2. To: (Receiving Organization) Plutonium Finishing Plant		3. From: (Originating Organization) Criticality and Shielding		4. Related EDT No.: NA	
5. Proj./Prog./Dept./Div.: PFP		6. Design Authority/ Design Agent/Cog. Engr.: R. F. Richard		7. Purchase Order No.: NA	
8. Originator Remarks: Transmittal of Radiological Dose Assessment for Vault Storage Concepts				9. Equip./Component No.: NA	
				10. System/Bldg./Facility: 2736Z/PFP	
11. Receiver Remarks: 11A. Design Baseline Document? ☐ Yes ☒ No				12. Major Assm. Dwg. No.: ES-W460-A3	
				13. Permit/Permit Application No.: NA	
				14. Required Response Date: NA	

15. DATA TRANSMITTED					(F)	(G)	(H)	(I)
(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	Approval Designator	Reason for Transmittal	Originator Disposition	Receiver Disposition
1	HNF-SD-W460-ER-001		0	Radiological Dose Assessment for Vault Storage Concepts	NA	1,2		

16. KEY					
Approval Designator (F)		Reason for Transmittal (G)		Disposition (H) & (I)	
E, S, Q, D or N/A (see WHC-CM-3-5, Sec.12.7)	1. Approval 2. Release 3. Information	4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment	4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged	

17. SIGNATURE/DISTRIBUTION (See Approval Designator for required signatures)											
(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN	(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN
		Design Authority	NA								
		Design Agent	NA								
1	1	Cog. Eng.	R. F. Richard	2/18/97	40-35	1	1	Tech. Rvw.	K. E. Hillesland	2/19/97	40-35
1		Cog. Mgr.	J. Greenborg	2/19/97	40-35						
		QA	NA								
		Safety	NA								
		Env.	NA								

18. R. F. Richard <i>R. F. Richard</i> 2-18-97 Signature of EDT Originator		19. _____ Authorized Representative Date for Receiving Organization		20. J. Greenborg <i>J. Greenborg</i> 2-19/97 Design Authority/ Cognizant Manager		21. DOE APPROVAL (if required) Ctrl. No. ☐ Approved ☐ Approved w/comments ☐ Disapproved w/comments	
--	--	--	--	--	--	---	--

Radiological Dose Assessment for Vault Storage Concepts

R. F. Richard

Fluor Daniel Northwest, Richland, WA 99352

U.S. Department of Energy Contract DE-AC06-96RL13200

EDT/ECN: 620288

UC: 721

Org Code: 403

Charge Code: K6182

B&R Code: EW7003000

Total Pages: 86 87 KN

Key Words: Radiological dose, vault, infloor, cubicle

Abstract: This radiological dose assessment presents neutron and photon dose rates in support of project W-460. Dose rates are provided for a single 3013 container, the "infloor" storage vault concept, and the "cubicle" storage vault concept.

TRADEMARK DISCLAIMER. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

Printed in the United States of America. To obtain copies of this document, contact: Document Control Services, P.O. Box 950, Mailstop H6-08, Richland WA 99352, Phone (509) 372-2420; Fax (509) 376-4989.

Karen S. Noland 2/25/97
Release Approval Date

Release Stamp

Approved for Public Release

CONTENTS

1.0 INTRODUCTION AND SUMMARY	2
2.0 CALCULATIONAL METHOD	2
3.0 SOURCE	3
4.0 3013 CONTAINER	4
4.1 Container Model	4
4.2 Dose Rate Calculations	4
4.3 Benchmark Validation of Single Package Model	5
5.0 INFLOOR STORAGE CONCEPT	7
5.1 Infloor Model	7
5.2 Dose Rate Results	11
6.0 CUBICLE STORAGE	15
6.1 MCNP Models	15
6.2 Dose Rate Results	19
6.2.1 28 Canisters Per Cubicle	19
6.2.2 20 Canisters Per Cubicle	21
7.0 REFERENCES	22
APPENDIX A: SOURCE LISTINGS AND DOSE CONVERSION FACTORS	23
APPENDIX B: MODEL VALIDATION	28
APPENDIX C: CONCRETE COMPOSITIONS	32
APPENDIX D: INFLOOR DOSE RATE CONTOUR PLOTS	33
APPENDIX E: INPUT FILES	42
APPENDIX F: REVIEWER COMMENTS	77
APPENDIX G: CUBICLE DOSE RATE TABLES	82

Radiological Dose Assessment for Vault Storage Concepts

1.0 Introduction and Summary

Neutron and photon dose rates have been calculated for two plutonium oxide storage concepts being considered for a vault in the 2736Z building.

The infloor concept has three layers of plutonium storage containers, with 336 containers per layer, below a 30.48 cm thick concrete floor in a vault. Dose rates were determined at 30 cm and 150 cm above the floor. Both neutron and photon dose rates were done with all storage locations closed and repeated with one storage location open. The neutron dose rates dominate the photon dose rates in all cases since the concrete is a more effective photon shield than neutron shield.

The cubicle storage concept consists of 68 storage cubicles in a vault, arranged in rows. Each cubicle has seven shelves each with four canister pedestals. Neutron and photon dose rates were calculated with 28 canisters per cubicle and 20 canisters per cubicle. Dose rates were calculated with 20 canisters per cubicle because the criticality assessment determined that it would not be possible to safely store 28 cans of plutonium oxide (each containing 4.5 kg of plutonium) in each cubicle (Watson). The dose rates were determined with all cubicles closed and with one cubicle open. The dose rates for this concept were also dominated by the neutrons.

A high and low ^{240}Pu content source at two densities was used for all dose rate calculations.

2.0 Calculational Method

MCNP (Carter) was used to calculate the neutron and photon dose rates. MCNP is a general purpose, continuous energy, generalized geometry, Monte Carlo transport Computer code.

Dose rates are determined by tallies of particles (neutrons or photons) from the source at the region of interest.

ORIGEN (Schmittroth) and MCNP input files are provided in appendix E.

3.0 Source

Four sources have been specified for these dose rate analyses. They were defined by the letter of instruction. The four sources are comprised of two plutonium isotopic distributions at two PuO_2 densities. Isotopic distributions are referred to as high and low ^{240}Pu content and are given in Table 3-1.

Table 3-1. Isotopic Distribution (% Plutonium on a per gram basis)

Distribution	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am
Low	0.01	93.77	6.00	0.20	0.03	0.14
High	0.24	80.66	16.98	1.44	0.69	2.80

These two sources were input into ORIGEN which then generated the neutron source and photon spectrum which are used by MCNP to generate the desired dose rates. The ORIGEN generated neutron sources and photon spectrums and dose conversion factors are provided in Appendix A.

The high and low PuO_2 densities to be used are given in Table 3-2.

Table 3-2. Source Density

Density	PuO_2 Density (g/cm^3)	PuO_2 Mass (g)	Volume in 3013 Convenience Can (cm^3)
Low	2.0	3000	1500
High	6.0	5000	835

These densities combined with the low and high ^{240}Pu isotopic distributions give the four sources used for the dose rate calculations.

4.0 3013 Container

4.1 Container Model

The 3013 container consists of three nested stainless steel cans (convenience, inner and outer) with dimensions as given in Table 4-1. The convenience can necks down to an inner diameter of 90 mm and has a 6 mm thick top. The outer can lid thickness is 10 mm. AN MCNP plot of the container model is presented in Figure 4-1.

Table 4-1. 3013 Container Dimensions (mm)

Can	Inner Diameter	Outer Diameter	Inner Height
Convenience	110	112	213.5
Inner	114	117	231
Outer	119	125	254

As described in section 3.0, dose rate calculations were done for two sources with different plutonium isotopic distributions. In addition, for each source dose rate calculations were done for low and high PuO₂ densities.

4.2 Dose Rate Calculations

Both neutron and photon dose rates were calculated at the radial surface of, and 30 cm from, a single 3013 container. Dose rates above the container would be lower due to the increased lid thickness and greater distance between the source location and can lid as compared to the side wall. Neutron dose rates are presented in Table 4-3, and photon dose rates are presented in Table 4-4.

Table 4-3. 3013 Container - Neutron Dose

Source		mrem/h (uncertainty)	
²⁴⁰ Pu	PuO ₂ Density	Contact	30 cm
high	low	131 (0.77%)	8.5 (1.96%)
high	high	305 (0.78%)	16.6 (2.09%)
low	low	41 (0.77%)	2.7 (1.95%)
low	high	96 (0.80%)	5.3 (2.09%)

Table 4-4. 3013 Container - Photon Dose

Source		mrem/h (uncertainty)	
²⁴⁰ Pu	PuO ₂ Density	Contact	30 cm
high	low	125 (2.78%)	8.4 (4.47%)
high	high	116 (2.07%)	6.2 (5.67%)
low	low	56 (1.49%)	3.8 (3.52%)
low	high	48 (1.73%)	2.5 (4.71%)

Contact dose rates were calculated at 2 cm from the container surface. This approximates the location of the active part of a detector.

Neutron dose rates are primarily a function of distance from the source since the stainless steel is not an effective neutron shield. The high ²⁴⁰Pu source emits more neutrons than the low ²⁴⁰Pu source and therefore a higher dose rate results. A higher density source provides more source material, again increasing the neutron dose rate.

In contrast to neutron dose rates, the photon dose rates decrease as the source density increases. This is due to the self-shielding effect of the source. As for the neutron dose rates, photon dose rates are higher for the high ²⁴⁰Pu content source.

4.3 Benchmark Validation of Single Package Model

MCNP neutron and photon dose rate calculations were done to validate the methods used for this analysis. Benchmark calculations were done using an existing PFP inventory item containing PuO₂ and is discussed in Appendix B.

Figure 4-1. 3013 Container

02/05/97 13:14:00
PFP 3013 can

probid = 02/05/97 13:10:18
basis:
(1.000000, 0.000000, 0.000000)
(0.000000, 0.000000, 1.000000)
origin:
(0.00, 0.00, 12.00)
extent = (14.00, 14.00)

5.0 Infloor Storage Concept

The infloor storage concept is proposed for a vault located in the 2736Z building. For this analysis containers are stored in a three layer array of 336 containers per layer. The array is located below a 30.48 cm thick concrete floor.

5.1 Infloor model

The containers are arranged as a horizontal 19 x 19 square lattice array with three vertical layers. Center to center horizontal spacing between the containers is 35.5 cm by 37.6 cm. Stacked cans are separated 5.09 cm vertically. A 144.78 cm x 228.60 cm section along one side of the array represents an equipment area and eliminates a 4 x 6 portion of the array. A concrete column in the center of the room eliminates an additional container. This results in 336 containers per layer for a total of 1008 containers for the room. The array is located vertically between two 30.48 cm thick concrete slabs that are 91.44 cm apart. The array is enclosed on the sides by concrete of thickness 22.86 cm in the x-direction and 25.4 cm in the y-direction. The vault walls and ceiling are modeled as concrete 30.48 cm thick. The concrete ceiling is 215.9 cm above the floor. MCNP plots of the infloor geometry are presented in Figures 5-1 and 5-2.

All modeling was done without any installed neutron poisons. Dry concrete was used for this analysis.

Dose rates were also calculated above an open infloor storage location. For these cases a 16.828 cm diameter hole was cut through the concrete floor above a stack of three storage containers. The hole is at location $x=-108.775$ cm, $y=-112.8$ cm with respect to the center array position as shown in Figure 5-3.

Figure 5-1. Infloor Storage - xy plot

Figure 5-2. Infloor Storage - yz plot

Figure 5-3. Infloor Storage Hole Location

5.2 Dose Rate Results

Both neutron and photon dose rates were calculated at 30 cm and 150 cm above the floor for the infloor storage concept. The results are shown in the tables below. Each table provides dose rates, for both heights, above a typical storage position, at the center of the room (location of the concrete column), and at the location of the maximum dose rate. Dose rates for both the open and closed condition are provided.

Each Table presents results based on one of the sources used. Table 5-1 is the high ^{240}Pu , high density case; Table 5-2 the high ^{240}Pu , low density case; Table 5-3 the low ^{240}Pu , high density case; and Table 5-4 the low ^{240}Pu , low density case.

For each dose rate there is an open and closed hole state. Only one storage location is open, the rest remain closed. The "above hole" column contains the dose rates for that storage location when it is opened and closed. In Table 5-1 the neutron dose has clearly increased above the open hole at both 30 cm and 150 cm. The photon dose rate has tripled above the open hole at 30 cm but remains unchanged at 150 cm. The neutron dose rate clearly dominates for all cases.

Dose rate uncertainties less than 10% are generally reliable for the given modeling and materials. For the neutron dose rates, presented in the following tables, the uncertainties are less than 5% indicating that the neutrons contributing to the dose rates are being effectively sampled. In the case of the photon dose rates the uncertainties range from less than 10% to at least one instance of greater than 50%. Values with uncertainties greater than 50% are not useful, and those between 20% and 50% are reliable within a factor of a few.

Table 5-1. High ^{240}Pu , High Density, mrem/h

		Center		Above Hole		Maximum	
	Hole State	30 cm	150 cm	30 cm	150 cm	30 cm	150 cm
Neutron	Closed	156 (2.4%)	144 (2.6%)	160 (2.3%)	138 (2.2%)	167 (2.4%)	144 (3.3%)
	Open	154 (2.3%)	144 (2.4%)	198 (2.4%)	141 (2.1%)	198 (2.4%)	145 (2.1%)
Photon	Closed	0.3 (8.5%)	0.3 (6.5%)	0.33 (8.3%)	0.3 (5.1%)	0.5 (14.7%)	0.4 (15.9%)
	Open	0.3 (8.9%)	0.3 (6.4%)	0.9 (21.5%)	0.3 (5.1%)	0.9 (21.5%)	0.6 (34.7%)

Table 5-2. High ^{240}Pu , Low Density, mrem/h

		Center		Above Hole		Maximum	
	Hole State	30 cm	150 cm	30 cm	150 cm	30 cm	150 cm
Neutron	Closed	55 (3.0%)	47 (2.9%)	54 (2.9%)	44 (2.6%)	58 (3.0%)	50 (2.7%)
	Open	54 (2.9%)	48 (2.9%)	66 (3.0%)	46 (2.7%)	66 (3.0%)	51 (2.7%)
Photon	Closed	0.3 (6.2%)	0.3 (4.9%)	0.4 (7.9%)	0.3 (5.3%)	0.3 (16.9%)	0.4 (43.2%)
	Open	0.3 (6.3%)	0.3 (5.2%)	1.1 (14.3%)	0.3 (5.5%)	1.1 (14.3%)	0.5 (29.8%)

Table 5.2 results (high ^{240}Pu , low density), follow the same pattern as the dose rates of Table 5-1. However, the neutron dose rates are about a third of those for the high density cases while the photon dose rates are slightly higher but nearly the same.

Table 5-3. Low ^{240}Pu , High Density, mrem/h

		Center		Above Hole		Maximum	
	Hole State	30 cm	150 cm	30 cm	150 cm	30 cm	150 cm
Neutron	Closed	62 (3.3%)	56 (2.5%)	63 (2.4%)	54 (2.1%)	66 (2.4%)	57 (2.4%)
	Open	61 (2.5%)	56 (2.5%)	78 (2.6%)	55 (2.1%)	78 (2.6%)	58 (2.7%)
Photon	Closed	0.1 (20.5%)	0.1 (17.2%)	0.1 (18.7%)	0.1 (11.9%)	0.2 (25.8%)	0.2 (29.9%)
	Open	0.1 (20.5%)	0.1 (16.7%)	0.3 (45.6%)	0.1 (11.5%)	0.3 (45.6%)	0.3 (56.5%)

Again, the dose rates of Table 5-3 follow a pattern similar to that of Table 5-1. In this case both the neutron and photon dose rates are less than the Table 5-1 cases.

Table 5-4. Low ^{240}Pu , Low Density, mrem/h

		Center		Above Hole		Maximum	
	Hole State	30 cm	150 cm	30 cm	150 cm	30 cm	150 cm
Neutron	Closed	18 (2.4%)	16 (2.2%)	18 (2.4%)	15 (2.2%)	19 (3.1%)	17 (2.1%)
	Open	18 (2.4%)	16 (2.2%)	22 (2.5%)	16 (2.4%)	22 (2.5%)	17 (2.2%)
Photon	Closed	0.1 (13.4%)	0.1 (11.9%)	0.1 (16.3%)	0.1 (13.0%)	0.2 (22.7%)	0.2 (65.8%)
	Open	0.1 (13.5%)	0.1 (11.6%)	0.4 (26.6%)	0.1 (12.8%)	0.4 (26.6%)	0.2 (49.8%)

Table 5-4 (low ^{240}Pu , high density) is similar to the previous Tables, but the dose rates are all much lower.

For all cases the difference between the closed and open state is most pronounced at 30 cm above the floor. At 150 cm the affect is less noticable.

Figure 5-4 is a neutron dose rate contour plot 150 cm above the floor for the high ^{240}Pu , high density case. From the plot it can be easily seen that the dose rates are greatest near the center of the room and decrease at the edges. Additional infloor dose rate contour plots are provided in Appendix D.

Figure 5-4

6.0 Cubicle Storage

With the cubicle storage concept, vaults in building 2736Z would be modified to contain multiple rows of cubicles. The inner dimensions of each cubicle is 60.96 cm wide by 30.48 cm deep by 243.84 cm high. Each cubicle contains seven vertical shelves with pedestal positions for four storage containers and has a 20.32 cm thick concrete door. Adjacent cubicles are separated by 20.32 cm of concrete. A single vault contains 68 cubicles; a row of 10 on the south and north wall plus three rows each with 8 back to back pairs of cubicles. An MCNP plot of the room layout is provided in Figure 6-1.

6.1 MCNP Models

A full room model was used to calculate dose rates with a cubicle door open. This model proved ineffective for determining dose rates with the cubicle doors closed. Figures 6-1 and 6-2 are MCNP plots of the full room. A half row reflected boundary model, Figure 6-3, was used to calculate both the neutron and photon closed door dose rates. The half row reflected boundary model simulates the full room.

For both neutron and photons, dose rates were determined with both dry and wet ordinary concrete. The dry concrete has a hydrogen weight fraction of 0.0031 and a density of 2.258 g/cc. Wet concrete has a hydrogen weight fraction of 0.0064 and a density of 2.328 g/cc. For the neutron case the wet concrete reduces the calculated dose rates by more than 50%. The photon dose rate is reduced by 20 - 30%.

Figure 6-1. Cubicle Storage - xy plot

02/05/97 11:48:51
PFP 3013 cans in storage
cubicles - 3 rows & north &
south walls
probid = 02/05/97 10:12:19
basis:
(1.000000, 0.000000, 0.000000)
(0.000000, 1.000000, 0.000000)
origin:
(300.00, 238.00, 15.00)
extent = (440.00, 440.00)

```

02/05/97 12:51:08
PFP 3013 cans in storage
cubicles - 3 rows & north &
south walls
probid = 02/05/97 10:12:19
basis:
( 0.000000, 1.000000, 0.000000)
( 0.000000, 0.000000, 1.000000)
origin:
( 300.00, 238.00, 15.00)
extent = ( 440.00, 440.00)
    
```

Figure 6-2. Cubicle Storage - yz plot

02/05/97 12:57:55
FFP 3013 cans in storage
cubicles

probid = 02/05/97 12:56:43
basis:
(1.000000, 0.000000, 0.000000)
(0.000000, 1.000000, 0.000000)
origin:
(200.00, 0.00, 15.00)
extent = (250.00, 250.00)

Figure 6-3. Cubicle Storage - Reflected Half Row

6.2 Dose Rate Results

For each of the four specified sources, dose rates were calculated for the open and closed cubicle door. For the closed door case the dose rates were calculated 30 cm from the door surface. Dose rates were calculated 60 cm from the rear inside surface for the open door case. For both, the dose rate calculations are 150 cm above the floor surface. Due to constraints resulting from the criticality assessment, dose rate were calculated with 20 canisters per cubicle in addition to 28 canisters per cubicle.

6.2.1 28 Canisters Per Cubicle

Both neutron and photon dose rates were calculated with 28 canisters per storage cubicle. For the closed door case the dose rates were calculated 150 cm above the floor and 30 cm from a cubicle door to simulate human torso height and distance. Dose rates were determined by particle tallies through a surface at this position. In order to improve to efficiency of the calculation, and reduce the necessary computer time, the concrete door was split into thinner regions to facilitate transport of the particles through the door. These closed door calculations were done with the reflected half row model. Neutron dose rate results are presented in Table 6-1 and photon dose rate results in Table 6-2.

Table 6-1. Cubicle Neutron Dose Rates (mrem/h)
28 cans per full cubicle

^{240}Pu fraction	PuO_2 Density	Concrete Composition	Closed Full	Open Full	Open Half Full
high	high	dry	537 (4.75%)	637 (21.3%)	335 (15.1%)
		new	251 (6.04%)	-	-
high	low	dry	214 (4.30%)	206 (9.94%)	113 (8.34%)
		new	114 (9.26%)	-	-
low	high	dry	225 (4.16%)	181 (15.2%)	83 (10.1%)
		new	86 (5.74%)	-	-
low	low	dry	81 (5.33%)	67 (10.0%)	37 (9.27%)
		new	37 (4.19%)	-	-

Table 6-2. Cubicle Photon Dose Rates (mrem/h)
28 cans per full cubicle

^{240}Pu fraction	PuO_2 Density	Concrete Composition	Closed Full	Open Full	Open Half Full
high	high	dry	3.8 (15.0%)	43 (13.6%)	22 (12.9%)
		new	3.4 (20.8%)	-	-
high	low	dry	4.1 (5.82%)	59 (10.7%)	38 (22.4%)
		new	3.2 (5.72%)	-	-
low	high	dry	1.6 (34.1%)	17 (18.8%)	6.8 (20.4%)
		new	1.4 (38.3%)	-	-
low	low	dry	1.6 (9.58%)	28 (21.5%)	17 (38.5%)
		new	1.2 (10.1%)	-	-

Uncertainties less than 10% are generally reliable. The closed door neutron dose rates are mostly around 5%, indicating that neutrons contributing to the dose rates are being effectively sampled. Open door neutron dose rate uncertainties are 10 to 20%. Photon dose rates uncertainties range from 5 to around 40%. This indicates poorer sampling of the photons contributing to the calculated dose rates. Fewer photons are able to travel through the cubicle door and walls to the dose tally area. Values with uncertainties greater than 50% are not useful, and those between 20% and 50% are reliable within a factor of a few.

Examination of the open and closed door neutron dose rates reveals an apparent inconsistency. For most variations with dry concrete, the results show a dose rate increase from the open door case to the closed door case. The dose rate should decrease with the closed door. However, when wet concrete is used the dose rate decreases as expected. This result indicates that the dry concrete is an ineffective neutron shield. Also it is likely that neutrons from cubicles adjacent to the open cubicle are not being sampled as efficiently as those from the open cubicle. This is indicated by the higher uncertainties associated with the open cubicle calculations.

Photon dose rates decrease from the open to closed cubicle condition as is expected. Uncertainties for these dose rates are lower than the closed door cases due to the increased number of photons reaching the dose tally area through the open door.

6.2.2 20 Canisters Per Cubicle

The calculations of Section 6.2.1 were repeated with 20 canisters per cubicle. Neutron dose rates are presented in Table 6-3 and the photon dose rates in Table 6-4.

Table 6-3. Cubicle Neutron Dose Rates (mrem/h)
20 cans per full cubicle

^{240}Pu fraction	PuO_2 Density	Concrete Composition	Closed Full	Open Full	Open Half Full
high	high	dry	239 (8.14%)	219 (11.6%)	141 (23.5%)
		new	118 (10.7%)	-	-
high	low	dry	96 (4.23%)	160 (26.0%)	61 (15.7%)
		new	51 (4.92%)	-	-
low	high	dry	80 (4.52%)	54 (14.0%)	58 (24.9%)
		new	35 (5.49%)	-	-
low	low	dry	32 (4.29%)	37 (22.0%)	17 (17.5%)
		new	16 (5.17%)	-	-

Table 6-4. Cubicle Photon Dose Rates (mrem/h)
20 cans per full cubicle

^{240}Pu fraction	PuO_2 Density	Concrete Composition	Closed Full	Open Full	Open Half Full
high	high	dry	1.4 (8.53%)	13 (12.5%)	12 (22.3%)
		new	1.3 (8.51%)	-	-
high	low	dry	1.8 (7.00%)	18 (12.4%)	15 (24.6%)
		new	1.5 (8.34%)	-	-
low	high	dry	0.5 (14.8%)	6.2 (19.7%)	6.7 (46.7%)
		new	0.4 (14.6%)	-	-
low	low	dry	0.6 (12.1%)	8.2 (15.0%)	7.8 (17.5%)
		new	0.5 (13.5%)	-	-

Both the neutron and photon dose rates are reduced with respect to the 28 canister per cubicle dose rates. In addition, the photon dose rate uncertainties are lower indicating more reliable results.

As with the 28 canister case dose rates seem to be greater for the closed door calculations, with dry concrete, than for the open door. Again the uncertainties for the open door case are generally higher indicating MCNP inefficiencies in tallying particles from adjacent closed cubicles as compared to the particles from the open cubicle.

Tables with additional dose rate results are provided in appendix G.

7.0 References

Carter, L. L., *Certification of MCNP Version 4A for WHC Computer Platforms*, WHC-MP-SD-30001, Rev.5, Westinghouse Hanford Company, Richland, Washington, May 1995.

Nelson, J. V., "Estimation of Neutron Dose Rates from Nuclear Waste Packages," 8M730-JVN-96-007, March 8, 1996.

Schmittroth, F. A., *Conversion of ORIGEN2 to SUN Workstations*, WHC-SD-NR-SWD-006, Westinghouse Hanford Company, Richland, Washington, September 24, 1993.

Watson, W. T., "Criticality Assessment of Two Plutonium Oxide 2736Z Vault Storage Concepts," Fluor Daniel Northwest, Richland, Washington, January 21, 1997.

Bunch, W. L., "Effects of Heating on Attenuation Properties of Concrete," Engineering Compendium on Radiation Shielding, Edited by R. G. Jaeger (editor-in-chief) et. al., Springer-Verlag, New York, 1975.

Etherington, Harold, Editor, *Nuclear Engineering Handbook*, McGraw-Hill Book Company, Inc., 1958.

American nuclear Society, "Neutron and Gamma-ray Fluence-to-dose Factors," ANSI/ANS-6.1.1-1991.

American Nuclear Society, "Neutron Flux-to-Dose Rate Conversion Factors and Quality Factors," ANSI/ANS-6.1.1-1977.

Appendix A

Source Listings and Dose Conversion Factors

The MCNP neutron and photon sources used for these analyses were based on the isotopic distributions provided in the letter of instruction. Those isotopic distributions are repeated in Table A-1.

Table A-1. Isotopic Distribution (% Plutonium on a per gram basis)

Distribution	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am
Low	0.01	93.77	6.00	0.20	0.03	0.14
High	0.24	80.66	16.98	1.44	0.69	2.80

These distributions were used as input to ORIGEN which generated the neutron and photon sources used by MCNP. The date for the data in Table A-1 is January 1, 1994. These distributions were decayed by ORIGEN out to 20 years. The 3 year decay results, representing the current distribution, were taken as the source for these analyses.

Tables A-2 and A-3 presents the ORIGEN generated neutron sources used for these dose rate calculations. Table A-2 is the high ^{240}Pu content source and Table A-3 is the low ^{240}Pu content source.

Table A-2. Neutron Source (per kg Pu)
High ^{240}Pu

nuclide	α, n (n/s)	spontaneous fission (n/s)	total (n/s)
^{238}Pu	3.819e+04	6.228e+03	4.442e+04
^{239}Pu	3.653e+04	-	3.653e+04
^{240}Pu	2.932e+04	1.546e+05	1.839e+05
^{242}Pu	-	1.163e+04	1.163e+04
^{241}Am	9.813e+04	-	9.813e+04
Total	2.022e+05	1.725e+05	3.747e+05

Table A-3. Neutron Source (per kg Pu)
Low ^{240}Pu

nuclide	α, n (n/s)	spontaneous fission (n/s)	total (n/s)
^{238}Pu	1.591e+03	2.595e+02	1.851e+03
^{239}Pu	4.247e+04	-	4.247e+04
^{240}Pu	1.036e+04	5.461e+04	6.497e+04
^{242}Pu	-	5.057e+02	5.057e+02
^{241}Am	5.472e+03	-	5.472e+03
Total	5.989e+04	5.540e+04	1.153e+05

Table A-4 provides the ORIGEN generated photon spectrum for high and low ^{240}Pu content.

Table A-4. Photon Spectrum

Energy (MeV)	photons/s	
	High ²⁴⁰ Pu	Low ²⁴⁰ Pu
1.50e-02	1.409e+12	2.580e+11
2.50e-02	9.578e+10	5.344e+09
3.75e-02	8.626e+09	6.001e+08
5.75e-02	1.409e+12	7.920e+10
8.50e-02	1.306e+09	1.322e+08
1.25e-01	1.492e+09	3.121e+08
2.25e-01	3.656e+08	6.957e+07
3.75e-01	1.839e+08	1.426e+08
5.75e-01	3.078e+07	6.622e+06
8.50e-01	9.134e+06	1.030e+06
1.25e+00	1.911e+05	5.653e+04
1.75e+00	8.269e+04	2.677e+04
2.25e+00	4.734e+04	1.531e+04
2.75e+00	2.718e+04	8.788e+03
3.50e+00	2.403e+04	7.761e+03
5.00e+00	1.012e+04	3.266e+03
7.00e+00	1.143e+03	3.683e+02
1.10e+01	1.300e+02	4.186e+01
Total	2.926e+12	3.438e+11

These photon spectra do not account for photons resulting from any induced fission that may occur in the source. The total neutron source can be approximated by

$$S(t) = (S(SF) + S(\alpha, n)) / (1 - k_{eff}),$$

where $S(SF)$ is the spontaneous fission neutron source, and $S(\alpha, n)$ is the (α, n) neutron source (Nelson).

From Etherington, $\nu = 2.91$ for ²³⁹Pu and 7.51 photons/fission are released on average. From this photons from induced fissions can be

conservatively approximated by $S(t)$ neutrons $\times$ (7.51 (photons/fission)/2.91 (neutrons/fission)). MCNP k_{eff} calculations of the models used in this analysis give a k_{eff} of around 0.80. From this a conservative estimate of fission photons is 4.835×10^6 p/s for the high ^{240}Pu source and 1.493×10^6 p/s for the low ^{240}Pu source. These are both insignificant when compared to the source spectrums of Table A-4.

Table A-5 lists the flux to dose conversion factors used to calculate the photon dose rates (ANSI/ANS-6.1.1-1991).

Table A-5. Photon Flux to Dose Conversion Factors

Energy (MeV)	$\frac{(\text{mrem/h})}{\text{photon/cm}^2\text{-sec}}$	Energy (MeV)	$\frac{(\text{mrem/h})}{\text{photon/cm}^2\text{-sec}}$
0.010	2.232e-05	0.500	9.144e-04
0.015	5.625e-05	0.600	1.076e-03
0.020	8.568e-05	0.800	1.379e-03
0.030	1.184e-04	1.00	1.656e-03
0.040	1.314e-04	1.50	2.246e-03
0.050	1.382e-04	2.00	2.758e-03
0.060	1.440e-04	3.00	3.672e-03
0.080	1.624e-04	4.00	4.500e-03
0.100	1.919e-04	5.00	5.292e-03
0.150	2.797e-04	6.00	6.012e-03
0.200	3.708e-04	8.00	7.488e-03
0.300	5.616e-04	10.0	8.892e-03
0.400	7.416e-04	12.0	1.040e-02

Table A-6 lists the flux to dose conversion factors used to calculate the photon dose rates (ANSI/ANS-6.1.1-1991).

Table A-6. Neutron Flux to Dose Conversion Factors

Energy (MeV)	$\frac{(\text{mrem/h})}{\text{photon/cm}^2\text{-sec}}$	Energy (MeV)	$\frac{(\text{mrem/h})}{\text{photon/cm}^2\text{-sec}}$
2.5e-08	3.67e-03	0.5	9.26e-02
1.0e-07	3.67e-03	1.0	0.132
1.0e-06	4.46e-03	2.5	0.125
1.0e-05	4.54e-03	5.0	0.156
1.04e-04	4.18e-03	7.0	0.147
0.001	3.76e-03	10.0	0.147
0.061	3.56e-03	14.0	0.208
0.1	2.17e-02	20.0	0.277

Appendix B

Model Validation

In order to anchor the results of this analysis to a known measured quantity, a benchmark calculation was done using an existing PFP inventory item, a package containing PuO_2 . The benchmark can was modeled, and neutron and photon dose rates calculated, with MCNP. These calculated dose rates were then compared to measured values. The benchmark source was then placed into a 3013 container MCNP model and the dose rates for this configuration were calculated. These results were compared to the original benchmark results and checked for reasonableness.

The benchmark can consists of three nested cans with dimensions as shown in Table B-1. Wall thickness for each can is 0.0023 cm.

Table B-1. Benchmark Can Dimensions

Can	Outer Diameter (cm)	Height (cm)
Inner	8.73	14.29
Secondary	10.32	15.88
Outer	10.80	17.78

The can contains 1609.8 g PuO_2 with 1411 g plutonium and a plutonium isotopic distribution as specified in Table B-2. The isotopic content was determined on 10-23-87.

Table B-2. Benchmark Can Source

Nuclide	Weight %
^{238}Pu	0.091
^{239}Pu	86.137
^{240}Pu	12.107
^{241}Pu	1.458
^{242}Pu	0.207
^{241}Am	84 PPM Pu

ORIGEN was used to generate the MCNP neutron and photon sources. Dose rate measurements were taken of the benchmark can on 5-21-96, so the ORIGEN 10 year decayed neutron and photon sources were used. The neutron source is given in Table B-3 and the photon source is given in Table B-4.

Table B-3. Neutron Source
Low ^{240}Pu

nuclide	α, n (n/s)	spontaneous fission (n/s)	total (n/s)
^{238}Pu	1.957e+04	3.192e+03	2.276e+04
^{239}Pu	5.502e+04	-	5.502e+04
^{240}Pu	2.947e+04	1.554e+05	1.849e+05
^{242}Pu	-	4.888e+03	4.888e+03
^{241}Am	2.608e+04	-	2.608e+04
Total	1.301e+05	1.635e+05	2.936e+05

Table B-4. Photon Spectrum

Energy (MeV)	photons/s
1.50e-02	7.366e+11
2.50e-02	2.548e+10
3.750e-02	2.606e+09
5.75e-02	3.757e+11
8.50e-02	5.884e+08
1.25e-01	9.317e+08
2.25e-01	3.416e+08
3.75e-01	2.084e+08
5.75e-01	1.379e+07
8.50e-01	3.330e+06
1.25e+00	1.683e+05
1.75e+00	7.641e+04
2.25e+00	4.389e+04
2.75e+00	2.527e+04
3.50e+00	2.242e+04
5.00e+00	9.492e+03
7.00e+00	1.077e+03
1.10e+01	1.229e+02
Total	1.142e+12

Measured and calculated neutron and photon dose rates at 30 cm for the benchmark can are presented in Table B-5. Also included in the Table are the calculated dose rates for the benchmark source in the 3013 container.

Table B-5. Benchmark Source (mrem/h)

	photon dose	neutron dose
measurement	15	4
benchmark can - MCNP	18.7 (8.63%)	2.4 (0.76%)
3013 Container - MCNP	2.7 (4.34%)	2.5 (1.46%)

There is good agreement between the benchmark can measured dose rates and the calculated dose rates. The calculated photon dose rate is slightly higher than the measurement and the calculated neutron dose rate is slightly lower than the measurement.

Dose rate calculations were done with the benchmark source in the 3013 container. Since stainless steel is not an effective neutron shield, the neutron dose rate remained essentially unchanged. The photon dose rate decreased, consistent with the greater total wall thickness of the 3013 can. This calculation validates the 3013 container MCNP model.

Appendix C

Concrete Compositions

Table C-1 lists the concrete compositions used for this analysis (Bunch). The shielding effectiveness of concrete varies as hydrolysis and hydration occur during the curing process. The concrete used here is ordinary concrete.

Table C-1. Concrete Composition (g/cm³)

Element	Unheated (wet)	100°C (dry)
H	0.015	0.007
O	1.057	0.995
Na	0.041	0.041
Mg	0.085	0.085
Al	0.137	0.137
Si	0.487	0.487
P	0.002	0.002
S	0.002	0.002
K	0.015	0.015
Ca	0.295	0.295
Ti	0.011	0.011
Mn	0.003	0.003
Fe	0.178	0.178
Total	2.328	2.258

Appendix D
Infloor Dose Rate Contour Plots

Eleven infloor storage date rate plots are provided in this appendix. Neutron dose rate plots are provided for the high ^{240}Pu , high density and low ^{240}Pu , high density cases at 30 cm and 150 cm above the floor. Photon dose rate plots are provided for the high ^{240}Pu , high density case at 30 cm and 150 cm above the floor.

Appendix E

Input Files

ORIGEN files, cubicle dose rate MCNP files, 3013 container and benchmark can MCNP files are stored on cfs directory /w98142/dosew460. Infloor dose rate MCNP files are store on group machine directory /home/w85112/oldwork/w460/mcnp.

Following are the ORIGEN input files for the high and low ²⁴⁰Pu content sources, and two representative MCNP cubicle input files.

```

-1
-1
-1
TIT SOURCE FOR PFP 3013 CAN - high PU240 BOUNDING CASE
LIP 0 0 0
LIB 0 1 2 3 381 382 383 9 3 0 1 43
PHO 101 102 103 10
RDA 1 kg
INP -1 1 -1 -1 1 1
MOV -1 1 0 1.0
BUP
DEC 1.0 1 2 4 1
DEC 5.0 2 3 4 0
DEC 10.0 3 4 4 0
DEC 50.0 4 5 4 0
DEC 100.0 5 6 4 0
DEC 200.0 6 7 4 0
DEC 1.0 7 8 5 0
DEC 3.0 8 9 5 0
DEC 5.0 9 10 5 0
DEC 10.0 10 11 5 0
DEC 20.0 11 12 5 0
BUP
CUT 5 1.E-20 7 1.E-20 9 1.E-20 -1
RDA ACTIVATION PRODUCTS OUTPUT TABLE OPTIONS
OPTL 8 8 8 8 7 8 7 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8
RDA FISSION PRODUCTS OUTPUT TABLE OPTIONS
OPTF 8 8 8 8 7 8 7 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8
RDA ACTINIDE AND DAUGHTER OUTPUT TABLE OPTIONS
OPTA 8 8 8 8 7 8 7 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8
OUT 12 1 -1 0
STP 4
2 922340 0.000E+00 922350 0.000E+00 922360 0.000E+00 922380 0.000E+00
2 932370 0.000E+00 932390 0.000E+00 942380 2.400E+00 942390 8.066E+02
2 942400 1.698E+02 942410 1.440E+01 952410 2.800E+01 952421 0.000E+00
2 952420 0.000E+00 952430 0.000E+00 962420 0.000E+00 962430 0.000E+00
2 962440 0.000E+00 942420 6.900E+00 00000 0.000E+00 00000 0.000E+00

```

0
END

-1
-1
-1

TIT SOURCE FOR PFP 3013 CAN - low PU240 BOUNDING CASE

LIP 0 0 0

LIB 0 1 2 3 381 382 383 9 3 0 1 43

PHO 101 102 103 10

RDA 1 kg

INP -1 1 -1 -1 1 1

MOV -1 1 0 1.0

BUP

DEC 1.0 1 2 4 1

DEC 5.0 2 3 4 0

DEC 10.0 3 4 4 0

DEC 50.0 4 5 4 0

DEC 100.0 5 6 4 0

DEC 200.0 6 7 4 0

DEC 1.0 7 8 5 0

DEC 3.0 8 9 5 0

DEC 5.0 9 10 5 0

DEC 10.0 10 11 5 0

DEC 20.0 11 12 5 0

BUP

CUT 5 1.E-20 7 1.E-20 9 1.E-20 -1

RDA ACTIVATION PRODUCTS OUTPUT TABLE OPTIONS

OPTL 8 8 8 8 7 8 7 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8

RDA FISSION PRODUCTS OUTPUT TABLE OPTIONS

OPTF 8 8 8 8 7 8 7 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8

RDA ACTINIDE AND DAUGHTER OUTPUT TABLE OPTIONS

OPTA 8 8 8 8 7 8 7 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8

OUT 12 1 -1 0

STP 4

2 922340 0.000E+00 922350 0.000E+00 922360 0.000E+00 922380 0.000E+00

2 932370 0.000E+00 932390 0.000E+00 942380 1.000E-01 942390 9.377E+02

2 942400 6.000E+01 942410 2.000E+00 952410 1.400E+00 952421 0.000E+00

2 952420 0.000E+00 952430 0.000E+00 962420 0.000E+00 962430 0.000E+00

2 962440 0.000E+00 942420 3.000E-01 00000 0.000E+00 00000 0.000E+00

0

END

MCNP INPUT - HALF ROW REFLECTIVE BOUNDARY MODEL

PFP 3013 cans in storage cubicles

c 4 cubicles - 20 cans per cubicle

c reflective surfaces simulates complete room

```

c neutron dose rate - high pu240 content - high puo2 density
  1 1 -6.00 -2 -18 8 u=1 imp:n=1 $ source
  2 2 -0.00129 (((-2 18 -17 -9):(9 -17 -10 )):(17 -4 -10 )):(-14 10 -4 )
    u=1 imp:n=1
  3 3 -7.99 (-14 10 4 -3):(4 -1 -10 17 ) u=1 imp:n=2 $ can neck
  4 3 -7.99 (2 -1 -17 8):(-8 7 -1 ) u=1 imp:n=2 $ conven can wall
  5 3 -7.99 (-20 14 -22):(-14 21 -22 3 ) u=1 imp:n=2 $ conven can
top
  6 2 -0.00129 (22 -1 -20 21):(3 -1 -21 10) u=1 imp:n=2 $ air
  7 2 -0.00129 -20 1 -29 7 u=1 imp:n=2 $ airspace
  8 2 -0.00129 20 -29 -26 u=1 imp:n=2 $ airspace
  9 3 -7.99 (26 -27 -29):(27 -28 1 -29) u=1 imp:n=2 $ inner can
top
 10 2 -0.00129 27 -28 -1 u=1 imp:n=2 $ airspace
 11 3 -7.99 (25 -28 29 -30):(25 -7 -29) u=1 imp:n=2 $ inner can
wall
 12 2 -0.00129 (25 -28 30 -40):(28 -43 -40) u=1 imp:n=2 $ airspace
 13 3 -7.99 (42 -44 40 -41):(42 -25 -40) u=1 imp:n=2 $ outer can
wall
 14 3 -7.99 43 -44 -40 u=1 imp:n=1 $ outer can top
c cubicle walls
 29 4 -2.258 (51 -54 50 -136 60 -61) imp:n=8 $ front side
350 4 -2.258 (51 -54 136 -134 60 -61) imp:n=8 $ front
351 4 -2.258 (51 -54 134 -132 60 -61) imp:n=8 $ front
352 4 -2.258 (51 -54 132 -130 60 -61) imp:n=8 $ front
353 4 -2.258 (51 -54 130 -55 60 -61) imp:n=4 $ front
354 4 -2.258 (51 -54 55 -128 60 -61) imp:n=4 $ front
355 4 -2.258 (51 -54 128 -126 60 -61) imp:n=4 $ front
356 4 -2.258 (51 -54 126 -124 60 -61) imp:n=4 $ front
357 4 -2.258 (51 -54 124 -122 60 -61) imp:n=4 $ front
 30 4 -2.258 (51 -52 56 -57 60 -61) imp:n=1 $ left side
 31 4 -2.258 (53 -54 56 -57 60 -61) imp:n=1 $ right side
 32 4 -2.258 (51 -54 122 -56 60 -61) imp:n=4 $ front side
 33 4 -2.258 (51 -54 57 -58 60 -61) imp:n=1 $ back side
 34 4 -2.258 (51 -112 114 -58 59 -60) imp:n=1 $ floor
 35 4 -2.258 (51 -112 114 -58 61 -62) imp:n=1 $ ceiling
c can stacks
c stack 1
 36 0 -63 67 -68 fill=1 imp:n=1 $ can 1
 37 like 36 but TRCL=4 $ can 2
 40 like 36 but TRCL=5 $ can 3
 41 like 36 but TRCL=8 $ can 6
 42 like 36 but TRCL=9 $ can 7
c stack 2
 43 like 36 but TRCL=1 $ can 1
 44 like 36 but TRCL=10 $ can 2
 47 like 36 but TRCL=11 $ can 3
 48 like 36 but TRCL=14 $ can 6
 49 like 36 but TRCL=15 $ can 7

```

```

c  stack 3
50  like 36 but TRCL=2    $ can 1
51  like 36 but TRCL=16   $ can 2
54  like 36 but TRCL=17   $ can 3
55  like 36 but TRCL=20   $ can 6
56  like 36 but TRCL=21   $ can 7
c  stack 4
57  like 36 but TRCL=3    $ can 1
58  like 36 but TRCL=22   $ can 2
61  like 36 but TRCL=23   $ can 3
62  like 36 but TRCL=26   $ can 6
63  like 36 but TRCL=27   $ can 7
c  airspace around cans
70  2  -0.00129 52 -53 56 -57 60 -61 #36 #37 #40 #41 #42
    #43 #44 #47 #48 #49 #50 #51 #54 #55 #56 #57 #58
    #61 #62 #63  imp:n=4  $ air
C  second cubicle
c  cubicle walls
100 4  -2.258 (54 -100 56 -57 60 -61)  imp:n=1 $ left side
101 4  -2.258 (101 -102 56 -57 60 -61)  imp:n=1 $ right side
102 4  -2.258 (54 -102 57 -58 60 -61)  imp:n=1 $ back side
103 4  -2.258 (54 -102 55 -56 60 -61)  imp:n=1 $ front side
104 4  -2.258 (54 -102 50 -55 60 -61)  imp:n=1 $ front side
c  can stacks
c  stack 1
105  like 36 but TRCL=28   $ can 1
106  like 36 but TRCL=29   $ can 2
109  like 36 but TRCL=30   $ can 3
110  like 36 but TRCL=33   $ can 6
111  like 36 but TRCL=34   $ can 7
c  stack 2
112  like 36 but TRCL=35   $ can 1
113  like 36 but TRCL=36   $ can 2
116  like 36 but TRCL=37   $ can 3
117  like 36 but TRCL=40   $ can 6
118  like 36 but TRCL=41   $ can 7
c  stack 3
119  like 36 but TRCL=42   $ can 1
120  like 36 but TRCL=43   $ can 2
123  like 36 but TRCL=44   $ can 3
124  like 36 but TRCL=47   $ can 6
125  like 36 but TRCL=48   $ can 7
c  stack 4
126  like 36 but TRCL=49   $ can 1
127  like 36 but TRCL=50   $ can 2
130  like 36 but TRCL=51   $ can 3
131  like 36 but TRCL=54   $ can 6
132  like 36 but TRCL=55   $ can 7
c  airspace around cans

```

```

133 2 -0.00129 100 -101 56 -57 60 -61 #105 #106
    #109 #110 #111 #112 #113 #116 #117 #118
    #119 #120 #123 #124 #125 #126 #127
    #130 #131 #132 imp:n=1 $ air
C third cubicle
c cubicle walls
134 4 -2.258 (102 -103 56 -57 60 -61) imp:n=1 $ left side
135 4 -2.258 (104 -105 56 -57 60 -61) imp:n=1 $ right side
136 4 -2.258 (102 -105 57 -58 60 -61) imp:n=1 $ back side
137 4 -2.258 (102 -105 55 -56 60 -61) imp:n=1 $ front side
138 4 -2.258 (102 -105 50 -55 60 -61) imp:n=1 $ front side
c can stacks
c stack 1
140 like 36 but TRCL=56 $ can 1
141 like 36 but TRCL=57 $ can 2
144 like 36 but TRCL=58 $ can 3
145 like 36 but TRCL=61 $ can 6
146 like 36 but TRCL=62 $ can 7
c stack 2
147 like 36 but TRCL=63 $ can 1
148 like 36 but TRCL=64 $ can 2
151 like 36 but TRCL=65 $ can 3
152 like 36 but TRCL=68 $ can 6
153 like 36 but TRCL=69 $ can 7
c stack 3
154 like 36 but TRCL=70 $ can 1
155 like 36 but TRCL=71 $ can 2
158 like 36 but TRCL=72 $ can 3
159 like 36 but TRCL=75 $ can 6
160 like 36 but TRCL=76 $ can 7
c stack 4
161 like 36 but TRCL=77 $ can 1
162 like 36 but TRCL=78 $ can 2
165 like 36 but TRCL=79 $ can 3
166 like 36 but TRCL=82 $ can 6
167 like 36 but TRCL=83 $ can 7
c airspace around cans
168 2 -0.00129 103 -104 56 -57 60 -61 #140 #141
    #144 #145 #146 #147 #148 #151 #152 #153
    #154 #155 #158 #159 #160 #161 #162
    #165 #166 #167 imp:n=1 $ air
C fourth cubicle
c cubicle walls
169 4 -2.258 (105 -106 56 -57 60 -61) imp:n=1 $ left side
170 4 -2.258 (107 -108 56 -57 60 -61) imp:n=1 $ right side
171 4 -2.258 (105 -108 57 -58 60 -61) imp:n=1 $ back side
172 4 -2.258 (105 -108 55 -56 60 -61) imp:n=1 $ front side
173 4 -2.258 (105 -108 50 -55 60 -61) imp:n=1 $ front side
c can stacks

```



```

c stack 1
174 like 36 but TRCL=84 $ can 1
175 like 36 but TRCL=85 $ can 2
178 like 36 but TRCL=86 $ can 3
179 like 36 but TRCL=89 $ can 6
180 like 36 but TRCL=90 $ can 7
c stack 2
181 like 36 but TRCL=91 $ can 1
182 like 36 but TRCL=92 $ can 2
185 like 36 but TRCL=93 $ can 3
186 like 36 but TRCL=96 $ can 6
187 like 36 but TRCL=97 $ can 7
c stack 3
188 like 36 but TRCL=98 $ can 1
189 like 36 but TRCL=99 $ can 2
192 like 36 but TRCL=100 $ can 3
193 like 36 but TRCL=103 $ can 6
194 like 36 but TRCL=104 $ can 7
c stack 4
195 like 36 but TRCL=105 $ can 1
196 like 36 but TRCL=106 $ can 2
199 like 36 but TRCL=107 $ can 3
200 like 36 but TRCL=110 $ can 6
201 like 36 but TRCL=111 $ can 7
c airspace around cans
202 2 -0.00129 106 -107 56 -57 60 -61 #174 #175
    #178 #179 #180 #181 #182 #185 #186 #187
    #188 #189 #192 #193 #194 #195 #196
    #199 #200 #201 imp:n=1 $ air
c air space
300 2 -0.00129 108 -110 50 -58 60 -61 imp:n=1
c concrete wall
305 4 -2.258 110 -112 114 -58 60 -61 imp:n=1
c tally cells
310 2 -0.00129 120 -50 51 -110 60 -61 imp:n=16
315 2 -0.00129 114 -120 51 -110 60 -61 imp:n=16
c beyond cubicles
1100 2 -0.00129 (-59 :62 :-51 :112 :-114 :58) (-90 -91 92)
    imp:n=1
c outside world
1200 0 90: 91: -92 imp:n=0 $ outside world
c surface cards - convenience can

1 c/z 10.00 8.5 5.6000000
2 c/z 10.00 8.5 5.5000000
3 c/z 10.00 8.5 4.7300000
4 c/z 10.00 8.5 4.5000000
7 pz 1.0500000

```

8	pz	1.150000			
9	pz	17.670000			
10	pz	19.800000			
14	pz	21.800000			
17	k/z	10.0	8.5	27.180000	0.3333330 -1.0
18	pz	9.95			
c cards for cap on convenience can					
20	pz	22.400000			
21	pz	20.200000			
22	c/z	10.0	8.5	5.0300000	
c inner can surfaces					
25	pz	0.90000			
26	pz	22.9500			
27	pz	23.0500			
28	pz	24.0000			
29	c/z	10.0	8.5	5.7000	
30	c/z	10.0	8.5	5.8500	
c outer can surfaces					
40	c/z	10.0	8.5	5.950	
41	c/z	10.0	8.5	6.250	
42	pz	0.0			
43	pz	24.40			
44	pz	25.40			
c concrete wall, floor, ceiling surfaces: 8 inches thick					
50	py	-35.56			
*51	px	-40.65			
52	px	-30.48			
53	px	30.48			
54	px	40.65			
55	py	-25.41			
56	py	-15.24			
57	py	15.24			
*58	py	25.41			
59	pz	-42.823			
c floor : upper surface					
60	pz	-14.823			
c ceiling : 8 feet above floor					
61	pz	229.017			
62	pz	249.347			
c can radial boundaries					
c 7 cans per stack					
c can stack 1					
63	c/z	10.00	8.50	6.2	
c can stack 2					
64	c/z	-10.00	8.50	6.2	
c can stack 3					
65	c/z	23.23	-5.239	6.2	
c can stack 4					
66	c/z	-23.23	-5.239	6.2	

```

c  can axial boundaries
c  layer 1
67      pz      0.100
68      pz      25.300
c  layer 2
69      pz      32.920
70      pz      58.520
c  layer 3
71      pz      65.940
72      pz      91.540
c  layer 4
73      pz      98.960
74      pz      124.560
c  layer 5
75      pz      131.980
76      pz      157.580
c  layer 6
77      pz      165.000
78      pz      190.600
c  layer 7
79      pz      198.020
80      pz      223.620
c  outside world surfaces
90      cz      2000
91      pz      300
92      pz      -100
c  cubicle two surfaces
100     px      50.82
101     px      111.78
102     px      121.95
c  cubicle three surface
103     px      132.12
104     px      193.08
105     px      203.25
c  cubicle four surfaces
106     px      213.42
107     px      274.38
108     px      284.55
c  bounding surfaces
110     px      365.85
112     px      397.00
*114    py      -81.28
c  tally & importance surfaces
120     py      -65.56
122     py      -17.27
124     py      -19.30
126     py      -21.33
128     py      -23.36
130     py      -27.42

```

```

132 py -29.45
134 py -31.48
136 py -33.51
140 pz 145.0
142 pz 125.0
144 px -10.16
146 px 10.16

*tr1 -20.0 0 0
*tr2 13.23 -13.739 0
*tr3 -33.23 -13.739 0
*tr4 0 0 33.02
*tr5 0 0 66.04
*tr6 0 0 99.06
*tr7 0 0 132.08
*tr8 0 0 165.01
*tr9 0 0 198.12
*tr10 -20.0 0 33.02
*tr11 -20.0 0 66.04
*tr12 -20.0 0 99.06
*tr13 -20.0 0 132.08
*tr14 -20.0 0 165.01
*tr15 -20.0 0 198.12
*tr16 13.23 -13.739 33.02
*tr17 13.23 -13.739 66.04
*tr18 13.23 -13.739 99.06
*tr19 13.23 -13.739 132.08
*tr20 13.23 -13.739 165.01
*tr21 13.23 -13.739 198.12
*tr22 -33.23 -13.739 33.02
*tr23 -33.23 -13.739 66.04
*tr24 -33.23 -13.739 99.06
*tr25 -33.23 -13.739 132.08
*tr26 -33.23 -13.739 165.01
*tr27 -33.23 -13.739 198.12
*tr28 61.30 0 0.0
*tr29 61.30 0 33.02
*tr30 61.30 0 66.04
*tr31 61.30 0 99.06
*tr32 61.30 0 132.08
*tr33 61.30 0 165.01
*tr34 61.30 0 198.12
*tr35 81.30 0 0.0
*tr36 81.30 0 33.02
*tr37 81.30 0 66.04
*tr38 81.30 0 99.06
*tr39 81.30 0 132.08
*tr40 81.30 0 165.01
*tr41 81.30 0 198.12

```

*tr42	48.07	-13.739	0.0
*tr43	48.07	-13.739	33.02
*tr44	48.07	-13.739	66.04
*tr45	48.07	-13.739	99.06
*tr46	48.07	-13.739	132.08
*tr47	48.07	-13.739	165.01
*tr48	48.07	-13.739	198.12
*tr49	94.53	-13.739	0.0
*tr50	94.53	-13.739	33.02
*tr51	94.53	-13.739	66.04
*tr52	94.53	-13.739	99.06
*tr53	94.53	-13.739	132.08
*tr54	94.53	-13.739	165.01
*tr55	94.53	-13.739	198.12
*tr56	142.6	0	0.0
*tr57	142.6	0	33.02
*tr58	142.6	0	66.04
*tr59	142.6	0	99.06
*tr60	142.6	0	132.08
*tr61	142.6	0	165.01
*tr62	142.6	0	198.12
*tr63	162.6	0	0.0
*tr64	162.6	0	33.02
*tr65	162.6	0	66.04
*tr66	162.6	0	99.06
*tr67	162.6	0	132.08
*tr68	162.6	0	165.01
*tr69	162.6	0	198.12
*tr70	129.37	-13.739	0.0
*tr71	129.37	-13.739	33.02
*tr72	129.37	-13.739	66.04
*tr73	129.37	-13.739	99.06
*tr74	129.37	-13.739	132.08
*tr75	129.37	-13.739	165.01
*tr76	129.37	-13.739	198.12
*tr77	175.83	-13.739	0.0
*tr78	175.83	-13.739	33.02
*tr79	175.83	-13.739	66.04
*tr80	175.83	-13.739	99.06
*tr81	175.83	-13.739	132.08
*tr82	175.83	-13.739	165.01
*tr83	175.83	-13.739	198.12
*tr84	223.9	0	0.0
*tr85	223.9	0	33.02
*tr86	223.9	0	66.04
*tr87	223.9	0	99.06
*tr88	223.9	0	132.08
*tr89	223.9	0	165.01
*tr90	223.9	0	198.12

```

*tr91 243.9 0 0.0
*tr92 243.9 0 33.02
*tr93 243.9 0 66.04
*tr94 243.9 0 99.06
*tr95 243.9 0 132.08
*tr96 243.9 0 165.01
*tr97 243.9 0 198.12
*tr98 210.67 -13.739 0.0
*tr99 210.67 -13.739 33.02
*tr100 210.67 -13.739 66.04
*tr101 210.67 -13.739 99.06
*tr102 210.67 -13.739 132.08
*tr103 210.67 -13.739 165.01
*tr104 210.67 -13.739 198.12
*tr105 257.13 -13.739 0.0
*tr106 257.13 -13.739 33.02
*tr107 257.13 -13.739 66.04
*tr108 257.13 -13.739 99.06
*tr109 257.13 -13.739 132.08
*tr110 257.13 -13.739 165.01
*tr111 257.13 -13.739 198.12
mode n
m1 94238.50c -.00240 94239.55c -0.80660 94240.50c -0.16980
    94241.50c -0.0144 94242.50c -0.0069 95241.50c -0.0280 8016.50c -0.1377
m2 7014.50c 0.790000 8016.50c 0.210000
m3 26000.55c 0.05536 24000.50c 0.01641 28000.50c 0.011220
    25055.50c 0.00155 42000.50c 0.00126 6000.50c 0.0002003
m4 1001.50c -0.0031 8016.50c -0.4407 11023.50c -0.0182
    12000.50c -0.0376 13027.50c -0.0607 14000.50c -0.2157
    15031.50c -0.0009 16032.50c -0.0009 36084.50c -0.0066
    20000.50c -0.1306 22000.50c -0.0049 26000.55c -0.0788
c wgt = (3.747e+05/kg pu) x 4.410 kg pu (5.0 kg puo2) x 80 cans = 1.322e+08
sdef erg=d1 pos=d4 rad=d2 ext=d3 axs 0 0 1 wgt=1.322e+08
sc1 spontaneous fission source spectrum (pu240)
spl -3 0.799 4.903
sc2 radius
si2 0 5.500
sp2 -21 1
sc3 extent

si3 -4.40 4.40
sp3 -21 0
si4 1 10.00 8.50 5.55
    10.00 8.50 38.52
    10.00 8.50 71.54
    10.00 8.50 170.60
    10.00 8.50 203.62
    -10.00 8.50 5.55
    -10.00 8.50 38.52

```

-10.00	8.50	71.54
-10.00	8.50	170.60
-10.00	8.50	203.62
23.23	-5.239	5.55
23.23	-5.239	38.52
23.23	-5.239	71.54
23.23	-5.239	170.60
23.23	-5.239	203.62
-23.23	-5.239	5.55
-23.23	-5.239	38.52
-23.23	-5.239	71.54
-23.23	-5.239	170.60
-23.23	-5.239	203.62
71.30	8.50	5.55
71.30	8.50	38.52
71.30	8.50	71.54
71.30	8.50	170.60
71.30	8.50	203.62
91.30	8.50	5.55
91.30	8.50	38.52
91.30	8.50	71.54
91.30	8.50	170.60
91.30	8.50	203.62
58.07	-5.239	5.55
58.07	-5.239	38.52
58.07	-5.239	71.54
58.07	-5.239	170.60
58.07	-5.239	203.62
104.53	-5.239	5.55
104.53	-5.239	38.52
104.53	-5.239	71.54
104.53	-5.239	170.60
104.53	-5.239	203.62
152.60	8.50	5.55
152.60	8.50	38.52
152.60	8.50	71.54
152.60	8.50	170.60
152.60	8.50	203.62
172.60	8.50	5.55
172.60	8.50	38.52
172.60	8.50	71.54
172.60	8.50	170.60
172.60	8.50	203.62
139.37	-5.239	5.55
139.37	-5.239	38.52
139.37	-5.239	71.54
139.37	-5.239	170.60
139.37	-5.239	203.62
185.83	-5.239	5.55

```

185.83 -5.239 38.52
185.83 -5.239 71.54
185.83 -5.239 170.60
185.83 -5.239 203.62
233.90 8.50 5.55
233.90 8.50 38.52
233.90 8.50 71.54
233.90 8.50 170.60
233.90 8.50 203.62
253.90 8.50 5.55
253.90 8.50 38.52
253.90 8.50 71.54
253.90 8.50 170.60
253.90 8.50 203.62
220.67 -5.239 5.55
220.67 -5.239 38.52
220.67 -5.239 71.54
220.67 -5.239 170.60
220.67 -5.239 203.62
267.13 -5.239 5.55
267.13 -5.239 38.52
267.13 -5.239 71.54
267.13 -5.239 170.60
267.13 -5.239 203.62
sp4 1 79r
sb4 1 2 5 10 1 1 2 5 10 1 1 2 5 10 1 1 2 5 10 1 60r
c ansi/ans-6.1.1-1977 fluence-to-dose,neutrons(mrem/hr/(n/cm**2/s)
de0 log 2.5e-08 1.0e-07 1.0e-06 1.0e-05 1.0e-04
      .001 .01 .1 .5 1.0
      2.5 5.0 7.0 10.0 14.0 20.0
df0 log 3.67e-3 3.67e-3 4.46e-3 4.54e-3 4.18e-3
      3.76e-3 3.56e-3 2.17e-2 9.26e-2 .132
      .125 .156 .147 .147 .208 .227
print 10 60 100 110 120 126 130 140 150 170
prdmp j -240 1 3
fc2 surface tally 30 cm in front of cubicle
f2:n 120
fs2 53 140 -142 146 144 52
sd2 1 1 1 406.4 406.4 406.4 1
ctme 600

```

MCNP INPUT - FULL ROOM MODEL

PFP 3013 cans in storage cubicles - 3 rows & north & south walls
 c neutron dose rate - high pu240 content - high puo2 density


```

c open cubicle - 20 cans per cubicle
  1 1 -6.00 -2 -18 8 u=1 imp:n=1 $ source
  2 2 -0.00129 ((-2 18 -17 -9):(9 -17 -10 )):(17 -4 -10 )):(-14 10 -4 )
    u=1 imp:n=1
  3 3 -7.99 (-14 10 4 -3):(4 -1 -10 17 ) u=1 imp:n=2 $ can neck
  4 3 -7.99 (2 -1 -17 8 ):(-8 7 -1 ) u=1 imp:n=2 $ conven can wall
  5 3 -7.99 (-20 14 -22 ):(-14 21 -22 3 ) u=1 imp:n=2 $ conven can
top
  6 2 -0.00129 (22 -1 -20 21):(3 -1 -21 10) u=1 imp:n=2 $ air
  7 2 -0.00129 -20 1 -29 7 u=1 imp:n=2 $ airspace
  8 2 -0.00129 20 -29 -26 u=1 imp:n=2 $ airspace
  9 3 -7.99 (26 -27 -29):(27 -28 1 -29) u=1 imp:n=2 $ inner can
top
 10 2 -0.00129 27 -28 -1 u=1 imp:n=2 $ airspace
 11 3 -7.99 (25 -28 29 -30):(25 -7 -29) u=1 imp:n=2 $ inner can
wall
 12 2 -0.00129 (25 -28 30 -40):(28 -43 -40) u=1 imp:n=2 $ airspace
 13 3 -7.99 (42 -44 40 -41):(42 -25 -40) u=1 imp:n=2 $ outer can
wall
 14 3 -7.99 43 -44 -40 u=1 imp:n=4 $ outer can top
c cubicle walls
 29 4 -2.258 (51 -54 50 -55 60 -61) u=2 imp:n=1 $ front side
 30 4 -2.258 (51 -52 56 -57 60 -61) u=2 imp:n=1 $ left side
 31 4 -2.258 (53 -54 56 -57 60 -61) u=2 imp:n=1 $ right side
 32 4 -2.258 (51 -54 55 -56 60 -61) u=2 imp:n=1 $ front side
 33 4 -2.258 (51 -54 57 -58 60 -61) u=2 imp:n=1 $ back side
 34 4 -2.258 (163 -164 120 -125 59 -113) imp:n=4 $ floor
 35 4 -2.258 (163 -164 120 -125 114 -62) imp:n=4 $ ceiling
c can stacks
c stack 1
 36 0 -63 67 -68 fill=1 u=2 imp:n=2 $ can 1
 37 like 36 but TRCL=4 u=2 $ can 2
 40 like 36 but TRCL=5 u=2 $ can 3
 41 like 36 but TRCL=8 u=2 $ can 6
 42 like 36 but TRCL=9 u=2 $ can 7
c stack 2
 43 like 36 but TRCL=1 u=2 $ can 1
 44 like 36 but TRCL=10 u=2 $ can 2
 47 like 36 but TRCL=11 u=2 $ can 3
 48 like 36 but TRCL=14 u=2 $ can 6
 49 like 36 but TRCL=15 u=2 $ can 7
c stack 3
 50 like 36 but TRCL=2 u=2 $ can 1
 51 like 36 but TRCL=16 u=2 $ can 2
 54 like 36 but TRCL=17 u=2 $ can 3
 55 like 36 but TRCL=20 u=2 $ can 6
 56 like 36 but TRCL=21 u=2 $ can 7
c stack 4
 57 like 36 but TRCL=3 u=2 $ can 1

```

```

58   like 36 but TRCL=22 u=2   $ can 2
61   like 36 but TRCL=23 u=2   $ can 3
62   like 36 but TRCL=26 u=2   $ can 6
63   like 36 but TRCL=27 u=2   $ can 7
c   airspace around cans
69 2 -0.00129 52 -53 56 -57 60 -61 #36 #37 #40 #41 #42
    #43 #44 #47 #48 #49 #50 #51 #54 #55 #56 #57 #58
    #61 #62 #63 u=2 imp:n=1 $ air
c   rear cubicle
70 4 -2.258 (51 -54 217 -103 60 -61) u=2 imp:n=1 $ front side
610 4 -2.258 (51 -54 216 -217 60 -61) u=2 imp:n=1
611 4 -2.258 (51 -54 215 -216 60 -61) u=2 imp:n=1
612 4 -2.258 (51 -54 214 -215 60 -61) u=2 imp:n=1
613 4 -2.258 (51 -54 102 -214 60 -61) u=2 imp:n=1
614 4 -2.258 (51 -54 212 -102 60 -61) u=2 imp:n=1
615 4 -2.258 (51 -54 211 -212 60 -61) u=2 imp:n=1
616 4 -2.258 (51 -54 210 -211 60 -61) u=2 imp:n=1
617 4 -2.258 (51 -54 209 -210 60 -61) u=2 imp:n=1
71 4 -2.258 (53 -54 100 -101 60 -61) u=2 imp:n=1 $ left side
72 4 -2.258 (51 -52 100 -101 60 -61) u=2 imp:n=1 $ right side
73 4 -2.258 (51 -54 101 -209 60 -61) u=2 imp:n=1 $ front side
74 4 -2.258 (51 -54 58 -100 60 -61) u=2 imp:n=1 $ back side
c   can stacks
c   stack 1
75   like 36 but TRCL=28 u=2   $ can 1
76   like 36 but TRCL=29 u=2   $ can 2
79   like 36 but TRCL=30 u=2   $ can 3
80   like 36 but TRCL=33 u=2   $ can 6
81   like 36 but TRCL=34 u=2   $ can 7
c   stack 2
82   like 36 but TRCL=35 u=2   $ can 1
83   like 36 but TRCL=36 u=2   $ can 2
86   like 36 but TRCL=37 u=2   $ can 3
87   like 36 but TRCL=40 u=2   $ can 6
88   like 36 but TRCL=41 u=2   $ can 7
c   stack 3
89   like 36 but TRCL=42 u=2   $ can 1
90   like 36 but TRCL=43 u=2   $ can 2
93   like 36 but TRCL=44 u=2   $ can 3
94   like 36 but TRCL=47 u=2   $ can 6
95   like 36 but TRCL=48 u=2   $ can 7
c   stack 4
96   like 36 but TRCL=49 u=2   $ can 1
97   like 36 but TRCL=50 u=2   $ can 2
100  like 36 but TRCL=51 u=2   $ can 3
101  like 36 but TRCL=54 u=2   $ can 6
102  like 36 but TRCL=55 u=2   $ can 7
c   airspace around cans
105 2 -0.00129 52 -53 100 -101 60 -61 #75 #76 #79 #80

```

```

#81 #82 #83 #86 #87 #88 #89 #90 #93 #94 #95
#96 #97 #100 #101 #102 u=2 imp:n=1 $ air
c south row of cubicles
110 0 105 -106 107 -108 109 -110 lat=1 fill=2 u=3 imp:n=1
111 0 111 -104 112 -115 113 -114 fill=3 imp:n=1
c space between wall & south row
115 2 -0.00129 162 -112 111 -104 113 -114 imp:n=1 $ air
c space between south & middle row
116 2 -0.00129 115 -180 111 -104 113 -114 imp:n=16 $ air
117 2 -0.00129 180 -121 111 -104 113 -114 imp:n=16 $ air
c cubicle walls (middle row)
120 4 -2.258 (51 -54 126 -220 60 -61) u=4 imp:n=1 $ front side
120 4 -2.258 (51 -54 220 -221 60 -61) u=4 imp:n=1
121 4 -2.258 (51 -54 221 -222 60 -61) u=4 imp:n=1
122 4 -2.258 (51 -54 222 -223 60 -61) u=4 imp:n=1
123 4 -2.258 (51 -54 223 -127 60 -61) u=4 imp:n=1
124 4 -2.258 (51 -54 127 -225 60 -61) u=4 imp:n=1
125 4 -2.258 (51 -54 225 -226 60 -61) u=4 imp:n=1
126 4 -2.258 (51 -54 226 -227 60 -61) u=4 imp:n=1
127 4 -2.258 (51 -54 227 -228 60 -61) u=4 imp:n=1
121 4 -2.258 (51 -52 128 -129 60 -61) u=4 imp:n=1 $ left side
122 4 -2.258 (53 -54 128 -129 60 -61) u=4 imp:n=1 $ right side
123 4 -2.258 (51 -54 228 -128 60 -61) u=4 imp:n=1 $ front side
124 4 -2.258 (51 -54 129 -130 60 -61) u=4 imp:n=1 $ back side
c can stacks
c stack 1
125 like 36 but TRCL=56 u=4 $ can 1
126 like 36 but TRCL=57 u=4 $ can 2
129 like 36 but TRCL=58 u=4 $ can 3
130 like 36 but TRCL=61 u=4 $ can 6
131 like 36 but TRCL=62 u=4 $ can 7
c stack 2
132 like 36 but TRCL=63 u=4 $ can 1
133 like 36 but TRCL=64 u=4 $ can 2
136 like 36 but TRCL=65 u=4 $ can 3
137 like 36 but TRCL=68 u=4 $ can 6
138 like 36 but TRCL=69 u=4 $ can 7
c stack 3
139 like 36 but TRCL=70 u=4 $ can 1
140 like 36 but TRCL=71 u=4 $ can 2
143 like 36 but TRCL=72 u=4 $ can 3
144 like 36 but TRCL=75 u=4 $ can 6
145 like 36 but TRCL=76 u=4 $ can 7
c stack 4
146 like 36 but TRCL=77 u=4 $ can 1
147 like 36 but TRCL=78 u=4 $ can 2
150 like 36 but TRCL=79 u=4 $ can 3
151 like 36 but TRCL=82 u=4 $ can 6
152 like 36 but TRCL=83 u=4 $ can 7

```

```

c   airspace around cans
    153 2 -0.00129 52 -53 128 -129 60 -61 #125 #126 #129 #130
        #131 #132 #133 #136 #137 #138 #139 #140 #143
        #144 #145 #146 #147 #150 #151 #152 u=4 imp:n=1 $ air
c   rear cubicle
    154 4 -2.258 (51 -54 133 -134 60 -61) u=4 imp:n=1 $ front side
    155 4 -2.258 (53 -54 131 -132 60 -61) u=4 imp:n=1 $ left side
    156 4 -2.258 (51 -52 131 -132 60 -61) u=4 imp:n=1 $ right side
    157 4 -2.258 (51 -54 132 -133 60 -61) u=4 imp:n=1 $ front side
    158 4 -2.258 (51 -54 130 -131 60 -61) u=4 imp:n=1 $ back side
c   can stacks
c   stack 1
    159 like 36 but TRCL=84 u=4 $ can 1
    160 like 36 but TRCL=85 u=4 $ can 2
    163 like 36 but TRCL=86 u=4 $ can 3
    164 like 36 but TRCL=89 u=4 $ can 6
    165 like 36 but TRCL=90 u=4 $ can 7
c   stack 2
    166 like 36 but TRCL=91 u=4 $ can 1
    167 like 36 but TRCL=92 u=4 $ can 2
    170 like 36 but TRCL=93 u=4 $ can 3
    171 like 36 but TRCL=96 u=4 $ can 6
    172 like 36 but TRCL=97 u=4 $ can 7
c   stack 3
    173 like 36 but TRCL=98 u=4 $ can 1
    174 like 36 but TRCL=99 u=4 $ can 2
    177 like 36 but TRCL=100 u=4 $ can 3
    178 like 36 but TRCL=103 u=4 $ can 6
    179 like 36 but TRCL=104 u=4 $ can 7
c   stack 4
    180 like 36 but TRCL=105 u=4 $ can 1
    181 like 36 but TRCL=106 u=4 $ can 2
    184 like 36 but TRCL=107 u=4 $ can 3
    185 like 36 but TRCL=110 u=4 $ can 6
    186 like 36 but TRCL=111 u=4 $ can 7
c   airspace around cans
    187 2 -0.00129 52 -53 131 -132 60 -61 #159 #160 #163 #164
        #165 #166 #167 #170 #171 #172 #173 #174 #177
        #178 #179 #180 #181 #184 #185 #186 u=4 imp:n=1 $ air
c   middle row of cubicles
    188 0 135 -136 107 -108 109 -110 lat=1 fill=4 u=5 imp:n=1
    190 0 111 -309 121 -122 113 -114 fill=5 imp:n=1
    191 0 309 -310 121 -122 113 -114 fill=13 imp:n=8
    192 0 310 -104 121 -122 113 -114 fill=5 imp:n=1
c   c air between middle & north row
    195 2 -0.00129 122 -123 111 -104 113 -114 imp:n=1 $ air
c   cubicle walls (north row)
    200 4 -2.258 (51 -54 140 -141 60 -61) u=6 imp:n=1 $ front side
    201 4 -2.258 (51 -52 142 -143 60 -61) u=6 imp:n=1 $ left side

```

```

202  4  -2.258  (53 -54 142 -143 60 -61) u=6  imp:n=1  $ right side
203  4  -2.258  (51 -54 141 -142 60 -61) u=6  imp:n=1  $ front side
204  4  -2.258  (51 -54 143 -144 60 -61) u=6  imp:n=1  $ back side
c    can stacks
c    stack 1
205  like 36 but TRCL=112 u=6  $ can 1
206  like 36 but TRCL=113 u=6  $ can 2
209  like 36 but TRCL=114 u=6  $ can 3
210  like 36 but TRCL=117 u=6  $ can 6
211  like 36 but TRCL=118 u=6  $ can 7
c    stack 2
212  like 36 but TRCL=119 u=6  $ can 1
213  like 36 but TRCL=120 u=6  $ can 2
216  like 36 but TRCL=121 u=6  $ can 3
217  like 36 but TRCL=124 u=6  $ can 6
218  like 36 but TRCL=125 u=6  $ can 7
c    stack 3
219  like 36 but TRCL=126 u=6  $ can 1
220  like 36 but TRCL=127 u=6  $ can 2
223  like 36 but TRCL=128 u=6  $ can 3
224  like 36 but TRCL=131 u=6  $ can 6
225  like 36 but TRCL=132 u=6  $ can 7
c    stack 4
226  like 36 but TRCL=133 u=6  $ can 1
227  like 36 but TRCL=134 u=6  $ can 2
230  like 36 but TRCL=135 u=6  $ can 3
231  like 36 but TRCL=138 u=6  $ can 6
232  like 36 but TRCL=139 u=6  $ can 7
c    airspace around cans
233  2  -0.00129 52 -53 142 -143 60 -61 #205 #206 #209 #210
      #211 #212 #213 #216 #217 #218 #219 #220 #223
      #224 #225 #226 #227 #230 #231 #232 u=6 imp:n=1  $ air
c    rear cubicle
234  4  -2.258  (51 -54 147 -148 60 -61) u=6  imp:n=1  $ front side
235  4  -2.258  (53 -54 145 -146 60 -61) u=6  imp:n=1  $ left side
236  4  -2.258  (51 -52 145 -146 60 -61) u=6  imp:n=1  $ right side
237  4  -2.258  (51 -54 146 -147 60 -61) u=6  imp:n=1  $ front side
238  4  -2.258  (51 -54 144 -145 60 -61) u=6  imp:n=1  $ back side
c    can stacks
c    stack 1
239  like 36 but TRCL=140 u=6  $ can 1
240  like 36 but TRCL=141 u=6  $ can 2
243  like 36 but TRCL=142 u=6  $ can 3
244  like 36 but TRCL=145 u=6  $ can 6
245  like 36 but TRCL=146 u=6  $ can 7
c    stack 2
246  like 36 but TRCL=147 u=6  $ can 1
247  like 36 but TRCL=148 u=6  $ can 2
250  like 36 but TRCL=149 u=6  $ can 3

```

```

251   like 36 but TRCL=152 u=6 $ can 6
252   like 36 but TRCL=153 u=6 $ can 7
c    stack 3
253   like 36 but TRCL=154 u=6 $ can 1
254   like 36 but TRCL=155 u=6 $ can 2
257   like 36 but TRCL=156 u=6 $ can 3
258   like 36 but TRCL=159 u=6 $ can 6
259   like 36 but TRCL=160 u=6 $ can 7
c    stack 4
260   like 36 but TRCL=161 u=6 $ can 1
261   like 36 but TRCL=162 u=6 $ can 2
264   like 36 but TRCL=163 u=6 $ can 3
265   like 36 but TRCL=166 u=6 $ can 6
266   like 36 but TRCL=167 u=6 $ can 7
c    airspace around cans
267 2 -0.00129 52 -53 145 -146 60 -61 #239 #240 #243 #244
    #245 #246 #247 #250 #251 #252 #253 #254 #257
    #258 #259 #260 #261 #264 #265 #266 u=6 imp:n=1 $ air
c    north row of cubicles
268 0 149 -150 107 -108 109 -110 lat=1 fill=6 u=7 imp:n=1
270 0 111 -104 123 -124 113 -114 fill=7 imp:n=1
c    c air north of north row
275 2 -0.00129 124 -165 111 -104 113 -114 imp:n=1 $ air
c    cubicle on south wall
280 4 -2.258 (51 -54 156 -155 60 -61) u=8 imp:n=1 $ front side
281 4 -2.258 (53 -54 158 -157 60 -61) u=8 imp:n=1 $ left side
282 4 -2.258 (51 -52 158 -157 60 -61) u=8 imp:n=1 $ right side
283 4 -2.258 (51 -54 157 -156 60 -61) u=8 imp:n=1 $ front side
284 4 -2.258 (51 -54 159 -158 60 -61) u=8 imp:n=1 $ back side
c    can stacks
c    stack 1
285   like 36 but TRCL=168 u=8 $ can 1
286   like 36 but TRCL=169 u=8 $ can 2
289   like 36 but TRCL=170 u=8 $ can 3
290   like 36 but TRCL=173 u=8 $ can 6
291   like 36 but TRCL=174 u=8 $ can 7
c    stack 2
292   like 36 but TRCL=175 u=8 $ can 1
293   like 36 but TRCL=176 u=8 $ can 2
296   like 36 but TRCL=177 u=8 $ can 3
297   like 36 but TRCL=180 u=8 $ can 6
298   like 36 but TRCL=181 u=8 $ can 7
c    stack 3
299   like 36 but TRCL=182 u=8 $ can 1
300   like 36 but TRCL=183 u=8 $ can 2
303   like 36 but TRCL=184 u=8 $ can 3
304   like 36 but TRCL=187 u=8 $ can 6
305   like 36 but TRCL=188 u=8 $ can 7
c    stack 4

```

```

306   like 36 but TRCL=189 u=8   $ can 1
307   like 36 but TRCL=190 u=8   $ can 2
310   like 36 but TRCL=191 u=8   $ can 3
311   like 36 but TRCL=194 u=8   $ can 6
312   like 36 but TRCL=195 u=8   $ can 7
c   airspace around cans
313 2   -0.00129 52 -53 158 -157 60 -61 #285 #286 #289 #290
      #291 #292 #293 #296 #297 #298 #299 #300 #303
      #304 #305 #306 #307 #310 #311 #312 u=8 imp:n=1 $ air
c   row of cubicles by south wall
314 0   161 -160 107 -108 109 -110 lat=1 fill=8 u=9 imp:n=1
315 0   163 -164 120 -162 113 -114 fill=9 imp:n=1
c   cubicle walls (north wall)
320 4   -2.258 (51 -54 174 -173 60 -61) u=10 imp:n=1 $ front side
321 4   -2.258 (51 -52 172 -171 60 -61) u=10 imp:n=1 $ left side
322 4   -2.258 (53 -54 172 -171 60 -61) u=10 imp:n=1 $ right side
323 4   -2.258 (51 -54 173 -172 60 -61) u=10 imp:n=1 $ front side
324 4   -2.258 (51 -54 171 -170 60 -61) u=10 imp:n=1 $ back side
c   can stacks
c   stack 1
325   like 36 but TRCL=196 u=10 $ can 1
326   like 36 but TRCL=197 u=10 $ can 2
329   like 36 but TRCL=198 u=10 $ can 3
330   like 36 but TRCL=201 u=10 $ can 6
331   like 36 but TRCL=202 u=10 $ can 7
c   stack 2
332   like 36 but TRCL=203 u=10 $ can 1
333   like 36 but TRCL=204 u=10 $ can 2
336   like 36 but TRCL=205 u=10 $ can 3
337   like 36 but TRCL=208 u=10 $ can 6
338   like 36 but TRCL=209 u=10 $ can 7
c   stack 3
339   like 36 but TRCL=210 u=10 $ can 1
340   like 36 but TRCL=211 u=10 $ can 2
343   like 36 but TRCL=212 u=10 $ can 3
344   like 36 but TRCL=215 u=10 $ can 6
345   like 36 but TRCL=216 u=10 $ can 7
c   stack 4
346   like 36 but TRCL=217 u=10 $ can 1
347   like 36 but TRCL=218 u=10 $ can 2
350   like 36 but TRCL=219 u=10 $ can 3
351   like 36 but TRCL=222 u=10 $ can 6
352   like 36 but TRCL=223 u=10 $ can 7
c   airspace around cans
353 2   -0.00129 52 -53 172 -171 60 -61 #325 #326 #329 #330
      #331 #332 #333 #336 #337 #338 #339 #340 #343
      #344 #345 #346 #347 #350 #351 #352 u=10 imp:n=1 $ air
c   north wall cubicle lattice
355 0   176 -175 107 -108 109 -110 lat=1 fill=10 u=11 imp:n=1

```

```

360 0 163 -164 165 -125 113 -114 fill=11 imp:n=1
c west air space
500 2 -0.00129 163 -111 162 -165 113 -114 imp:n=1 $ air
c east air space
510 2 -0.00129 104 -164 162 -165 113 -114 imp:n=1 $ air
c open cubicle
c cubicle walls (middle row)
700 2 -0.00129 (301 -304 126 -220 60 -61) u=12 imp:n=8 $ front side
701 2 -0.00129 (301 -304 220 -221 60 -61) u=12 imp:n=8
702 2 -0.00129 (301 -304 221 -222 60 -61) u=12 imp:n=8
703 2 -0.00129 (301 -304 222 -223 60 -61) u=12 imp:n=8
704 2 -0.00129 (301 -304 223 -127 60 -61) u=12 imp:n=4
705 2 -0.00129 (301 -304 127 -225 60 -61) u=12 imp:n=4
706 2 -0.00129 (301 -304 225 -226 60 -61) u=12 imp:n=4
707 2 -0.00129 (301 -304 226 -227 60 -61) u=12 imp:n=4
708 2 -0.00129 (301 -304 227 -228 60 -61) u=12 imp:n=4
709 4 -2.258 (301 -302 128 -129 60 -61) u=12 imp:n=1 $ left side
710 4 -2.258 (303 -304 128 -129 60 -61) u=12 imp:n=1 $ right side
711 2 -0.00129 (301 -304 228 -128 60 -61) u=12 imp:n=4 $ front side
712 4 -2.258 (301 -304 129 -130 60 -61) u=12 imp:n=1 $ back side
c can stacks
c stack 1
713 like 36 but TRCL=224 u=12 $ can 1
714 like 36 but TRCL=225 u=12 $ can 2
717 like 36 but TRCL=226 u=12 $ can 3
718 like 36 but TRCL=229 u=12 $ can 6
719 like 36 but TRCL=230 u=12 $ can 7
c stack 2
720 like 36 but TRCL=231 u=12 $ can 1
721 like 36 but TRCL=232 u=12 $ can 2
724 like 36 but TRCL=233 u=12 $ can 3
725 like 36 but TRCL=236 u=12 $ can 6
726 like 36 but TRCL=237 u=12 $ can 7
c stack 3
727 like 36 but TRCL=238 u=12 $ can 1
728 like 36 but TRCL=239 u=12 $ can 2
731 like 36 but TRCL=240 u=12 $ can 3
732 like 36 but TRCL=243 u=12 $ can 6
733 like 36 but TRCL=244 u=12 $ can 7
c stack 4
734 like 36 but TRCL=245 u=12 $ can 1
735 like 36 but TRCL=246 u=12 $ can 2
738 like 36 but TRCL=247 u=12 $ can 3
739 like 36 but TRCL=250 u=12 $ can 6
740 like 36 but TRCL=251 u=12 $ can 7
c airspace around cans
741 2 -0.00129 302 -303 128 -129 60 -61 #713 #714 #717 #718
#719 #720 #721 #724 #725 #726 #727 #728 #731
#732 #733 #734 #735 #738 #739 #740 u=12 imp:n=4 $ air

```



```

c rear cubicle
742 4 -2.258 (301 -304 133 -134 60 -61) u=12 imp:n=1 $ front side
743 4 -2.258 (303 -304 131 -132 60 -61) u=12 imp:n=1 $ left side
744 4 -2.258 (301 -302 131 -132 60 -61) u=12 imp:n=1 $ right side
745 4 -2.258 (301 -304 132 -133 60 -61) u=12 imp:n=1 $ front side
746 4 -2.258 (301 -304 130 -131 60 -61) u=12 imp:n=1 $ back side
c can stacks
c stack 1
747 like 36 but TRCL=252 u=12 $ can 1
748 like 36 but TRCL=253 u=12 $ can 2
751 like 36 but TRCL=254 u=12 $ can 3
752 like 36 but TRCL=257 u=12 $ can 6
753 like 36 but TRCL=258 u=12 $ can 7
c stack 2
754 like 36 but TRCL=259 u=12 $ can 1
755 like 36 but TRCL=260 u=12 $ can 2
758 like 36 but TRCL=261 u=12 $ can 3
759 like 36 but TRCL=264 u=12 $ can 6
760 like 36 but TRCL=265 u=12 $ can 7
c stack 3
761 like 36 but TRCL=266 u=12 $ can 1
762 like 36 but TRCL=267 u=12 $ can 2
765 like 36 but TRCL=268 u=12 $ can 3
766 like 36 but TRCL=271 u=12 $ can 6
767 like 36 but TRCL=272 u=12 $ can 7
c stack 4
768 like 36 but TRCL=273 u=12 $ can 1
769 like 36 but TRCL=274 u=12 $ can 2
772 like 36 but TRCL=275 u=12 $ can 3
773 like 36 but TRCL=278 u=12 $ can 6
774 like 36 but TRCL=279 u=12 $ can 7
c airspace around cans
775 2 -0.00129 302 -303 131 -132 60 -61 #747 #748 #751 #752
#753 #754 #755 #758 #759 #760 #761 #762 #765
#766 #767 #768 #769 #772 #773 #774 u=12 imp:n=1 $ air
c lattice cell for open cubicle
880 0 135 -136 307 -308 109 -110 lat=1 fill=12 u=13 imp:n=8
c beyond room
1100 2 -0.00129 (-59 :62 :-163 :164 :-120 :125) (-90 -91 92)
imp:n=0
c outside world
1200 0 90: 91: -92 imp:n=0 $ outside world

c surface cards - convenience can
1 c/z 10.00 8.5 5.6000000
2 c/z 10.00 8.5 5.5000000
3 c/z 10.00 8.5 4.7300000
4 c/z 10.00 8.5 4.5000000

```

7	pz	1.050000			
8	pz	1.150000			
9	pz	17.670000			
10	pz	19.800000			
14	pz	21.800000			
17	k/z	10.0 8.5	27.180000	0.3333330	-1.0
18	pz	9.95			
c cards for cap on convenience can					
20	pz	22.400000			
21	pz	20.200000			
22	c/z	10.0 8.5	5.0300000		
c inner can surfaces					
25	pz	0.90000			
26	pz	22.9500			
27	pz	23.0500			
28	pz	24.0000			
29	c/z	10.0 8.5	5.7000		
30	c/z	10.0 8.5	5.8500		
c outer can surfaces					
40	c/z	10.0 8.5	5.950		
41	c/z	10.0 8.5	6.250		
42	pz	0.0			
43	pz	24.40			
44	pz	25.40			
c concrete wall, floor, ceiling surfaces: 8 inches thick					
50	py	-35.56			
51	px	-40.65			
52	px	-30.48			
53	px	30.48			
54	px	40.65			
55	py	-25.41			
56	py	-15.24			
57	py	15.24			
58	py	25.41			
59	pz	-42.823			
c floor : upper surface					
60	pz	-14.833			
c ceiling : 8 feet above floor					
61	pz	229.027			
62	pz	249.347			
c can radial boundaries					
c 7 cans per stack					
c can stack 1					
63	c/z	10.00 8.50	6.2		
c can stack 2					
64	c/z	-10.00 8.50	6.2		
c can stack 3					
65	c/z	23.23 -5.239	6.2		
c can stack 4					

66	c/z	-23.23	-5.239	6.2
c	can axial boundaries			
c	layer 1			
67	pz	0.100		
68	pz	25.300		
c	layer 2			
69	pz	32.920		
70	pz	58.520		
c	layer 3			
71	pz	65.940		
72	pz	91.540		
c	layer 4			
73	pz	98.960		
74	pz	124.560		
c	layer 5			
75	pz	131.980		
76	pz	157.580		
c	layer 6			
77	pz	165.000		
78	pz	190.600		
c	layer 7			
79	pz	198.020		
80	pz	223.620		
c	outside world surfaces			
90	cz	2000		
91	pz	300		
92	pz	-100		
c	rear cubicle surfaces			
100	py	35.58		
101	py	66.06		
102	py	76.23		
103	py	86.38		
c	edge of floor and ceiling			
104	px	609.45		
c	lattice surfaces			
105	py	-35.55		
106	py	86.37		
107	px	-40.64		
108	px	40.64		
109	pz	-14.823		
110	pz	229.017		
c	array edges			
111	px	-40.63		
112	py	-35.54		
113	pz	-14.813		
114	pz	229.007		
115	py	86.36		
c	y surfaces for additional rows & walls			
120	py	-187.94		

121	py	177.80
122	py	299.70
123	py	391.14
124	py	513.04
125	py	665.44
c y surfaces for mid row cubicle		
126	py	177.78
127	py	187.93
128	py	198.10
129	py	228.58
130	py	238.75
131	py	248.92
132	py	279.40
133	py	289.57
134	py	299.72
c y surfaces for lattice (mid row)		
135	py	177.79
136	py	299.71
c y surfaces for north row cubicle		
140	py	391.12
141	py	401.27
142	py	411.44
143	py	441.92
144	py	452.09
145	py	462.26
146	py	492.74
147	py	502.91
148	py	513.06
c y surfaces for lattice (north row)		
149	py	391.13
150	py	513.05
c y surfaces for south wall cubicle		
155	py	-126.96
156	py	-137.12
157	py	-147.29
158	py	-177.77
159	py	-187.96
c y surfaces for lattice (south wall)		
160	py	-126.98
161	py	-187.95
c array surfaces for south wall		
162	py	-126.99
163	px	-121.89
164	px	690.71
c north wall array surface		
165	py	604.49
c y surfaces for north wall cubicle		
170	py	665.46
171	py	655.27

172	py	624.79
173	py	614.62
174	py	604.47
c y surfaces for lattice (north wall)		
175	py	665.45
176	py	604.48
c tally surfaces		
180	py	168.68
181	pz	140.0
182	pz	130.0
183	px	365.0
184	px	360.0
185	px	355.0
186	px	350.0
187	px	345.0
188	px	340.0
189	px	335.0
190	px	330.0
191	px	325.0
192	px	320.0
193	px	315.0
194	px	310.0
195	px	305.0
196	px	300.0
197	px	295.0
198	px	290.0
199	px	285.0
c importance surfaces		
200	py	-17.5
201	py	-19.5
202	py	-21.5
203	py	-23.5
204	py	-25.5
205	py	-27.5
206	py	-29.5
207	py	-31.5
208	py	-33.5
209	py	68.0
210	py	70.0
211	py	72.0
212	py	74.0
213	py	76.1
214	py	78.2
215	py	80.3
216	py	82.3
217	py	84.4
220	py	179.8
221	py	181.8
222	py	183.9

223	py	185.9
224	py	188.0
225	py	190.0
226	py	192.1
227	py	194.1
228	py	196.1
229	py	281.4
230	py	283.5
231	py	285.5
232	py	287.6
233	py	289.6
234	py	291.7
235	py	293.7
236	py	295.7
237	py	297.7
240	py	393.1
241	py	395.1
242	py	397.2
243	py	399.2
244	py	401.3
245	py	403.3
246	py	405.4
247	py	407.4
248	py	409.4
249	py	494.7
250	py	496.7
251	py	498.8
252	py	500.8
253	py	502.9
254	py	504.9
255	py	507.0
256	py	509.0
257	py	511.0
260	py	-129.0
261	py	-131.0
262	py	-133.1
263	py	-135.1
264	py	-137.2
265	py	-139.2
266	py	-141.3
267	py	-143.3
268	py	-145.3
270	py	606.5
271	py	608.5
272	py	610.6
273	py	612.6
274	py	614.7
275	py	616.7
276	py	618.8

```

277 py 620.8
278 py 622.8
c additional surfaces for open cubicle
301 px 284.39
302 px 294.56
303 px 355.52
304 px 365.69
307 px 284.40
308 px 365.68
309 px 284.41
310 px 365.67

*tr1 -20.0 0 0
*tr2 13.23 -13.739 0
*tr3 -33.23 -13.739 0
*tr4 0 0 33.02
*tr5 0 0 66.04
*tr6 0 0 99.06
*tr7 0 0 132.08
*tr8 0 0 165.01
*tr9 0 0 198.12
*tr10 -20.0 0 33.02
*tr11 -20.0 0 66.04
*tr12 -20.0 0 99.06
*tr13 -20.0 0 132.08
*tr14 -20.0 0 165.01
*tr15 -20.0 0 198.12
*tr16 13.23 -13.739 33.02
*tr17 13.23 -13.739 66.04
*tr18 13.23 -13.739 99.06
*tr19 13.23 -13.739 132.08
*tr20 13.23 -13.739 165.01
*tr21 13.23 -13.739 198.12
*tr22 -33.23 -13.739 33.02
*tr23 -33.23 -13.739 66.04
*tr24 -33.23 -13.739 99.06
*tr25 -33.23 -13.739 132.08
*tr26 -33.23 -13.739 165.01
*tr27 -33.23 -13.739 198.12
*tr28 0 33.82 0
*tr29 0 33.82 33.02
*tr30 0 33.82 66.04
*tr31 0 33.82 99.06
*tr32 0 33.82 132.08
*tr33 0 33.82 165.01
*tr34 0 33.82 198.12
*tr35 -20.0 33.82 0
*tr36 -20.0 33.82 33.02
*tr37 -20.0 33.82 66.04

```

*tr38	-20.0	33.82	99.06
*tr39	-20.0	33.82	132.08
*tr40	-20.0	33.82	165.01
*tr41	-20.0	33.82	198.12
*tr42	13.23	47.556	0
*tr43	13.23	47.556	33.02
*tr44	13.23	47.556	66.04
*tr45	13.23	47.556	99.06
*tr46	13.23	47.556	132.08
*tr47	13.23	47.556	165.01
*tr48	13.23	47.556	198.12
*tr49	-33.23	47.556	0
*tr50	-33.23	47.556	33.02
*tr51	-33.23	47.556	66.04
*tr52	-33.23	47.556	99.06
*tr53	-33.23	47.556	132.08
*tr54	-33.23	47.556	165.01
*tr55	-33.23	47.556	198.12
*tr56	0	213.34	0
*tr57	0	213.34	33.02
*tr58	0	213.34	66.04
*tr59	0	213.34	99.06
*tr60	0	213.34	132.08
*tr61	0	213.34	165.01
*tr62	0	213.34	198.12
*tr63	-20.0	213.34	0
*tr64	-20.0	213.34	33.02
*tr65	-20.0	213.34	66.04
*tr66	-20.0	213.34	99.06
*tr67	-20.0	213.34	132.08
*tr68	-20.0	213.34	165.01
*tr69	-20.0	213.34	198.12
*tr70	13.23	199.601	0
*tr71	13.23	199.601	33.02
*tr72	13.23	199.601	66.04
*tr73	13.23	199.601	99.06
*tr74	13.23	199.601	132.08
*tr75	13.23	199.601	165.01
*tr76	13.23	199.601	198.12
*tr77	-33.23	199.601	0
*tr78	-33.23	199.601	33.02
*tr79	-33.23	199.601	66.04
*tr80	-33.23	199.601	99.06
*tr81	-33.23	199.601	132.08
*tr82	-33.23	199.601	165.01
*tr83	-33.23	199.601	198.12
*tr84	0	247.16	0
*tr85	0	247.16	33.02
*tr86	0	247.16	66.04

*tr87	0	247.16	99.06
*tr88	0	247.16	132.08
*tr89	0	247.16	165.01
*tr90	0	247.16	198.12
*tr91	-20.0	247.16	0
*tr92	-20.0	247.16	33.02
*tr93	-20.0	247.16	66.04
*tr94	-20.0	247.16	99.06
*tr95	-20.0	247.16	132.08
*tr96	-20.0	247.16	165.01
*tr97	-20.0	247.16	198.12
*tr98	13.23	260.896	0
*tr99	13.23	260.896	33.02
*tr100	13.23	260.896	66.04
*tr101	13.23	260.896	99.06
*tr102	13.23	260.896	132.08
*tr103	13.23	260.896	165.01
*tr104	13.23	260.896	198.12
*tr105	-33.23	260.896	0
*tr106	-33.23	260.896	33.02
*tr107	-33.23	260.896	66.04
*tr108	-33.23	260.896	99.06
*tr109	-33.23	260.896	132.08
*tr110	-33.23	260.896	165.01
*tr111	-33.23	260.896	198.12
*tr112	0	426.68	0
*tr113	0	426.68	33.02
*tr114	0	426.68	66.04
*tr115	0	426.68	99.06
*tr116	0	426.68	132.08
*tr117	0	426.68	165.01
*tr118	0	426.68	198.12
*tr119	-20.0	426.68	0
*tr120	-20.0	426.68	33.02
*tr121	-20.0	426.68	66.04
*tr122	-20.0	426.68	99.06
*tr123	-20.0	426.68	132.08
*tr124	-20.0	426.68	165.01
*tr125	-20.0	426.68	198.12
*tr126	13.23	412.941	0
*tr127	13.23	412.941	33.02
*tr128	13.23	412.941	66.04
*tr129	13.23	412.941	99.06
*tr130	13.23	412.941	132.08
*tr131	13.23	412.941	165.01
*tr132	13.23	412.941	198.12
*tr133	-33.23	412.941	0
*tr134	-33.23	412.941	33.02
*tr135	-33.23	412.941	66.04

*tr136 -33.23 412.941 99.06
*tr137 -33.23 412.941 132.08
*tr138 -33.23 412.941 165.01
*tr139 -33.23 412.941 198.12
*tr140 0 460.50 0
*tr141 0 460.50 33.02
*tr142 0 460.50 66.04
*tr143 0 460.50 99.06
*tr144 0 460.50 132.08
*tr145 0 460.50 165.01
*tr146 0 460.50 198.12
*tr147 -20.0 460.50 0
*tr148 -20.0 460.50 33.02
*tr149 -20.0 460.50 66.04
*tr150 -20.0 460.50 99.06
*tr151 -20.0 460.50 132.08
*tr152 -20.0 460.50 165.01
*tr153 -20.0 460.50 198.12
*tr154 13.23 474.236 0
*tr155 13.23 474.236 33.02
*tr156 13.23 474.236 66.04
*tr157 13.23 474.236 99.06
*tr158 13.23 474.236 132.08
*tr159 13.23 474.236 165.01
*tr160 13.23 474.236 198.12
*tr161 -33.23 474.236 0
*tr162 -33.23 474.236 33.02
*tr163 -33.23 474.236 66.04
*tr164 -33.23 474.236 99.06
*tr165 -33.23 474.236 132.08
*tr166 -33.23 474.236 165.01
*tr167 -33.23 474.236 198.12
*tr168 0 -179.53 0
*tr169 0 -179.53 33.02
*tr170 0 -179.53 66.04
*tr171 0 -179.53 99.06
*tr172 0 -179.53 132.08
*tr173 0 -179.53 165.01
*tr174 0 -179.53 198.12
*tr175 -20.0 -179.53 0
*tr176 -20.0 -179.53 33.02
*tr177 -20.0 -179.53 66.04
*tr178 -20.0 -179.53 99.06
*tr179 -20.0 -179.53 132.08
*tr180 -20.0 -179.53 165.01
*tr181 -20.0 -179.53 198.12
*tr182 13.23 -165.794 0
*tr183 13.23 -165.794 33.02
*tr184 13.23 -165.794 66.04

*tr185	13.23	-165.794	99.06
*tr186	13.23	-165.794	132.08
*tr187	13.23	-165.794	165.01
*tr188	13.23	-165.794	198.12
*tr189	-33.23	-165.794	0
*tr190	-33.23	-165.794	33.02
*tr191	-33.23	-165.794	66.04
*tr192	-33.23	-165.794	99.06
*tr193	-33.23	-165.794	132.08
*tr194	-33.23	-165.794	165.01
*tr195	-33.23	-165.794	198.12
*tr196	0	640.03	0
*tr197	0	640.03	33.02
*tr198	0	640.03	66.04
*tr199	0	640.03	99.06
*tr200	0	640.03	132.08
*tr201	0	640.03	165.01
*tr202	0	640.03	198.12
*tr203	-20.0	640.03	0
*tr204	-20.0	640.03	33.02
*tr205	-20.0	640.03	66.04
*tr206	-20.0	640.03	99.06
*tr207	-20.0	640.03	132.08
*tr208	-20.0	640.03	165.01
*tr209	-20.0	640.03	198.12
*tr210	13.23	626.291	0
*tr211	13.23	626.291	33.02
*tr212	13.23	626.291	66.04
*tr213	13.23	626.291	99.06
*tr214	13.23	626.291	132.08
*tr215	13.23	626.291	165.01
*tr216	13.23	626.291	198.12
*tr217	-33.23	626.291	0
*tr218	-33.23	626.291	33.02
*tr219	-33.23	626.291	66.04
*tr220	-33.23	626.291	99.06
*tr221	-33.23	626.291	132.08
*tr222	-33.23	626.291	165.01
*tr223	-33.23	626.291	198.12
*tr224	325.04	213.34	0
*tr225	325.04	213.34	33.02
*tr226	325.04	213.34	66.04
*tr227	325.04	213.34	99.06
*tr228	325.04	213.34	132.08
*tr229	325.04	213.34	165.01
*tr230	325.04	213.34	198.12
*tr231	305.04	213.34	0
*tr232	305.04	213.34	33.02
*tr233	305.04	213.34	66.04

```

*tr234 305.04 213.34 99.06
*tr235 305.04 213.34 132.08
*tr236 305.04 213.34 165.01
*tr237 305.04 213.34 198.12
*tr238 338.27 199.601 0
*tr239 338.27 199.601 33.02
*tr240 338.27 199.601 66.04
*tr241 338.27 199.601 99.06
*tr242 338.27 199.601 132.08
*tr243 338.27 199.601 165.01
*tr244 338.27 199.601 198.12
*tr245 291.81 199.601 0
*tr246 291.81 199.601 33.02
*tr247 291.81 199.601 66.04
*tr248 291.81 199.601 99.06
*tr249 291.81 199.601 132.08
*tr250 291.81 199.601 165.01
*tr251 291.81 199.601 198.12
*tr252 325.04 247.16 0
*tr253 325.04 247.16 33.02
*tr254 325.04 247.16 66.04
*tr255 325.04 247.16 99.06
*tr256 325.04 247.16 132.08
*tr257 325.04 247.16 165.01
*tr258 325.04 247.16 198.12
*tr259 305.04 247.16 0
*tr260 305.04 247.16 33.02
*tr261 305.04 247.16 66.04
*tr262 305.04 247.16 99.06
*tr263 305.04 247.16 132.08
*tr264 305.04 247.16 165.01
*tr265 305.04 247.16 198.12
*tr266 338.27 260.896 0
*tr267 338.27 260.896 33.02
*tr268 338.27 260.896 66.04
*tr269 338.27 260.896 99.06
*tr270 338.27 260.896 132.08
*tr271 338.27 260.896 165.01
*tr272 338.27 260.896 198.12
*tr273 291.81 260.896 0
*tr274 291.81 260.896 33.02
*tr275 291.81 260.896 66.04
*tr276 291.81 260.896 99.06
*tr277 291.81 260.896 132.08
*tr278 291.81 260.896 165.01
*tr279 291.81 260.896 198.12
mode n
ml 94238.50c -.00240 94239.55c -0.80660 94240.50c -0.16980
94241.50c -0.0144 94242.50c -0.0069 95241.50c -0.0280 8016.50c -0.1377

```

```

m2  7014.50c 0.790000 8016.50c 0.210000
m3  26000.55c 0.05536 24000.50c 0.01641 28000.50c 0.011220
    25055.50c 0.00155 42000.50c 0.00126 6000.50c 0.0002003
m4  1001.50c -0.0031 8016.50c -0.4407 11023.50c -0.0182
    12000.50c -0.0376 13027.50c -0.0607 14000.50c -0.2157
    15031.50c -0.0009 16032.50c -0.0009 36084.50c -0.0066
    20000.50c -0.1306 22000.50c -0.0049 26000.55c -0.0788
c wgt = (3.747e+05/kg pu) x 4.410 kg pu (5.0 kg puo2) x 60 cans = 9.915e+07
sdef erg=d1 pos=d4 rad=d2 ext=d3 axs 0 0 1 wgt=9.915e+07
sc1 spontaneous fission source spectrum (pu240)
spl -3 0.799 4.903
sc2 radius
si2 0 5.500
sp2 -21 1
sc3 extent

si3 -4.40 4.40
sp3 -21 0
si4 1 253.78 221.84 5.55
    253.78 221.84 38.52
    253.78 221.84 71.54
    253.78 221.84 170.60
    253.78 221.84 203.62
    233.78 221.84 5.55
    233.78 221.84 38.52
    233.78 221.84 71.54
    233.78 221.84 170.60
    233.78 221.84 203.62
    267.01 208.101 5.55
    267.01 208.101 38.52
    267.01 208.101 71.54
    267.01 208.101 170.60
    267.01 208.101 203.62
    220.55 208.101 5.55
    220.55 208.101 38.52
    220.55 208.101 71.54
    220.55 208.101 170.60
    220.55 208.101 203.62
    335.04 221.84 5.55
    335.04 221.84 38.52
    335.04 221.84 71.54
    335.04 221.84 170.60
    335.04 221.84 203.62
    315.04 221.84 5.55
    315.04 221.84 38.52
    315.04 221.84 71.54
    315.04 221.84 170.60
    315.04 221.84 203.62
    348.27 208.101 5.55

```

```

348.27 208.101 38.52
348.27 208.101 71.54
348.27 208.101 170.60
348.27 208.101 203.62
301.81 208.101 5.55
301.81 208.101 38.52
301.81 208.101 71.54
301.81 208.101 170.60
301.81 208.101 203.62
416.30 221.84 5.55
416.30 221.84 38.52
416.30 221.84 71.54
416.30 221.84 170.60
416.30 221.84 203.62
396.30 221.84 5.55
396.30 221.84 38.52
396.30 221.84 71.54
396.30 221.84 170.60
396.30 221.84 203.62
429.53 208.101 5.55
429.53 208.101 38.52
429.53 208.101 71.54
429.53 208.101 170.60
429.53 208.101 203.62
383.07 208.101 5.55
383.07 208.101 38.52
383.07 208.101 71.54
383.07 208.101 170.60
383.07 208.101 203.62
sp4 1 59r
sb4 1 20r 2 5 10 1 1 2 5 10 1 1 2 5 10 1 1 2 5 10 1 20r
c ansi/ans-6.1.1-1977 fluence-to-dose,neutrons(mrem/hr/(n/cm**2/s))
de0 log 2.5e-08 1.0e-07 1.0e-06 1.0e-05 1.0e-04
      .001 .01 .1 .5 1.0
      2.5 5.0 7.0 10.0 14.0 20.0
df0 log 3.67e-3 3.67e-3 4.46e-3 4.54e-3 4.18e-3
      3.76e-3 3.56e-3 2.17e-2 9.26e-2 .132
      .125 .156 .147 .147 .208 .227
print 10 60 100 110 120 126 130 140 150 170

prdmp j -240 1 3

fc2 surface tallies 60 cm from back of open cubicle

f2:n 180
fs2 185 181 -182 189 193 197
sd2 1 1 1 200 200 200 1
ctme 1600

```

Appendix F

Reviewer Comments

Calculational Review

The modeled dimensions were verified against the drawings in a model for a single cubicle used to construct an infinite array. The single cubicle model is used as a basis for all other models. Dimensions of the 3013 can were checked in the single container model against those specified. Densities of plutonium oxide and concrete, as well as their composition, were checked as well. ORIGEN2 input and output were checked for correct entry and use in subsequent MCNP calculations. UO_2 Bremsstrahlung was assumed for the ORIGEN2 runs, which is appropriate. The source specification was also checked in some of the models for both the cubicle and the infloor storage.

Although source neutrons included both spontaneous fission neutrons as well as (a,n) neutrons, only the fission spectrum was used. The energy peak for fission is lower than that for (a,n). The average energy for the fission spectrum and the (a,n) spectrum are both about 2 MeV, due to the higher maximum energy of spontaneous fission. ORIGEN2 gives 54% of the neutrons as coming from (a,n), and 46% from spontaneous fission. However, the calculated k_{eff} of the system indicates that when induced fission is included, the portion of (a,n) becomes smaller yet. Since the average energies of the spontaneous fission and the (a,n) neutrons are the same, and because most of the neutrons will be from induced fission, use of the spontaneous fission spectrum for (a,n) neutrons should not effect dose rates enough to invalidate this analysis. For information on the (a,n) spectrum, see Liskien and Jacobs, "Energy Spectra of Neutrons Produced by α -Particles in Thick Targets of Light Elements" (*Ann. Nucl. Energy*, Vol. 10, No. 10, Pergamon Press Ltd, Great Britain, 1983).

Photon dose rates for the infloor model will be lower relative to the neutrons in comparison to the cubicle model because there is significantly more self-shielding, shielding in the can (top), and shielding by the thicker concrete floor. It is also important to note that the hole exists over the top of only one stack of cans, yet a number of cans surrounding that single stack will also contribute to the dose. This is why very little change is seen when the hole is present.

The dose rates for the open cubicle calculations are lower than calculated dose rates for all closed cubicles. If the cubicle doors do not provide much shielding, this is not surprising, considering the high uncertainties in the calculations for the open cubicle calculations. Criticality analysis for this room has indicated that eight inches of concrete, which is the thickness of the door, does not provide much shielding.

k_{eff} of System

Early calculations of neutron dose rates were plagued by extreme neutron multiplication per source particle, so much so that there were occasional "bank overflows". One of the possibilities considered for this phenomenon was that at least some of the systems analyzed would be near critical. This is because fission will often create more than one neutron, requiring that any neutron beyond the first one be placed into a "bank" while the current neutron track is completed. For a super-critical system, for example, the rate at which neutrons are added to the bank due to fission would be greater than the rate at which neutron tracks are terminated. For this reason, the cases given in Table F-1 were run to insure that the systems analyzed are not critical. The calculations are for cubicles filled with 28 cans each. A quarter of the room was modeled, with reflective boundary conditions on two boundaries to model the full 68 cubicles of a room. As the results indicate, this was not the problem. Table F-2 below gives results of k_{eff} calculations for the infloor configuration.

Table F-1. Calculations of k_{eff} for Cubicle Storage

Case	Pu-240 content	PuO ₂ density	k_{eff}	1 σ
iqhphd	17 wt%	6.0 g/cc	0.773	0.003
iqhpld	17 wt%	2.0 g/cc	0.606	0.002
iqlphd	6 wt%	6.0 g/cc	0.827	0.002
iqlpld	6 wt%	2.0 g/cc	0.658	0.002

Table F-2. Calculations of k_{eff} for Infloor Storage

Case	Pu-240 content	PuO ₂ density	k_{eff}	1 σ
ifhphd	17 wt%	6.0 g/cc	0.774	0.002
iqlphd	6 wt%	6.0 g/cc	0.820	0.002

Alternate Method of Accommodating Induced Fission in Neutron Dose Calculations

An alternate way of calculating neutron dose rates is to exclude neutrons from induced fission events in the MCNP calculation, and to afterwards scale the results of the calculation using the k_{eff} of the system (Nelson). The following approximation would be used:

$$D(T) = D(F)/(1-k_{\text{eff}}) \quad (\text{F-1})$$

where $D(T)$ is the total dose rate of the system, and $D(F)$ is the fixed neutron source, typically due to spontaneous fission and (α, n) reactions. This approximation relies on a number of simplifying assumptions which are not detailed here. Rather, a comparison is made between results of this method and a standard neutron dose rate calculation in Table F-5 below.

Table F-3. NORMAL Case: In-Floor Storage, Low Pu240 High Density PuO₂ Neutron Dose Rates (mrem/hour)

Center (30 cm)	Center (150 cm)	Above Hole (30 cm)	Above Hole (150 cm)
62.23 3.3%	55.52 2.5%	63.35 2.4%	54.19 2.1%

Table F-4. NONU¹ Case: In-Floor Storage, Low Pu240 High Density PuO₂ Neutron Dose Rates (mrem/hour)

Center (30 cm)	Center (150 cm)	Above Hole (30 cm)	Above Hole (150 cm)
9.74 3.2%	9.32 3.6%	10.78 3.5%	9.15 3.0%

¹A NONU card is used in MCNP to treat fission events as capture.

Table F-5. Increase Factor from NONU to NORMAL Case

Center (30 cm)	Center (150 cm)	Above Hole (30 cm)	Above Hole (150 cm)	From Eqn F-1
6.39	5.96	5.88	5.92	5.56

Photons from Induced Fission and (n,p) Reactions

For photons arising from induced fission, a discussion is given in the body of this text as to why this is not a significant factor in calculating dose rates. Photons from (n,p) reactions can be important when neutron shielding is used without significant photon shielding, and is therefore not a concern in this analysis. One could include both of these effects by using an MCNP mode np calculation, in which the neutron source is entered, but a photon tally is used to measure secondary photons. The difficulty in a mode np calculation is that biasing may be necessary for both particle types.

An additional calculation was made using the model of an open cubicle in np mode to evaluate the contribution from neutron induced photons. The case run was for low ^{240}Pu content and low PuO_2 density, with 20 cans in the cubicle. The photon dose rate was calculated to be 0.4 mrem/hr (19% statistical uncertainty), lending support to the assumption that the photons from (n,p) and induced fission are negligible.

Complications of Implicit Capture

When running MCNP with analog capture, a neutron track will be terminated if a capture event is sampled. However, MCNP will use implicit capture rather than analog capture by default. Implicit capture accounts for capture events by simply reducing a neutron's weight by the capture probability, and samples from the other possible events. To terminate particles when using implicit capture, MCNP will use a weight cut-off. A problem may arise if the user is not aware that implicit capture is being used. For example, if importance splitting is used, the weight of individual particles after a split may cause a reduction in weight below the weight cut-off. If the weight falls below the weight cut-off, the additional particles created by importance splitting may be lost again through russian roulette. To turn off implicit capture, a CUT:N card must be used, with the third entry set to zero.

CHECKLIST FOR INDEPENDENT TECHNICAL REVIEW

DOCUMENT REVIEWED

NUMBER: HNF-SD-W460-ER-001, Rev 0

TITLE: Radiological Dose Assessment for Vault Storage Concepts

Reviewer(s) K. E. Hillesland

I. Method(s) of Review

- ☒ Input data checked for accuracy
- ☐ Independent calculation performed
 - ☐ Hand calculation
 - ☐ Alternate computer code: _____
- ☐ Comparison to experiment or previous results
- ☐ Alternate method (define) _____

II. Checklist (either check or enter NA if not applied)

- ☒ Task completely defined
- ☒ Activity consistent with task specification
- ☒ Necessary assumptions explicitly stated and supported
- ☒ Resources properly identified and referenced
- ☒ Resource documentation appropriate for this application
- ☒ Input data explicitly stated
- ☒ Input data verified to be consistent with original source
- ☒ Geometric model adequate representation of actual geometry
- ☒ Material properties appropriate and reasonable
- ☒ Mathematical derivations checked including dimensional consistency
- ☒ Hand calculations checked for errors
- ☒ Assumptions explicitly stated and justified
- ☒ Computer software appropriate for task and used within range of validity
- ☒ Use of resource outside range of established validity is justified
- ☒ Software runstreams correct and consistent with results
- ☒ Software output consistent with input
- ☒ Results consistent with applicable previous experimental or analytical findings
- ☒ Results and conclusions address all points and are consistent with task requirements and/or established limits or criteria
- ☒ Conclusions consistent with analytical results and established limits
- ☒ Uncertainty assesment appropriate and reasonable
- ☒ Other (define) _____

III. Comments:

see preceding Reviewer's Comments

IV.

REVIEWER:

K. E. Hillesland

DATE:

2/19/97

Appendix G Cubicle Dose Rate Tables

Tables G-1 through G-8 Present cubicle storage dose rate results. Table G-1 and G-2 are neutron and photon dose rates for closed cubicles with 28 canisters each. Dose rates are 150 cm above the floor and 30 cm from the front of the cubicle.

Table G-1. Closed Cubicle Neutron Dose Rates (mrem/h)
28 cans per cubicle

²⁴⁰ Pu fraction	PuO ₂ Density	Concrete Composition	Horizontal dose rate variation in front of a cubicle (calculational uncertainty)		
high	high	dry	543 (5.02%)	537 (4.75%)	524 (3.91%)
		new	237 (6.14%)	251 (6.04%)	223 (4.27%)
high	low	dry	204 (4.55%)	214 (4.30%)	232 (5.75%)
		new	108 (7.60%)	114 (9.26%)	101 (4.96%)
low	high	dry	225 (4.30%)	225 (4.16%)	221 (4.29%)
		new	81 (5.41%)	86 (5.74%)	77 (3.71%)
low	low	dry	76 (5.01%)	81 (5.33%)	81 (7.15%)
		new	35 (5.65%)	37 (4.19%)	35 (4.56%)

Table G-2. Closed Cubicle Photon Dose Rates (mrem/h)
28 cans per cubicle

²⁴⁰ Pu fraction	PuO ₂ Density	Concrete Composition	Horizontal dose rate variation in front of a cubicle (calculational uncertainty)		
high	high	dry	4.1 (25.4%)	3.8 (15.0%)	2.9 (4.90%)
		new	3.9 (36.8%)	3.4 (20.8%)	2.6 (5.80%)
high	low	dry	5.7 (24.9%)	4.1 (5.82%)	4.6 (22.2%)
		new	4.5 (3.1%)	3.2 (5.72%)	4.5 (23.1%)
low	high	dry	2.4 (49.2%)	1.6 (34.1%)	0.9 (10.5%)
		new	1.8 (59.6%)	1.4 (38.3%)	0.9 (10.3%)
low	low	dry	2.7 (40.2%)	1.6 (9.58%)	2.1 (38.8%)
		new	2.0 (51.3%)	1.2 (10.1%)	2.0 (37.9%)

The neutron dose rate uncertainties are all less than 10% and should be reliable for the given modeling and materials. These low uncertainties, mostly around 5%, indicate that neutrons contributing to the dose rates are being effectively sampled. In the case of the photon dose rates the uncertainties are generally much larger, and in some cases greater than 50%. This indicates poorer sampling of the photons contributing to the calculated dose rates. Fewer photons are able to travel through the cubicle door and walls to the dose tally area. Values with uncertainties greater than 50% are not useful, and those between 20% and 50% are reliable within a factor of a few.

Table G-3 presents the open door dose rates for neutrons and photons. For these calculations the full room model was used. These dose rate are 150 cm above the vault floor and 60 cm from the rear inside cubicle wall.

Table G-3. Open Cubicle Dose Rates (mrem/h)
28 cans per cubicle

^{240}Pu fraction	PuO_2 Density	Radiation	Horizontal dose rate variation in front of a cubicle (calculational uncertainty)		
high	high	neutron	502 (16.2%)	637 (21.3%)	403 (15.4%)
		photon	34 (13.3%)	43 (13.6%)	37 (13.5%)
high	low	neutron	179 (13.6%)	206 (9.94%)	--
		photon	58 (10.5%)	59 (10.7%)	58 (11.3%)
low	high	neutron	124 (13.5%)	181 (15.2%)	184 (24.4%)
		photon	14 (22.5%)	17 (18.8%)	12 (20.7%)
low	low	neutron	67 (14.2%)	67 (10.0%)	54 (14.1%)
		photon	21 (13.4%)	28 (21.5%)	23 (13.0%)

Examination of the open and closed door neutron dose rates reveals an apparent inconsistency. For most variations with dry concrete, the results show a dose rate increase from the open door case to the closed door case. The dose rate should decrease with the closed door. However, when wet concrete is used the dose rate decreases as expected. This result indicates that the dry concrete is an ineffective neutron shield. Also it is likely that neutrons from cubicles adjacent to the open cubicle are not being sampled as efficiently as those from the open cubicle. This is indicated by the higher uncertainties associated with the open cubicle calculations.

Photon dose rates decrease from the open to closed cubicle condition as is expected. Uncertainties for these dose rates are lower than the closed door cases due to the increased number of photons reaching the dose tally area through the open door.

Dose rates in Table G-4 are for the open cubicle with 14 rather than 28 canisters. These dose rates are generally half those of of Table G-3.

Table G-4. Open Cubicle Dose Rates (mrem/h)
28 cans in closed cubicles, 14 cans in open cubicle

^{240}Pu fraction	PuO_2 Density	Radiation	Horizontal dose rate variation in front of a cubicle (calculational uncertainty)		
high	high	neutron	244 (11.0%)	335 (15.1%)	280 (12.3%)
		photon	19 (12.8%)	22 (12.9%)	29 (23.5%)
high	low	neutron	115 (14.3%)	113 (8.34%)	120 (11.4%)
		photon	32 (13.1%)	38 (22.4%)	36 (18.1%)
low	high	neutron	82 (13.0%)	83 (10.1%)	93 (16.3%)
		photon	5.8 (17.1%)	6.8 (20.4%)	15 (34.7%)
low	low	neutron	32 (11.0%)	37 (9.27%)	43 (13.5%)
		photon	14 (20.8%)	17 (38.5%)	19 (26.4%)

Neutron closed door dose rates are presented in Table G-5 and the photon closed door dose rates in Table G-6. Results for both dry and wet concrete are presented.

Table G-5. Closed Cubicle Neutron Dose Rates (mrem/h)
20 cans per cubicle

^{240}Pu fraction	PuO_2 Density	Concrete Composition	Horizontal dose rate variation in front of a cubicle (calculational uncertainty)		
high	high	dry	225 (8.40%)	239 (8.14%)	200 (6.15%)
		new	116 (7.13%)	118 (10.7%)	107 (5.60%)
high	low	dry	101 (4.94%)	96 (4.23%)	104 (4.75%)
		new	50 (4.04%)	51 (4.92%)	52 (4.07%)
low	high	dry	80 (5.79%)	80 (4.52%)	78 (4.39%)
		new	37 (4.92%)	35 (5.49%)	35 (4.38%)
low	low	dry	32 (4.70%)	32 (4.29%)	34 (4.99%)
		new	16 (4.13%)	16 (5.17%)	17 (3.95%)

Table G-6. Closed Cubicle Photon Dose Rates (mrem/h)
20 cans per cubicle

^{240}Pu fraction	PuO_2 Density	Concrete Composition	Horizontal dose rate variation in front of a cubicle (calculational uncertainty)		
high	high	dry	1.2 (9.62%)	1.4 (8.53%)	1.5 (8.30%)
		new	1.4 (16.6%)	1.3 (8.51%)	1.2 (5.06%)
high	low	dry	1.5 (8.18%)	1.8 (7.00%)	1.8 (6.52%)
		new	1.2 (7.41%)	1.5 (8.34%)	1.5 (6.36%)
low	high	dry	0.4 (11.8%)	0.5 (14.8%)	0.5 (11.5%)
		new	0.4 (14.8%)	0.4 (14.6%)	0.4 (14.6%)
low	low	dry	0.6 (13.8%)	0.6 (12.1%)	0.6 (10.7%)
		new	0.5 (14.8%)	0.5 (13.5%)	0.6 (10.7%)

Both the neutron and photon dose rates are reduced with respect to the 28 canister per cubicle dose rates. In addition, the photon dose rate uncertainties are lower indicating more reliable results.

Table G-7 presents the open cubicle dose rates for both neutrons and photons with 20 canisters per cubicle.

Table G-7. Open Cubicle Dose Rates (mrem/h)
20 cans per cubicle

^{240}Pu fraction	PuO_2 Density	Radiation	Horizontal dose rate variation in front of a cubicle (calculational uncertainty)		
high	high	neutron	204 (21.2%)	219 (11.6%)	204 (12.0%)
		photon	28 (36.0%)	13 (12.5%)	18 (17.5%)
high	low	neutron	118 (20.3%)	160 (26.0%)	87 (11.1%)
		photon	36 (26.2%)	18 (12.4%)	16 (13.4%)
low	high	neutron	85 (42.0%)	54 (14.0%)	53 (15.1%)
		photon	11 (44.9%)	6.2 (19.7%)	8.2 (20.6%)
low	low	neutron	30 (11.0%)	37 (22.0%)	28 (12.7%)
		photon	14 (32.7%)	8.2 (15.0%)	8.5 (18.2%)

As with the 28 canister case dose rates seem to be greater for the closed door calculations, with dry concrete, than for the open door. Again the uncertainties for the open door case are generally higher indicating MCNP inefficiencies in tallying particles from adjacent closed cubicles as compared to the particles from the open cubicle.

Table G-8 gives the dose rate with the open cubicle half full (10 canisters in the open cubicle). The dose rates are generally about half those for the full open cubicle case.

Table G-8. Open Cubicle Dose Rates (mrem/h)
20 cans in closed cubicles, 10 cans in open cubicle

^{240}Pu fraction	PuO_2 Density	Radiation	Horizontal dose rate variation in front of a cubicle (calculational uncertainty)		
high	high	neutron	103 (13.7%)	141 (23.5%)	108 (15.3%)
		photon	9.2 (16.4%)	12 (22.3%)	19 (29.3%)
high	low	neutron	49 (14.9%)	61 (15.7%)	63 (17.7%)
		photon	9.8 (16.6%)	15 (24.6%)	16 (29.4%)
low	high	neutron	26 (16.1%)	58 (24.9%)	38 (21.9%)
		photon	3.3 (29.7%)	6.7 (46.7%)	1.2 (33.6%)
low	low	neutron	16 (14.7%)	17 (17.5%)	23 (17.7%)
		photon	3.6 (18.0%)	7.8 (28.8%)	8.4 (28.3%)

DISTRIBUTION SHEET

To Distribution	From Criticality and Shielding	Page 1 of 1			
		Date February 19, 1997			
Project Title/Work Order Radiological Dose Assessment for Vault Storage Concepts		EDT No. 620288			
		ECN No.			

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
------	------	-----------------------------	-----------	------------------------------	-----------------

J. Greenborg	H0-35	X
D. R. Hekkala	T5-57	X
K. E. Hillesland	H0-35	X
T. E. Huber	T5-50	X
G. A. Johnston	T5-50	X
J. S. Lan	H0-35	X
J. L. Mejia	T5-08	X
C. T. O'Neill	G3-17	X
R. F. Richard	H0-35	X
V. E. Roetman	H0-35	X
R. W. Szempruch	T5-48	X
E. V. Weiss	T5-50	X
Central Files (original +1)	A3-88	X