d2
nps     2e+7
totnu
f105:n      5.293    0.0    85.417712   0.0
f115:n      0.0      0.0   185.167712   0.0
f204:n     55
f214:n     56
de0     1.0e-10 2.5e-08 1.0e-07 1.0e-06 1.0e-05 1.0e-04 1.0e-03 1.0e-02 1.0e-01
        5.0e-01 1.0     2.5     5.0     7.0     10.0    14.0    20.0
df0     3.67e-06  3.67e-06  4.46e-06  4.54e-06 4.18e-06 3.76e-06 3.56e-06
        2.17e-05  9.26e-05  1.32e-04  1.20e-04 1.25e-04 1.56e-04 1.47e-04
```

```
       1.47e-04  2.08e-04  2.27e-04
prdmp       3j   2
wwg   105  10  0.5    23.4 0.0 21.3199
wwge:n  1.0e-7  1.0e-5  0.05   0.20   1.0  20.0
imp:n  1.5 1.5 1.0 1.5 1.0 1.5 1.5 1.5 1.0 1.0 1.0 1.0 2.0 2.0 1.0
       3.0 3.0 2.0 3.0 1.0 3.0 3.0 3.0 1.0 1.0 1.0 4.0 1.0
       1.0 1.0 1.0 1.5 4.0 5.0 1.7 1.0 6.0 1.0 1.0 1.0 1.8 1.0 6.0
       6.0 6.0 6.0 1.8 1.8 1.8 1.0 1.0 1.0 1.0 0.0
si1     1.8316e-01 2.9720e-01 3.6883e-01
        4.9787e-01 6.0810e-01 7.4274e-01 8.2085e-01 1.0026
        1.3534     1.6530     1.9205     2.2313     2.3457
        2.3653     2.4660     2.7253     3.0119     3.6788
        4.9659     6.0653
sp1     0.0000e+00  178.       151.        297.        279.
        365.        232.       537.        1040.       877.
        988.        1400.0     606.        103.        521.0
        1530.       1940.      3860.       3180.       343.
si2    0.0  1.277151
ft105   scx 1
```

APPENDIX B

MCNP Information

B.1. MCNP Input and Output File Identification:

Table B.1 shows the job names for the MCNP calculations. All input and output files are stored on the WSMS workstation cluster under /raid1/users/rwebb/9968/hac (for HAC cases) or raid1/users/rwebb/9968/nct (for NCT cases). Input file names are as shown in Table B.1; output files have a ***.out*** extension.

It should be noted that for neutron and (n,γ) calculations, the source location/geometry is the same for side and bottom dose receptors, hence only a single calculation (*e.g.* nnks8 or npks9) was needed to get doses at the side and bottom. Doses at the surface and at a distance of 1 meter were also computed in the same calculation.

In the MCNP calculations, both point and volume tallies were used. Reported values were taken from the point detector tallies. The volume tallies were used as an independent confirmatory mechanism.

TABLE B.1. MCNP File Names

		HAC		NCT
Neutron	side	nnks8		nnnks1
	bottom	nnks8		nnnks1
	top	nnkt9		nnnkt1
(n,γ)	side	npks9		nnpks1
	bottom	npks9		nnpks1
	top	npkt9		nnpkt1
Photon	side	Groups 16 - 18	gks2a	ngks3
		Groups 8 - 15	gks3a	
	bottom	Groups 16 - 18	gkb2a	ngkb3
		Groups 8 - 15	gkb3a	
	top	Groups 16 - 18	gkt2a	ngkt3
		Groups 8 - 15	gkt3a	

B.2. Renormalization of MCNP Results

The MCNP point and volume flux tallies have units of 1/cm^2 per starting particle. In the calculations, the flux-to-dose conversion factors from ANS-6.1.1-1977 were used. The conversion factors have units of rem/hr per 1/cm^2-s, which can be restated as rem-cm^2-s per hour. The MCNP tallies therefore have units of rem-s/hr per starting particle. To obtain the dose in mrem/hr the MCNP tally value must be multiplied by 1000 mrem/rem and by the total particle emission rate. The particle emission rate is determined from Table 8 and the number of source groups in the calculation. For example, for a neutron source calculation using neutron Groups 7 – 25, the neutron emission rate is 18427 neutrons/s per gram of actinide (sum of the emission rates for Groups 7 – 25) multiplied by 100 grams of actinide. Table B.2 shows the normalization factor, the MCNP tally value, and the renormalized value for the different cases. Where calculated, the values for the MCNP volume tallies are also presented and can be compared to the corresponding point detector values. The column labeled "E.R.E. 1-sigma" is the Estimated Relative Error from MCNP – the E.R.E. multiplied by the estimated mean gives the 1-sigma uncertainty.

TABLE B.2. MCNP Tally Results and Normalization Constants

	Calc. Type	Dose Receptor Location	Job Name	Normalization Constant (1/s)	POINT DETECTORS			VOLUME TALLIES	
					Unnorm. Mean (rem-s/h)	E.R.E. 1-sigma	Mean (mrem/h)	Normed Mean (rem-s/h)	E.R.E. 1-sigma
HAC	Neutron	side @ 1 m	nnks8	1.8427E+09	1.2403E-09	0.0004	2.286	Not Calculated	
		bottom @ 1 m			1.0240E-09	0.0004	1.887		
		top @ 1 m	nnkt9	1.85012E+09	3.8261E-10	0.0020	0.708		
	(n,γ)	side @ 1 m	npks9	1.85012E+09	4.0329E-12	0.0018	7.461E-03		
		bottom @ 1 m			2.7615E-12	0.0016	5.109E-03		
		top @ 1 m	npkt9	1.85012E+09	1.0291E-12	0.0056	1.904E-03		
	Photon Groups 16 - 18	side @ 1 m	gks2a	1.6667E+14	1.6882E-14	0.0054	2.814	2.0201E-14	0.1437
		bottom @ 1 m	gkb2a	1.6667E+14	1.1565E-14	0.0067	1.928	1.1554E-14	0.184
		top @ 1 m	gkt2a	1.6667E+14	4.7908E-18	0.0827	7.985E-04	0	0
	Photon Groups 8 - 15	side @ 1 m	gks3a	1.7815E+11	9.3468E-12	0.0005	1.665	9.3238E-12	0.0157
		bottom @ 1 m	gkb3a	1.7815E+11	7.7128E-12	0.0006	1.374	7.7867E-12	0.0178
		top @ 1 m	gkt3a	1.7815E+11	8.6100E-13	0.0255	0.1534	7.6634E-13	0.0672
NCT	Neutron	side @ surface	nnnks1	1.84270E+09	3.9333E-08	0.0037	72.479	3.8487E-08	0.0046
		bottom @ surface			2.9652E-08	0.0076	54.640	2.9036E-08	0.0061
		top @ surface	nnnkt1	1.84270E+09	1.1415E-08	0.0037	21.034	1.1267E-08	0.0062
	(n,γ)	side @ surface	nnpks1	1.85012E+09	9.4295E-11	0.0207	0.1745	8.9378E-11	0.0126
		bottom @ surface			1.0536E-10	0.0123	0.1949	1.0196E-10	0.0123
		top @ surface	nnpkt1	1.85012E+09	3.6887E-11	0.0050	0.0682	3.6965E-11	0.0133
	Photon Groups 8 - 15	side @ surface	ngks3	1.7815E+11	7.0263E-11	0.0225	12.517	6.9461E-11	0.0070
		bottom @ surface	ngkb3	1.7815E+11	1.3814E-10	0.0087	24.610	1.3638E-10	0.0117
		top @ surface	ngkt3	1.7815E+11	1.3012E-11	0.0106	2.318	1.2911E-11	0.0187
	Neutron	side @ 1 m	nnnks1	1.84270E+09	9.4453E-10	0.0004	1.740	9.6097E-10	0.0159
		bottom @ 1 m			7.9385E-10	0.0005	1.463	7.8852E-10	0.0174
		top @ 1 m	nnnkt1	1.84270E+09	4.0836E-10	0.0005	0.7525	4.0239E-10	0.0157
	(n,γ)	side @ 1 m	nnpks1	1.85012E+09	2.1783E-12	0.0024	4.030E-03	2.0909E-12	0.0456
		bottom @ 1 m			2.3757E-12	0.0042	4.395E-03	2.5447E-12	0.0416
		top @ 1 m	nnpkt1	1.85012E+09	1.0987E-12	0.0012	2.033E-03	1.1180E-12	0.0393
	Photon Groups 8 - 15	side @ 1 m	ngks3	1.7815E+11	2.3721E-12	0.0030	0.4226	2.1923E-12	0.0335
		bottom @ 1 m	ngkb3	1.7815E+11	3.9764E-12	0.0009	0.7084	4.1464E-12	0.0365
		top @ 1 m	ngkt3	1.7815E+11	6.1568E-13	0.0090	0.1097	5.8826E-13	0.0472

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