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Addendum 1 to CSER 96-025: PFP Storage of 9.25/9.5 inch Tall, 4.4 kg Pu Cans on Existing Vault 4 Pedestals

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Abstract: A nuclear criticality safety analysis has been performed to increase the approved plutonium mass limit for cans stored in Vault #4 cubicles at PFP. The original CSER 96-025 accommodated the storage of 4.4 kg of plutonium in PuO_2 (5.0 kg PuO_2) in Vault #4 by requiring that half the cubicles be left vacant. This addendum allows for all the cubicles to be used, but with a fissile plutonium mass limit of 58 kg per cubicle. A mass limit for each cubical allows for storage of a larger number of cans if some have less than the 4.4 kg Pu limit per can. The highest k_{eff} calculated is 0.932 ± 0.003 when an overbatched can is present in every fourth cubicle. This is below the criticality safety limit of $k_{eff} = 0.935$, and consequently, an increase of plutonium mass to 4.4 kg per can is within acceptable safety limits for the given mass limit.

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CONTENTS

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Addendum 1 to CSER-96-025

Title: Addendum 1 to CSER 96-025: PFP Storage of 9.25/9.5 inch Tall, 4.4 kg Pu Cans on Existing Vault 4 Pedestals

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1.0 INTRODUCTION

A nuclear criticality safety analysis has been completed to increase the approved plutonium mass limit for cans stored in Vault #4 cubicles at PFP. The cubicles were approved to hold up to 2.5 kg of plutonium in plutonium oxide (PuO_2) on each pedestal (Chiao, 1978). CSER 96-025 (Hillesland, 1997) allows for the use of all pedestal positions, but half the cubicles must be left vacant. Furthermore, the cans were assumed to be filled with 4.5 kg of plutonium, even though they will typically have less than this amount. This addendum provides for a total plutonium mass limit in each cubicle. This allows for the use of all cubicles, and implicitly takes credit for the fact that most, if not all cans will have less than 4.5 kg of plutonium.

The cubicles will be used to hold cans of dry PuO_2 ($H/Pu < 2$). The PuO_2 is quadruple canned in the Hanford Convenience Can (HCC) configuration, with each can being sealed or welded shut. Each can is made of metal, and has a lid on it. There may also be one or more plastic bags around the cans. Note that the original CSER 96-025 (Hillesland, 1997) refers to a

9.25 inch can. In actuality, this can will be 9.5 inches high. However, since this dimension is not relevant to the criticality analysis, either here or in the original CSER 96-025, both analyses encompass both the 9.25 and 9.5 inch cans.

2.0 SUMMARY AND CONCLUSIONS

This analysis has shown that the storage of 4.5 kg plutonium in the Hanford Convenience Can (HCC) under the controls listed in Section 3 is safe from a criticality stand point. These controls include a 58 kg mass limit for each cubicle. No single identified contingency exceeds the criticality safety limit of k_{eff}=0.935 for plutonium systems calculated using the MONK6B * code.

All results of this analysis can be found in Section 6. The worst case normal condition was found to be the case of closing all the doors in the vault and shifting the position of each convenience can within the unit into its respective corner of the cubicle to the maximum displacement possible (see Section 6.2.5, Figure 6). For this case (ccfar), $k_{eff} \pm 1\sigma$ is 0.928 ± 0.003.

For the off normal condition (contingency) analysis the overbatch case with the doors closed (cbatch2) the $k_{eff} \pm 1\sigma$ is 0.932 ± 0.003. When a fully loaded Fixed Array Wagon (case cwag) is brought into the room, thus violating the limit that there be only one can in transit at a time, the $k_{eff} \pm 1\sigma$ can be as high as 0.931 ± 0.003. The case of a wagon in front of an open cubicle (owag), which is also used to bound the case of two cans in transit at a time, yielded a maximum $k_{eff} \pm 1\sigma$ of 0.928 ± 0.003. When an extra can over the fissile mass limit is placed on the floor of the vault and the doors are closed (case ctest2), the $k_{eff} \pm 1\sigma$ becomes 0.927 ± 0.003, which is lower than the comparable normal condition case, indicating a negligible change in reactivity. If the doors are open, a person may be moving the additional can around inside the cubicle. A search on worst case position results in a maximum $k_{eff} \pm 1\sigma$ of 0.922 ± 0.003 (cases oxcent2 and oxcent3). The case of optimal internal moderation (case cint4a) gives a $k_{eff} \pm 1\sigma$ of 0.929 ± 0.003. For optimal interspersed moderation (cases cp002 and cp01), the $k_{eff} \pm 1\sigma$ is 0.930 ± 0.003. The $k_{eff} \pm 1\sigma$ for a case where a person falls into the cubicle (case opincell) is 0.757 ± 0.003.

The results from Table 2 indicate that k_{eff} goes up less than linearly with increases in plutonium mass. Therefore, relatively small additions above the mass limit for a cubicle would not be catastrophic, thus allowing recovery from a non-conformance of this nature.

As can be seen, all of the normal and off-normal results are below the criticality safety limit. This analysis shows that the mass loadings of the cans may be increased from the current 2.5 kg of plutonium limit to 4.5 kg of plutonium provided that all limits and requirements listed in section 3 are followed. Since no single identified contingency exceeds the criticality safety limit, this CSER meets the requirements for criticality analysis of the Hanford Site Nuclear Criticality Safety Manual, CM-4-29.

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*MONK6B is a trademark of ANSWERS, the marketing service of the United Kingdom Atomic Energy Authority, Winfrith, England. KN

3.0 DESIGN FEATURES AND ADMINISTRATIVELY CONTROLLED LIMITS AND REQUIREMENTS

The administratively controlled limits applicable to this evaluation of the vault #4 pedestals using a mass limit are for the storage of plutonium oxide in the Hanford Convenience Can (HCC) configuration are:

1) No more than 58 kg of plutonium shall be stored in any given cubicle.

2) Every can shall be placed on an available pedestal.

3) Each storage can shall contain no more than 4.5 kg of plutonium, in oxide form only, as determined by the upper tolerance NDA measurement.

4) Lead shielding thickness around a can is limited to 0.635 cm (1/4") or less. If lead shielding is used, it shall be accompanied by a total steel thickness of at least 0.91 cm (0.036 in.). Quadruple canning or equivalent thickness of steel meets this requirement.

5) The PuO_2 shall have a denisty not in excess of 5.5 g Pu/cm^3 and be moderation controlled to an H/Pu of less than 2.

6) Cans in transit within Vault #4 shall be separated by a minimum distance of 3.3 m (10 ft. 8 in.) in the east-west direction, and a minimum distance of 4.3 m (14 ft.) in the north-south direction at all times. To make this limit more practical from an operational standpoint, only one can should be allowed to be in transit at a time within the entire vault.

7) The 2736-Z building and the Vault #4 cubicles shall be seismically qualified for storage of the new fully loaded HCC cans.

8) The criticality firefighting category for this area shall be category C.

9) The east wall of Vault #4 is an external wall. No reportable quantity of material shall be stored within 183 cm (6 ft) of the east wall, external to the Vault.

Fissile material may be stored using a mix of the configuration outlined in Rev. 0 of CSER 96-025 (Hillesland, 1997), and the mass limit given here. However, the restriction that cubicles behind, on the side, and across the aisle of a fully loaded (>58 kg Pu) cubicle allowed for in Rev. 0 of CSER 96-025 must still remain vacant. Furthermore, the requirement that the north wall storage rack of Vault #3 be left vacant is still applicable if there are any fully loaded cubicles (>58 kg Pu) on the south wall of Vault #4.

4.0 DESCRIPTION OF SYSTEM AND FACILITY

The 2345-Z Building, more commonly referred to as the Plutonium Finishing Plant (PFP), is located in the 200 West area. This facility was historically used to process plutonium into oxide or metal forms. The facility is now undergoing a cleanup phase to stabilize the plutonium still stored there. The Vault #4 storage room is located in building 2736-Z. This building is adjacent to PFP on its south side. The Vault #4 pedestals were historically approved to hold containers with a maximum of 2.5 kg of PuO_2 or metal.

There are 68 cubicles in the vault. The internal horizontal dimensions of each cubicle are 61 cm (24 in.) wide and 30 cm (12 in.) deep. The walls of each cubicle, including the door, are 20 cm (8 in.) thick concrete. Figure 1 shows a cross-sectional view of a cubicle. Inside each cubicle are two racks, one on either side, with 14 pedestals attached to each rack. Each side of a rack has 7 pedestals, staggered between the two sides as shown in Figure 2. The vertical distance between pedestals in a column is 30 cm (12 in.). The horizontal, center-to-center distance between the columns is 19 cm (7.5 in.). The 28 pedestals in each cubicle are designed to hold cans with a diameter of 10.8 cm (4.25 in.), fitted with a magnetic security plate on the bottom of each can. The walls of the cubicle are as high as 246 cm (8 ft. 1 in.) above the floor, and the top of the doors are 244 cm (8 ft.) above the floor, with a 15 cm (6 in.) gap beneath the doors.

Figure 1. Cross-Section of Cubicle

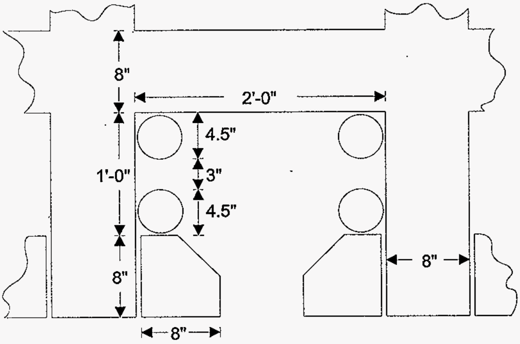
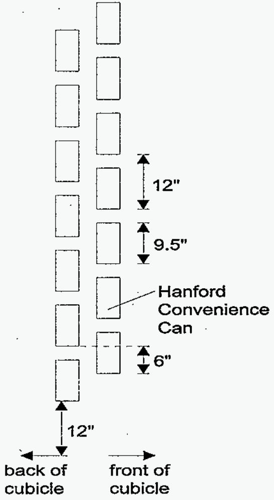
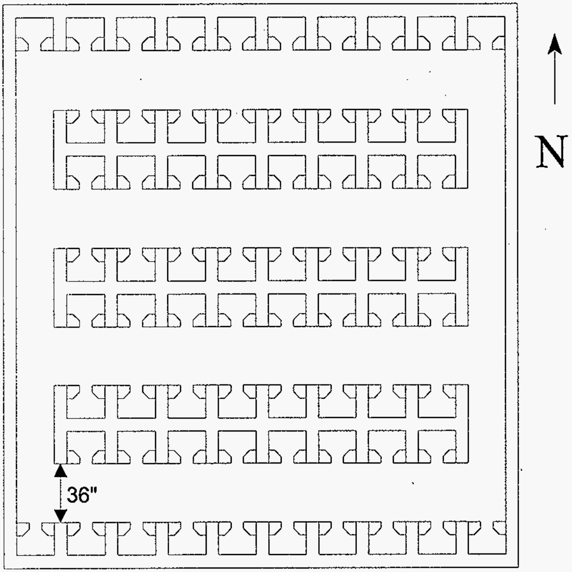


Figure 2. Rack Arrangement



The cubicles are arranged in rows running east and west. There are ten cubicles on the north and south walls. The cubicles in the middle of the room are arranged in rows, back-to-back, 8 cubicles long. For each cubicle in the middle of the room, there is another cubicle directly opposite, 91 cm (36 in.) away. Figure 3 shows the layout of Vault #4.

Figure 3. Vault #4 Room Layout



North of Vault #4 is Vault #3, which contains cubicles of the same design and arrangement as that in Vault #4, and is used to store quantities of up to 2.5 kg of plutonium on each pedestal in every cubicle.

The west wall is shared with a hallway, through which fissile material may occasionally pass. All other rooms near Vault #4 are separated by at least two 20 cm (8 in.) walls of concrete and at least a hallway or the space between the 2736-Z building and the 2736-ZB building. East of the 2736-Z building is the 2731-Z building.

The plutonium will be quadruple canned before it is brought into the vault. The cans are made of steel, and have a wall thickness of approximately 0.023 cm (0.009 in.). The dimensions of the four cans can be found in Table 1. The height of the outer can has been revised to 24.1 cm (9.5 in.) rather than the 23.5 cm (9.3 in.) in Table 1 of CSER 96-025 (Hillesland, 1997). However, since the plutonium geometry is set by the size of the inner most convenience can, and the spacing is fixed by the pedestals, the results of this analysis are equally applicable to the taller (24.1 cm) cans.

Table 1. Can Dimensions.

Can	OD (cm)	H (cm)	OD (in.)	H (in.)
Convenience	8.7	20.3	3.4	8.0
Secondary	9.2	21.0	3.6	8.3
Tertiary	10.3	22.9	4.1	9.0
Outer	10.8	24.1	4.3	9.5

5.0 METHODOLOGY

Appendix B provides a summary for the documentation (Maklin 1992, Miller 1994) of the validation carried out for the MONK6B Monte Carlo* code and its predecessor versions as applicable to plutonium materials encountered at PFP. With the cross-section library supplied, the MONK6A/6B validation calculations indicate an allowed maximum k-effective (k_{eff}) value of 0.935 for new system calculations to assure subcriticality with an acceptable margin, including the uncertainties in the analytical methods and benchmark experimental data. The estimated standard deviation for all calculations in this analysis was less than or equal to 0.003.

6.0 EVALUATION AND RESULTS

6.1 MODEL DESCRIPTION AND ASSUMPTIONS

For the purposes of this analysis, the metal of the cans is not included except where explicitly stated otherwise. This is conservative because the metal acts as an absorber. The analysis of Section 6.2.3 was done to confirm that this is indeed the case. Each HCC is filled with 4.5 kg of plutonium in PuO_2 (5.1 kg PuO_2). This is conservative since it is more than the normal maximum loading of 4.4 kg of plutonium (5.0 kg PuO_2), and is meant to accommodate uncertainties in the fissile mass measurement. H_2O is added to produce an H/Pu ratio of 2, which is conservative because each can is tested for moisture content after being dried at about 1000°C.

The assumed Pu density is 5.5 g/cm^3. According to ARH-600 (Carter, 1968), if plutonium metal is burned, the resulting PuO_2 has a density of 5.3 g/cm^3 (4.7 g Pu/cm^3). However, CSER 95-005 Addendum 1 (Geiger, 1995) for the vertical calciner sets a threshold of the plutonium product density to be as high as 5.5 g Pu/cm^3 before imposing more restrictive limits. The plutonium is also assumed to be pure ^{239}Pu. In reality most of the plutonium at PFP will have more than 5 wt% ^{240}Pu, but there does exist some plutonium at PFP that has less than 3 wt% ^{240}Pu. Using pure ^{239}Pu is conservative.

For the purposes of this evaluation, it was conservatively assumed that the volume of PuO_2, with H_2O added at an H/Pu ratio of 2, is equal to the original volume of the plutonium at a density of 5.5 g/cm^3. This gives a material density of 6.65 g/cm^3.

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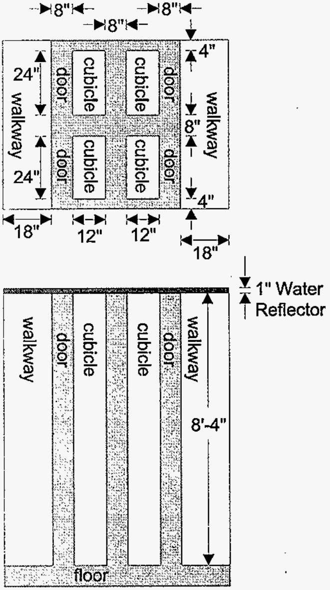
*Monte Carlo computer code developed by Los Alamos National Laboratory. KN

The PuO_2 is modeled as a cylinder with a diameter of 8.69 cm (3.42 in.), which is the inner diameter of the inner (convenience) can. Based on a material density of 6.65 g/cm^3 and a Pu mass of 4.5 kg, the height of the PuO_2 was modeled as 13.8 cm (5.44 in.). Each can contains 4.5 kg of plutonium in PuO_2 with H_2O added at an H/Pu ratio of 2.

The vault is modeled as an infinite horizontal array of cubicles, with each cubicle having other cubicles on the sides and back, and a 91.44 cm (36 in.) walkway between a given cubicle and the one opposite it. Figure 4 shows the base model used when the doors of all vaults are closed. To simulate the infinite array, the unit shown in Figure 4 has periodic boundary conditions on four sides. This allows for more manageable calculations. Since the vault is large, the reactivity of the actual vault should not be significantly less than that of the infinite array. In some instances, only one fourth of the unit cell illustrated in Figure 4 is used to simulate an infinite array by reflective boundary conditions when possible. The floor is 20.32 cm (8 in. thick) concrete, and the cubicle is modeled as being 254 cm (8 ft 4 in.) tall. At the top of the model is a 2.54 cm (1 in.) water reflector used to account for various objects, including the ceiling, that might provide further reflection above the top of the cubicle.

Figure 4. Unit Cell of Model
(Closed Doors)



6.2 NORMAL CONDITIONS

For normal conditions, the following variables were considered: storage density and fissile mass distribution, water content of concrete, steel and lead around the cans, cubicle doors open and closed, position of the inner (convenience) can within each HCC unit, and changes in reactivity as a person moves a can around within a cubicle, including the presence of a person's body and hands. Each of these variables is covered in the following sections.

6.2.1 Storage Density

CSER 79-028 (Chiao, 1979) authorizes storage of up to 2.5 kg of material on each of the 28 pedestals in each cubicle of Vaults #3 and #4. This amounts to 70 kg of material per cubicle. These limits are based on the analysis in CSER 78-022 (R. Carter, 1978), which allows for the storage of up to 2.5 kg of material on each of 35 pedestals in each cubicle of Vault #1, amounting to 87.5 kg per cubicle. This analysis is intended to allow for the storage of cans containing up to 4.4 kg of plutonium. To store 28 cans in every cubicle, each can with 4.4 kg of plutonium, would result in a storage density of 123.2 kg per cubicle.

Case cfull in Table 2 is a case in which every cubicle is filled with 28 cans of 4.5 kg of plutonium each. The result of this calculation is a k_{eff} of 1.079, indicating that the storage density of a fully loaded vault would not be acceptable. As a consequence, a number of calculations were made, varying the total mass in each cubicle until a k_{eff} less than 0.935 was reached. Case ox13t2, which includes the contingency of trying to add one can to every fourth cubicle when the mass limit has already been reached is the basis for choosing the 58 kg mass limit.

In general, the denser the plutonium, the more reactive. Therefore, it was assumed that given a mass, the worst configuration would be to stack cans loaded with the full 4.5 kg of plutonium at a bounding density. Furthermore, the 8 in. concrete floor can provide greater reflection than the 1 in. water reflection at the top (see Figure 4), giving a can near the floor greater reactivity than one near the top. Consequently, the pedestals are filled beginning with the lowest position and working upwards. The cases given in Table 3 were calculated to support these assumptions.

An additional configuration fills both sides of one rack from the bottom in each cubicle such that there is a full column of cans in one back corner of the cubicle. The filled rack for each cubicle alternates such that there is a full column just to the other side of the back and side wall of every back corner column of cans. The inner cans of Case cside are positioned as Case c1 in Table 6. The inner cans of Case cside2 are positioned as Case ccfar.

The storage density depends greatly on the hydrogen content of the concrete between cubicles. For this reason, the "Hanford ordinary, baked to 100° C" concrete of Section 6.2.2 was chosen for all of the cases in this section. This concrete has a low hydrogen content that allows increased interaction between cubicles. The increase in interaction and loss of neutron absorber raises reactivity more than the loss of reactivity due to decreased moderation by hydrogen and reflection by the concrete.

Table 2. Storage Density Effect

Case	Description	No. of 4.5 kg cans	k_{eff}
cfull	Every cubicle filled with 28 cans, each can with 4.5 kg plutonium	28	1.079
owr12t1	Wagon in front of open cubicle. Can in transit near bottom in every fourth cubicle	16	0.971
ow15t1	Wagon in front of open cubicle. Can in transit near bottom in every fourth cubicle	15	0.955
ox15t2	Extra (16th) can in open cubicle in transit near center of every fourth cubicle	15	0.955
ox14t2	Extra (15th) can in open cubicle in transit near center of every fourth cubicle	14	0.939
ox13t2	Extra (14th) can in open cubicle in transit near center of every fourth cubicle	13	0.914

Table 3. Distribution of Mass Effect on Reactivity

Case	Description	Cans	PuO_2+H_2O density (g/cm^3)	k_{eff}
ccfar	Cans stacked from bottom.	13	6.65	0.928
cspread	plutonium evenly distributed amongst all cans, each can filled to maximum volume	28	2.10	0.835
ctop	Cans stacked from top	13	6.65	0.901
cside	Filling one rack in each cubicle, alternating sides going down a row of cubicles. Inner cans as case c1 in Table 6	13	6.65	0.849
cside2	Filling one rack in each cubicle, alternating sides going down a row of cubicles. Inner cans as case ccfar in Table 6	13	6.65	0.852

6.2.2 Hydrogen Content and Density of Concrete

The hydrogen content of concrete can have varying effects on reactivity. As the hydrogen content increases, reactivity may rise due to the increase in moderation and/or the increase in reflectivity of the concrete. As hydrogen decreases, moderation, reflection, and absorption are lost, but with this comes an increase in interaction between cubicles, which can raise reactivity. The lowest hydrogen content considered was 0.31 wt% hydrogen, which resulted from a sampling of "Hanford ordinary concrete" baked to temperatures of around 100° C (W. Bunch, 1975). The highest hydrogen content considered was 1.0 wt% hydrogen, for Portland concrete (ARH-600). A comparison was also made to "Hanford ordinary concrete" that had not been baked, corresponding to relatively newly poured concrete (W. Bunch, 1975). Table 3 lists the results of calculations using different concretes, where each cubicle is filled with 13 cans, and each inner convenience can is centered within its unit. It was found that the lower hydrogen concrete was the most conservative and thus it was used in all subsequent calculations. Although the extremely low hydrogen content is not credible under normal conditions, it is used because it conservatively bounds low hydrogen content.

A subsequent calculation was done to show the effect of changes in concrete density that may arise due to air bubbles in the concrete due to improper casting. This was done using the lower hydrogen content of case ccent, but with the concrete density reduced by 10%. Although the lower density concrete gives a slightly higher k_{eff}, the already low hydrogen content of the concrete used is considered conservative enough to bound this analysis. The bounding hydrogen density increases reactivity seven times what the large decreases in concrete density would cause.

Table 3. Water Content and Density of Concrete Effect on Reactivity

Case	Concrete	wt% hydrogen	Density (g/cm^3)	k_{eff}
ccent	Hanford ordinary, baked to 100° C	0.31	2.26	0.920
cfresh	Hanford ordinary, fresh	0.64	2.33	0.849
cport	Portland	1.00	2.30	0.867
clowdens	Hanford ordinary	0.31	2.03	0.930

6.2.3 Steel or Lead Around Cans

The plutonium will be quadruple canned before it is brought into the vault. The cans are made of steel, and have a wall thickness of approximately 0.023 cm (0.009 in.). The steel of the four cans can contribute to isolation from other cans and self reflection. To evaluate these two effects, cases were run both with and without 0.091 cm (0.036 in.) thick stainless steel encasing the plutonium oxide. The 0.091 cm (0.036 in.) of stainless steel is used to represent the four layers of cans, each 0.023 cm (0.009 in.) thick.

Additionally, six cases were run to show the effects of various thicknesses of lead shielding. The first three cases (clead16, clead8, and clead4) for lead shielding do not include the metal of the cans. The other three include the metal of the cans. The results indicate that the addition of lead shielding increases reactivity. However, the reduction in reactivity from the presence of the steel in the cans nearly compensates for the presence of the lead shielding, as demonstrated by cases cslead4, cslead8, and cslead16. Because the effects of lead and steel nearly cancel one another, these cases have been run longer to achieve better convergence. This observation, together with the conservatism introduced by using tight-fitting steel and lead, is considered sufficient to warrant exclusion of both layers in further analysis.

Table 4. Steel of Can and Lead Shielding Effect on Reactivity

Case	Description	k_{eff}	sigma
ccentb	Bare PuO_2	0.922	0.001
ccans	Encased in 0.091 cm (0.036 in.) of steel	0.915	0.003
clead16	Encased in 0.159 cm (0.0625 in.) of lead	0.926	0.003
clead8	Encased in 0.318 cm (0.125 in.) of lead	0.927	0.003
clead4	Encased in 0.635 cm (0.250 in.) of lead	0.926	0.003
cslead16	Encased in 0.091 cm (0.036 in.) of steel and 0.159 cm (0.0625 in.) of lead	0.917	0.001
cslead8	Encased in 0.091 cm (0.036 in.) of steel and 0.318 cm (0.125 in.) of lead	0.915	0.001
cslead4	Encased in 0.091 cm (0.036 in.) of steel and 0.635 cm (0.250 in.) of lead	0.920	0.001

6.2.4 Cubicle Doors Open/Closed

The doors consist of two concrete columns, with outer dimensions of 20 cm x 20 cm x 100 cm (8 in. x 8 in. x 7 ft 6 in.). They are mounted such that they leave a 15 cm (6 in.) gap beneath them. When the doors are closed, moderation and reflection are increased. When open, interaction between cells across the hallway is possible. The cases in Table 5 show the effect of the doors. Although a 20 cm (8 in.) gap exists between the concrete sections of the doors even when closed, the case used to represent closed doors considers complete blockage of the entrance to the vault, thus eliminating the gap between, beneath, and above the doors.

For each of the cases of doors open and closed for a two dimensional horizontal array of cubicles, a second calculation in which a single infinitely long row of back-to-back cubicles was analyzed to show the amount of interaction across rows in each case. As indicated in Table 5, the interaction across rows is significant when the doors are open, but with the total concrete thickness of 41 cm (16 in.) the doors provide substantial isolation between rows when closed. As shown in section 6.2.3 above, as hydrogen content in the concrete rises, the isolating effect brings reactivity down further. By opening the doors, the interaction across the walkway is not increased enough to compensate for the loss of reflection from the concrete doors. Figure 4 above shows the model used for the doors closed. Figure 5 below shows the model used for doors open.

Figure 5. Model for Doors Open
(obase)

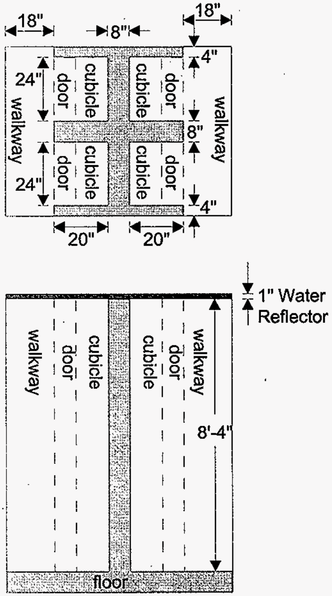


Table 5. Cubicle Door's Effect on Reactivity

Case	Doors	Number of back-to-back rows	k_{eff}
ccent	Closed	infinite	0.920
c1row	Closed	1	0.886
ocent	Open	infinite	0.880
o1row	Open	1	0.696

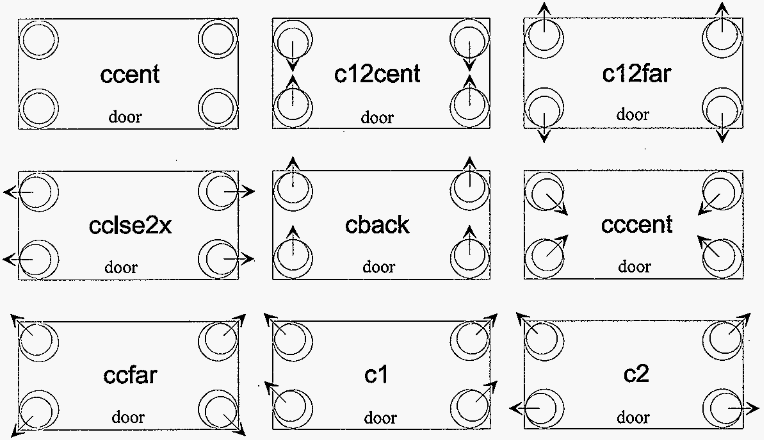
6.2.5 Position of Inner Can Within Unit

Although the outer can's position is fixed when placed on a pedestal, the inner (convenience) can could move as much as 0.96 cm (0.38 in.) within the outer can. Calculations were used to evaluate the effect of inner can position. Figure 6 below shows the different positions of the inner can that were considered in Table 6. These cases were run with the doors of the cubicle closed as described in section 6.2.4. Results indicate that the most reactive position of the inner can is near the sidewalls or corners of the cubicle. All subsequent calculations use inner can positions near the sidewalls or corners.

Table 6. How Inner Can Position in Unit Effects Reactivity

Case	Position of inner can within unit	k_{eff}
ccent	Centered	0.920
c12cent	Moved towards cans on other side of rack	0.925
c12far	Moved away from cans on other side of rack	0.924
cclse2x	Moved towards wall which the rack is mounted on	0.926
cback	Moved towards back wall	0.923
cccent	Moved 45 degrees towards center of cubicle	0.919
ccfar	Moved 45 degrees towards corners of cubicle	0.928
c1	Moved at 45 degree angle towards sidewalls and back of cubicle.	0.923
c2	Cans in back are moved 45 degrees towards back corners. Cans in front are moved towards sidewalls of cubicle	0.925

Figure 6. Positions of Inner Cans



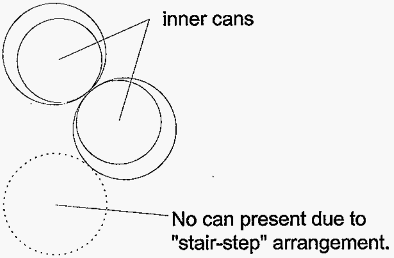
6.2.6 Person Moving a Can Within Cubicle Interior

The current CPS allows for only one container to be in transit at one time within Vault #4. When the doors are open, a person may stand in the doorway, while positioning the can anywhere in the cubicle. The worst case position of this can in transition was found to be between the two columns of cans on a rack, level to the center can in a back column as illustrated in Figure 7. This is shown in a sequence of calculations in which a can is moved to other locations in the analysis of Section 6.3.3. The worst case elevation of the can was determined by the cases given in Table 7 below. Because the model uses an infinite array, this case (as well as all others in this section with a can in transit) is modeled as having an additional can in transit in one fourth of the cubicles.

Table 7. Position of Can in Transition

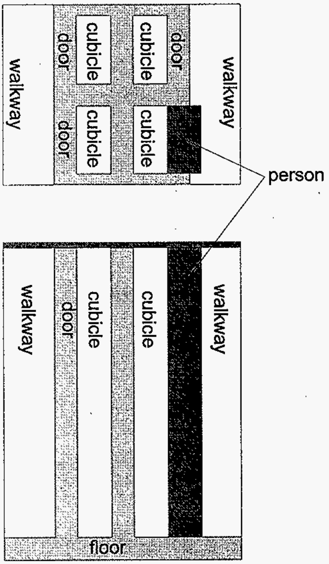
Case	Description	k_{eff}
omcent	Can in transit adjacent to second can from bottom of back column, between columns. Other cans have inner can moved towards sidewalls.	0.912
omcent2	As omcent, but can in transit adjacent to second can from bottom of front column	0.910
omcent3	As omcent, but other inner cans moved towards corners of cubicle	0.912

Figure 7. Worst Case Position of Can in Transit



Also, the effects of the presence of a person and the person's hand on reactivity were analyzed and the results are shown in Table 8. The presence of a person was modeled by replacing the doorway with a cuboid of water 30.48 cm (12 in.) thick, 60.96 cm (24 in.) wide and 254 cm (100 in.) tall. This is far larger than the expected size of a person, but represents a conservative upper bound in terms of the additional reflection provided by a body. The drop in reactivity with the introduction of a person indicates that the reflection provided by the body does not quite compensate for the loss of interaction across the walkway due to absorption of neutrons by the body. Figure 8 shows how the presence of a body was modeled.

Figure 8. Person in Doorway



The cases ohand and ohp introduce a hand modeled as a 2.54 cm (1 in.) reflector on the radial side of the outer can except where the cans meet. Case ohp includes a person in the doorway, whereas ohand does not. The introduction of the hand increases reactivity, whereas the introduction of a person reduces reactivity. Case ohand70 was run to show that a reduction in the water density from 1.0 g/cm^3 to 0.7 g/cm^3 causes little change in reactivity.

Figure 9. Hand Around Can

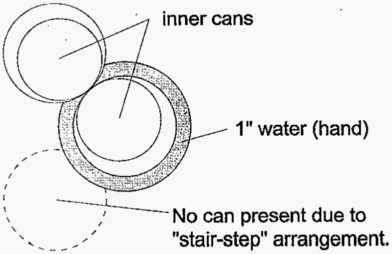


Table 8. Person Moving Can Inside Cubicle

Case	Body in doorway	Hand around can	k_{eff}
omcent3	No	No	0.912
operson	Yes	No	0.899
ohand	No	Yes	0.917
ohand70	No	Yes (70% density)	0.918
ohp	Yes	Yes	0.900

6.2.7 Storage of Fissile Material Near Vault #4

North of Vault #4 is Vault #3, which contains cubicles of the same design and arrangement as that in Vault #4. With only a 20 cm wall (8 in.) separating Vaults #3 and #4, the two vaults are neutronically coupled. Vault #3 is used to store quantities of up to 2.5 kg of plutonium on each pedestal in every cubicle (70 kg per cubicle). CSER 79-028 (Chiao, 1979) covers Vaults #3 and #4 for 2.5 kg cans based on calculations using an infinite array given in CSER 78-022 (Carter, 1978). The areal density of the analysis in CSER 78-022 for 2.5 kg units (85.7 kg per cubicle) is greater than that of this CSER (58 kg per cubicle), but is in units of smaller mass. In both this CSER and CSER 78-022, an infinite array was analyzed. Since both configurations have been shown to be safe as infinite arrays, then the analysis for the more reactive system bounds a mixed system of the two.

The west wall is shared with the hallway. Fissile material will be present in the hallways at times as individual cans are being weighed and cans are moved about in wagons. There are no cubicles on this wall, except at the corners of the room. The analysis for a wagon inside Vault #4 as a contingency in section 6.3.2 bounds any activities that may take place in the hallway.

All other rooms near Vault #4 are separated by at least two 20 cm (8 in.) walls of concrete and at least a hallway or the space between the 2736-Z building and the 2736-ZB building. As discussed in Section 6.2.4, the total of 41 cm (16 in.) of concrete provides significant isolation. Furthermore, the analysis of this CSER was done using an infinite array, which should more than compensate for interaction with the other rooms. Therefore, no further consideration with regards to interaction with other rooms is necessary.

The east wall of Vault #4 is an external wall. No reportable quantity of material shall be stored within 183 cm (6 ft) of the east wall.

6.3 OFF-NORMAL CONDITIONS

For off-normal conditions the following contingencies were considered: (1) Overbatch, (2) bringing a fully loaded Fixed Array Wagon into the vault and too many cans in transit, (3) exceeding the mass limit for the cubicle by 4.5 kg, (4) internal moderation, and (5) interspersed moderation. Each of these contingencies will be covered individually in the following sections. Since contingencies due to earthquakes were not analyzed, this CSER requires the seismic qualification of the building and the pedestals for restraint of fully loaded HCC cans.

The results of the cases involving interspersed moderation in section 6.3.5 show that water in the vault air is not a problem. Therefore, fire fighting can use water fog or foam, but not streams of water that could dislodge a Pu can. Consequently, Vault #4 shall be listed as a criticality fire fighting category C.

6.3.1 Overbatch Contingency

The volume of the inner can is approximately 1.2 liters, and at a plutonium density of 5.5 g/cm^3, the can could hold approximately 6.6 kg of plutonium. This is equivalent to approximately 7.5 kg of PuO_2, and is significantly more than a normal maximum loading of 4.4 kg of plutonium (5.0 kg PuO_2). Since each can will be weighed before it is brought into the vault, it is highly unlikely that any cans with this much material would be brought into Vault #4. Furthermore, the overbatched can is modeled as being present in every fourth cubicle, a conservatism intrinsic to the model used.

For the overbatch analysis, a single can containing approximately 6.6 kg of plutonium was placed on a pedestal near the mid height of the cubicle. A mid height position places the overbatched can in the most reactive position. This is illustrated in the analysis for a can in transit as given in Sections 6.2.6 and 6.3.3. The results are shown in Table 9. Case cbatch2 is the highest k_{eff} found and is below the allowable k_{eff} of 0.935.

Table 9. Overbatch Contingency

Case	Description	k_{eff}
ccfar	Normal condition, doors closed	0.928
cbatch	Overbatched can in second pedestal from bottom of back column of cans	0.931
cbatch2	Overbatched can in second pedestal from bottom of front column of cans	0.932

6.3.2 Loaded Fixed Array Wagon and Additional Can in Transit Contingencies

The current CPS allows for only one container to be in transit within Vault #4 at a time. Outside the vault, PuO_2 filled cans can be moved by wagon. Because security requires people to enter the vault in pairs, to exceed this limit would require an error by two people. Viewed from the perspective of the number of cans that may be placed in a Fixed Array Wagon, the scenario of bringing a wagon filled with five cans into the vault could be considered four contingencies, one contingency for each can beyond the first. However, since bringing the wagon into the vault could also be viewed as a single contingency without regard to the number of cans actually in the wagon, the act of bringing a Fixed Array Wagon filled with cans into the vault is considered in this analysis.

Figure 10 shows a sketch of a typical wagon. However, the wagon was conservatively modeled and positioned as shown in Figure 11 for calculational convenience. The wagon was conservatively modeled as having four HCC cans, with the fifth can in transit within the vault. A hand is placed around the can in transit. Also, the height of the wagon was adjusted to correspond to the height of the lowest cans in the column of cans nearest the door. The tighter packing of the wagon and its position relative to the lowest cans in the vault introduces some additional conservatism. The door was modeled as open to allow maximum interaction between the wagon and the cans in the vault in cases ohand, owag, owag2, owag3, and owag4. Furthermore, the infinite array places a wagon in front of every fourth cubicle, a conservatism intrinsic to the model.

In the case owag, the additional can is placed adjacent to the second can from the bottom in a back column of cans. The inner cans in the wagon are all moved closer to the vault interior. Case owag2 places the additional can adjacent to a can in the wagon, and a can in one of the front column of cans in the cubicle. The inner cans are moved such that the inner can of the can in transit and its adjacent can in the front column are moved as close together as possible. Case owag3 is identical to owag2, but a 30 cm (1 ft.) thick, 61 cm (2 ft.) wide, 183 cm (6 ft.) tall person is placed behind the wagon. Since the modeled wagon in actually only 13 in. long, this brings the person in closer to the vault than would be physically possible. In case owag4 the person is 15 cm (6 in.) thick, so that he may be placed adjacent to the wagon, and wedged into the vault space as far as possible.

Case cwag considers a wagon up against the door of a closed cubicle. The fifth can is placed on top of one of the cans in the wagon, up against the door. This actually corresponds to two contingencies, as stacking cans on the wagon is not allowed, but should bound any allowable position of the can in transit. The inner cans are stacked such that no credit is taken for the spacing provided by the outer can.

Table 10. Fixed Array Wagon in Vault Contingency

Case	Description	k_{eff}
ohand	Can in transition in vault, doors open	0.917
owag	Fixed Array Wagon in doorway with 4 cans, 5th can from wagon in transition adjacent to center can in back column, doors open	0.928
owag2	Fixed Array Wagon in doorway, can in transition adjacent to can in wagon and can on pedestal, doors open	0.926
owag3	As owag2, person standing behind wagon	0.897
owag4	As owag3, person standing next to wagon	0.909
ccfar	Doors closed	0.928
cwag	Doors closed, wagon against door, 5th can stacked on can in wagon nearest door	0.931

The cases for moving two cans at once within a cubicle are bounded by the cases in which a filled Fixed Array Wagon is brought up next to an open cubicle (cases owag, owag2, owag3, and owag4). Because the closest can in the wagon is placed nearly adjacent to a can in the cubicle, it can be considered a second can in transit. The other three cans in the wagon would represent additional conservatism in this context.

Figure 10. Sketch of Fixed Array Wagon

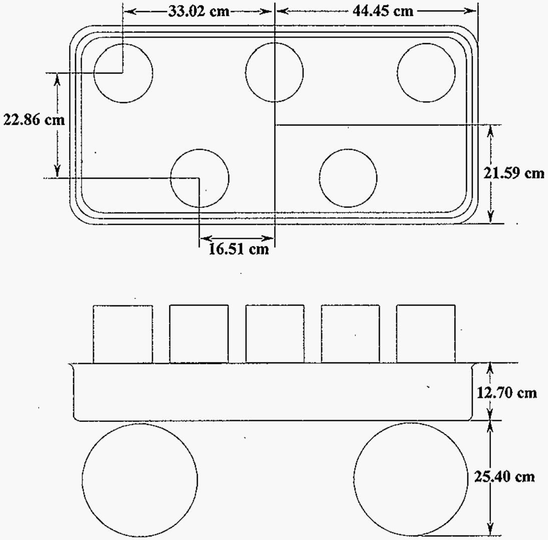
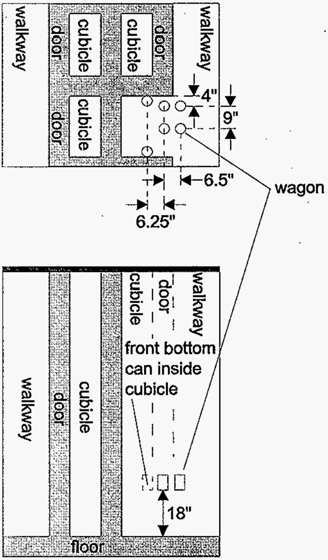


Figure 11. Model of Fixed Array Wagon in Vault



6.3.3 Additional Can Contingency

Each cubicle in use has enough pedestals to hold 28 cans. Cans left places other than on a pedestal are not allowed, except for one can that is allowed to be in transit in the vault at a time. Because security requires people to enter the vault in pairs, to exceed this limit would require an error by two people. However, both a case where a can is left on the floor, and a case of moving a full can above the mass limit around within a cubicle were considered.

The case ctest2 placed an extra can just below one of the back two columns of cans, which are the columns with the bottom can positioned closest to the floor of the vault. In the analysis the vault doors were closed. As can be seen in Table 11, the calculated k_{eff} for the case of a single additional can on the floor (ctest2) is less than the comparable normal condition case (ccfar). Therefore, the addition of a single can on the floor has negligible effect on reactivity (within one sigma). Placing an additional can in the next available pedestal (cped) also results in a negligible change in k_{eff}. Case oxcent places a can next to the second can from the bottom. The can is positioned as shown in Figure 7 above in cases oxcent2 and oxcent3 shown in Table 11 below. Again, the increase in reactivity is small if not negligible.

Table 11. Additional Can in Cubicle Contingency

Case	Description	k_{eff}
ccfar	Normal condition, doors closed	0.928
cped	Extra can on next available pedestal, doors closed	0.928
ctest2	Extra can on floor, doors closed	0.927
oclse2x	Normal condition, cans moved towards side, one door open	0.911
oxcentc	Additional can in transit, between two columns, adjacent to can in second pedestal from bottom of back column. Inner cans are all moved towards closest sidewall of cubicle.	0.914
oxcent	As ocentc, but inner cans of additional can and can it is adjacent to are moved as close together as possible.	0.919
oxcent2	As oxcent, but additional can is adjacent to second can from bottom of front column of cans.	0.922
oxcent3	As oxcent2, but all inner cans are moved towards corners of cubicle, excepting the additional can in transit and the adjacent can.	0.922
oxback	As oxcent, but additional can is against back wall.	0.919

6.3.4 Internal Moderation Contingency

The material placed into the cans is dry PuO_2. Dry in this case means the H/Pu ratio is less than 2. In practice, the H/Pu will be much less than 2, as each can is tested for moisture content after being dried at about 1000° C. Since each unit is quadruple canned, water could not enter the innermost can during fire fighting, or other scenarios of this nature. Therefore, the contingent condition would be to have one can with H/Pu >2 placed into the storage cubicle.

Optimizing internal moderation in a single can will have little effect on the reactivity of the whole system, just as indicated by the case of overbatching a single can in section 6.3.1 and for optimal internal moderation of a single can in the CSER for vault #2 (Erickson 1996). Rather than conducting a complete parametric study, only the limiting case from CSER 96-025 (Hillesland, 1997) was analyzed, with a few additional cases ran to verify the same trend. All but one calculation assumed one internally moderated can in each cubicle. This is quite conservative, as it assumes one contingency for every cubicle used. The limiting case was one in which nearly all of the interstitial volume of the PuO_2 is filled with water, resulting in an H/Pu ratio of 4. The k_{eff} for this case (cint4) is 0.940 for an internally moderated can in every cubicle. Since this is above the 0.935 limit, a second case (cint4a) was run that assumes an internally moderated can in every fourth cubicle. In this case, the k_{eff} is 0.929, which is below the 0.935

Table 12. Internal Moderation Contingency

Case	Cubicles with internal moderated can	H/Pu ratio	k_{eff}
ccfar	none	2.00	0.928
cdry	all	0.00	0.827
cint3	all	3.00	0.935
cint4	all	4.00	0.940
cint5p14	all	5.14	0.933
cint4a	one out of every four	4.00	0.929

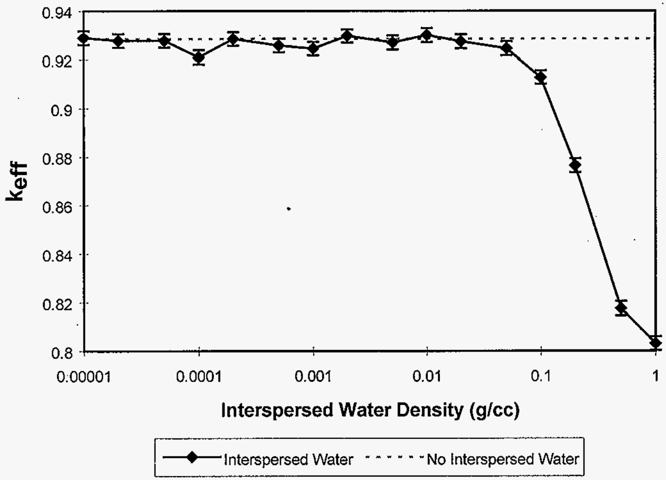
6.3.5 Interspersed Moderation Contingency

A parametric analysis of the water density in the vault was used to assess the contingency of water fog or steam for incidents such as fire. Results at water densities between 0% and 100% of full density were calculated to find the most reactive density. The results of the study can be found in Table 13. It was found that reactivity changes very little up to 0.05 g/cm^3. At densities greater than 0.05 g/cm^3, the reactivity begins to drop, until it reaches 0.803 at full water density. Figure 12 is a graph of k_{eff} vs. interspersed water moderation density. Introduction of water by firefighting or other means would not significantly affect the criticality safety of the storage vault.

Table 13. Interspersed Moderation Contingency

Case	Interspersed water density (g/cm^3)	k_{eff}	± 1σ
ccfar	0.0	0.928	0.003
cp00001	0.00001	0.929	0.003
cp00002	0.00002	0.928	0.003
cp00005	0.00005	0.928	0.003
cp0001	0.0001	0.921	0.003
cp0002	0.0002	0.928	0.003
cp0005	0.0005	0.926	0.003
cp001	0.001	0.924	0.003
cp002	0.002	0.930	0.003
cp005	0.005	0.927	0.003
cp01	0.01	0.930	0.003
cp02	0.02	0.927	0.003
cp05	0.05	0.924	0.003
cp1	0.1	0.913	0.003
cp2	0.2	0.877	0.003
cp5	0.5	0.817	0.003
c1p	1.0	0.803	0.003

Figure 12. $k_{eff} \pm 1\sigma$ as a Function of Interspersed Water Density



6.3.6 Person Falling into Cubicle

One case was run for the contingency of a person falling into the cubicle. The person is modeled as being a cuboid of water 244 cm (8 ft) tall, 61 cm (2 ft) wide, and 38 cm (15 in.) thick. Again, this is an excessively large person, but should be bounding. The k_{eff} for this case (opincell) is 0.757, indicating that the isolation between sides of the cubicle provided by the person's body lowers reactivity.

7.0 REFERENCES

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APPENDIX A

INDEPENDENT REVIEW COMMENTS AND CHECKLIST

Independent technical review was performed by Harvey J. Goldberg and Edward M. Miller. Comments and checklists of both reviewers are included.

Reviewer's Comments - H. J. Goldberg

H.J.Goldberg of the Shielding and Criticality group provided an independent technical review of this addendum to CSER 96-025. The review concentrated, but was not limited to, the computer runs. The models and assumptions were reviewed and were found to be consistently biased towards the side of conservatism.

The errors and accidents considered conservatively spanned the spectrum of the possible and the results offered a acceptable safety margin. These results were compared with handbook values and were consistent with these values. This consistency does not justify or validate the analysis, but does increase a reviewer's confidence in the result, as any inconsistency would tend to cast doubt on the results.

CHECKLIST FOR INDEPENDENT REVIEW

Document Reviewed: Addendum 1 to CSER 96-025: PFP Storage of 9.25/9.5 inch Tall, 4.4 kg Pu Cans on Existing Vault 4 Pedestals

Author: K. E. Hillesland

Yes	No	N/A	
☑	☐	☐	Problem completely defined.
☑	☐	☐	Necessary assumptions explicitly stated and supported.
☑	☐	☐	Computer codes and data files documented.
☑	☐	☐	Data checked for consistency with original source information as applicable.
☐	☐	☑	Mathematical derivations checked including dimensional consistency of results.
☑	☐	☐	Models appropriate and used within range of validity or use outside range of established validity justified.
☐	☐	☑	Hand calculations checked for errors.
☑	☐	☐	Code run streams correct and consistent with analysis documentation.
☑	☐	☐	Code output consistent with input and with results reported in analysis documentation.
☑	☐	☐	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
☑	☐	☐	Safety margins consistent with good engineering practices.
☑	☐	☐	Conclusions consistent with analytical results and applicable limits.
☑	☐	☐	Results and conclusions address all points required in the problem statement.
☑	☐	☐	Have all reasonable accidents been considered?
☑	☐	☐	Has low density water (steam) been evaluated as a moderator?
☑	☐	☐	Is the fuel and other hardware composition correct?
☑	☐	☐	Are the cases considered adequately conservative?
☑	☐	☐	Do the computer models adequately reflect the actual geometry? Have cross sectional cuts of the geometry been made and do they show the desired geometry?
☐	☐	☐	[?] Has the analysis been reviewed by Safety? This may not be required in a preliminary design.
☑	☐	☐	Has the reviewer completed the Criticality Safety Course for Managers and Engineers?

Date completed ~~7 July 1997~~ 20 December 1996 KEH

Reviewed by: Harvey J. Goldberg Harvey Goldberg Date 8 July 1997

NOTE: Any hand calculations, notes, or summaries generated as part of this review should be signed, dated, and attached to this checklist. Materials should be labeled and recorded so that it is intelligible to a technically-qualified third party.

Reviewer's Comments - E. M. Miller

E. M. Miller of the Criticality and Shielding group carried out an independent, technical review of Addendum 1 to CSER 96-025, for which the following comments were provided.

The technical arguments for qualifying the criticality safety of the PFP Pedestal Storage Vault 4 to contain 58 kg of Pu were found to be sound. All credible contingencies resulted in k_{eff}s that were within allowables.

Reviewing Table 2 of this CSER showed the rate of approach to criticality from the allowed configuration is gradual enough to accept operational contingencies. The allowable configuration is still well subcritical when four full cans are added to one open cubicle in four and a full fixed array wagon is also put in front of the same cubicle. The array is not on the brink of criticality, but can accept multiple errors in the number of cans, loading per can, moderation, arrangement, and moisture before a k_{eff} of 1.0 is reached. Note that filling each closed cubicle with about 18 full cans (81 kg of Pu) will raise the k_{eff} to a critical value. This margin of 5 cans allows confidence that a criticality safety program can accommodate mistakes and still maintain subcriticality.

This CSER looked closely at storage can arrangements to determine the most reactive arrangement for a limited maximum mass of Pu per cubicle. The position of the inner can inside the outer can, the location of cans in the cubicle, extra cans in various locations, workers in the cubicle, hands around cans, fissile material in surrounding areas, and concrete door positions were analyzed to ensure normal conditions did not exceed the allowed k_{eff}. Brief parameter studies were used to determine maximum reactivity for concrete density and its water content, for steel in the cans, for close fitting lead shielding, for over batching, for can moisture content, and for the water content of the air in the vault. The analysis is conservative. The model is of an infinite horizontal array of cubicles to ensure effects from other vaults or from the corridor are taken into account. The model is composed of four cubicles with horizontal reflective boundaries so the addition of a can to one cell is modelled as a can added to every fourth cell in the infinite array.

Comparing the characteristics of the fissile material in the vault to handbook values (Carter 1968) indicates that the subcriticality found in the analysis is justified. The density of the 58 kg allowed per cubicle volume of (30.5 cm x 61 cm x 203) 37,770,000 cc is 0.15 g/cc. This value is significantly below the minimum concentration of 7.8 g Pu/cc needed for criticality of Pu with water. Dry Pu requires higher densities. At densities of up to 5.5 g Pu/cc in fully water reflected geometries, 22 kg in a spherical volume of 4 liters are necessary for criticality. This is far higher density than even the inner cans of 1.2 liter volume with 4.4 kg of Pu have. Figure III.A.9(100)-5 shows that a total of 100 kg of dry Pu would be necessary for criticality in a single isolated cubicle with full water reflection on cans closely stacked. That the dry Pu needed for criticality is larger than that allowed for an infinite array of cubicles is as expected.

Some discrepancies in cubical dimensions, numerical inconsistencies, and editorial presentation were raised and have been resolved.

CHECKLIST FOR INDEPENDENT REVIEW

Document Reviewed: Addendum 1 to CSER 96-025: PFP Storage of 9.25/9.5 inch Tall, 4.4 kg Pu Cans on Existing Vault 4 Pedestals

Author: K. E. Hillesland

Yes	No	N/A	
[X]	[ ]	[ ]	Problem completely defined.
[X]	[ ]	[ ]	Necessary assumptions explicitly stated and supported.
[X]	[ ]	[ ]	Computer codes and data files documented.
[ ]	[*]	[*]	Data checked for consistency with original source information as applicable.
[ ]	[*]	[*]	Mathematical derivations checked including dimensional consistency of results.
[X]	[ ]	[ ]	Models appropriate and used within range of validity or use outside range of established validity justified.
[ ]	[*]	[*]	Hand calculations checked for errors.
[ ]	[*]	[*]	Code run streams correct and consistent with analysis documentation.
[X]	[ ]	[ ]	Code output consistent with input and with results reported in analysis documentation.
[X]	[ ]	[ ]	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
[X]	[ ]	[ ]	Safety margins consistent with good engineering practices.
[X]	[ ]	[ ]	Conclusions consistent with analytical results and applicable limits.
[X]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.
[X]	[ ]	[ ]	Have all reasonable accidents been considered?
[X]	[ ]	[ ]	Has low density water (steam) been evaluated as a moderator?
[X]	[ ]	[ ]	Is the fuel and other hardware composition correct?
[X]	[ ]	[ ]	Are the cases considered adequately conservative?
[ ]	[*]	[*]	Do the computer models adequately reflect the actual geometry? Have cross sectional cuts of the geometry been made and do they show the desired geometry?
[X]	[ ]	[ ]	Has the analysis been reviewed by Safety? This may not be required in a preliminary design.
[X]	[ ]	[ ]	Has the reviewer completed the Criticality Safety Course for Managers and Engineers?

Date completed 5/21/97

Reviewed by: Edward M. Miller Edward M. Miller Date 6-26-97

* Detail check of dimensions, hand calculations and computer runs is done by Harvey Goldberg

NOTE: Any hand calculations, notes, or summaries generated as part of this review should be signed, dated, and attached to this checklist. Materials should be labeled and recorded so that it is intelligible to a technically-qualified third party.

APPENDIX B

MONK VALIDATION

Validation Procedure

The validation of the method used in the analysis consists of testing the ability of the MONK6A code (UKEAE, 1988) and neutron cross-sections in calculation of known critical configurations from various benchmark experiments with plutonium (Pu) as the fissile material. Such analyses determine a calculational bias (the deviation of calculated k_{eff} from unity) and the uncertainties culminating from the experimental and calculational errors.

The safety criteria for future calculations on undetermined systems requires that the bias-adjusted k_{eff} does not exceed 0.95 at the 95% confidence interval. This is expressed by the following equation;

$$k_{eff} = k_{calc} - bias + (U_b^2 + U_c^2)^{\frac{1}{2}} \leq 0.95 \qquad (1)$$

where:
k_{calc} = k value given by the calculation of the system
bias = mean difference (k_{calc}-1.0) for benchmark criticals
U_b = 95% confidence level uncertainty in bias determination
U_c = 95% confidence level uncertainty in new calculation.

Thus, the bias-adjusted k_{eff} includes the statistical uncertainties.

Generic Validation of Plutonium Systems

A report by Maklin and Miller (1992) presents the results of calculations to determine a generic bias for plutonium configurations, as encountered in the Plutonium Finishing Plant. Seventy benchmark experiments were calculated, ranging from simple metal spheres to highly diluted (9g plutonium per liter) plutonium nitrate solution spheres, and compacts of PuO_2 blended with polystyrene. A mean k_{eff} value of 1.0047 was determined over the full experimental range, with an average standard deviation of 0.0097.

The direct calculational bias is thus +0.0047 (average k_{eff} greater than unity). Accounting for the uncertainties using tolerance limit analysis, the report then concludes that

At least 95% of all critical experiments of this type computed by the MONK6A code will produce calculated k_{eff} values greater than 0.9857 with 95% confidence.

For a standard deviation (σ) of 0.01 or less for the convergence of a future calculation (U_c), the 0.9857 value is lowered to 0.9855. Rounded conservatively, a value of +0.015 can be used for [$-\text{bias} + (U^2_b - U^2_c)^{1/2}$]. On this basis, it is determined that the true k_{eff} of an analyzed configuration with plutonium will not exceed 0.95 with a 95% confidence level if the calculated value (k_{calc}, $\sigma \leq 0.01$) is limited to a maximum of 0.935.

The 95% confidence level on 99.9% of the data is 0.9699. So a subcritical margin of 5% is 3.5% larger than the uncertainties between the 95.0% and the 99.9% coverage of the benchmark data.

Validation of MONK6B

The validation of MONK6B code on the SUN microcomputer was documented in Miller (1994). The essence of the validation was cross-correlation of calculational results obtained with this code version and computer with results for identical model input done on a CRAY machine with MONK6A. Also, the equivalence of MONK6A and MONK6B was well documented by the vendor in the verification package shipped with the software.

APPENDIX C

MONK FILES

All MONK6B input and output files are stored in CFS in the directory /w80395/ in the file CSER9625a1.tar.Z, which is stored in tarred, then compressed format. The input names can be derived from the case names called out in the document, but with a ".inp" extension. Similarly, the output files are derived from the same case names, but with a ".prt" extension. The input files ccfar.inp (worst case normal conditions), cbatch2.inp (worst case contingency condition), and owag.inp (worst case condition with doors open) are included in complete form.

MONK6B input file ccfar.inp

```
*
* File Name        :ccfar.inp
* Description      :PFP Vault 4 cubicle
* Author           :Karl Hillesland
* Date             :Feb 3, 1997
*
* CSER 96-025, rev. 1
*
* Code            :Monk 6B
*****************************
* Inner cans moved towards corners at 45 degrees
*****************************
*
FISSION
******************************************************
*        MATERIAL DATA AND MAIN CONTROL DATA          *
******************************************************
* Material #      Material Name               Symbol *
*    1            Plutonium Oxide               P    *
*    2            Water                         W    *
*    3            Concrete                      C    *
******************************************************
* Number of Materials           Number of Nuclides
          3                              6
NUCNAMES
*
* PuO2 at 5.5 g Pu/cm3 with H2O mixed in (H/Pu = 2)
ATOM  6.65   PU239 1.0   HINH2O 2.0  O 3.0
*
* Water
ATOM  1.00       HINH2O  2.0   O  1.0
*
* Concrete from "Bulk Shield Design for Neutron Energies Below 50 MeV"
* L. L. Carter, Nuclear Technology/Fusion Vol. 3, March 1983
ATOM  2.258  HINH2O 0.0642  O 0.5916  SI 0.2405  CA 0.0738  FE 0.0299
*
INCHES
*
**************************
* Part 1 - Global
*************************
NEST 2
*       ORIGIN      x       y       z  MAT          param1 param2 param3
1  BOX ORIGIN    -32    -42      0   P2           64    84     109
2  BOX ORIGIN    -32    -42      0    0           64    84     109
ALBEDO    1 1 0 1 1 0
PERIODIC  XY
*************************
* Part 2 - Array of cubicles
*************************
ARRAY   2 2 1
6 5 3 4
*
*************************
* Part 3 - +y side, empty cubicle, door closed
*************************
NEST  5
```

```
*      ORIGIN      x      y      z  MAT      param1 param2 param3
*  Vault
1  BOX ORIGIN      4      4      8   P7          24     12    100
*  Walls and door
2  BOX ORIGIN      0      0      8    3          32    24     100
*  Hallway
3  BOX ORIGIN      0      0      8    0          32     42    100
*  Floor
4  BOX ORIGIN      0      0      0    3          32     42    108
*  Top reflector
5  BOX ORIGIN      0      0      0    2          32     42    109
*
*************************
* Part 4 - +y side, empty cubicle, door closed
*************************
NEST  5
*      ORIGIN      x      y      z  MAT      param1 param2 param3
*  Vault
1  BOX ORIGIN      4      4      8   P7          24     12    100
*  Walls and door
2  BOX ORIGIN      0      0      8    3          32    24     100
*  Hallway
3  BOX ORIGIN      0      0      8    0          32     42    100
*  Floor
4  BOX ORIGIN      0      0      0    3          32     42    108
*  Top reflector
5  BOX ORIGIN      0      0      0    2          32     42    109
*
****************************
* Part 5 - -y side empty cubicle, doors closed
****************************
NEST  5
*      ORIGIN   x  y  z  ROTATE  x   y  z  theta  MAT
*  Vault
1  BOX ORIGIN  28 -4  8  ROTATE 90  90  0   180    P7
                                               24     12     100

*
*      ORIGIN      x      y      z  MAT      param1 param2 param3
*  Walls and door
2  BOX ORIGIN      0    -24      8    3          32    24     100
*  Hallway
3  BOX ORIGIN      0    -42      8    0          32     42    100
*  Floor
4  BOX ORIGIN      0    -42      0    3          32     42    108
*  Top reflector
5  BOX ORIGIN      0    -42      0    2          32     42    109
*
****************************
* Part 6 - -y side filled cubicle, doors closed
****************************
NEST  5
*      ORIGIN   x  y  z  ROTATE  x   y  z  theta  MAT
*  Vault
1  BOX ORIGIN  28 -4  8  ROTATE 90  90  0   180    P7
                                               24     12     100

*
*      ORIGIN      x      y      z  MAT      param1 param2 param3
*  Walls and door
2  BOX ORIGIN      0    -24      8    3          32    24     100
*  Hallway
```

```
3  BOX ORIGIN     0    -42     8    0          32     42    100
*  Floor
4  BOX ORIGIN     0    -42     0    3          32     42    108
*  Top reflector
5  BOX ORIGIN     0    -42     0    2          32     42    109
*
******************************
* Part 7 - vault interior, filled
******************************
ARRAY 2 2 17
*  Note that these are all "upside down" because
*  the array goes -x +x then -y +y
*  13 cans
    (8 8
     8 8)*2

   (10 11
     8 8

     8 8
    12 13)*3

    10 8
     8 8

     8 8
     8 8

    (8 8
     8 8)*6

     9 9
     9 9
*
******************************
* Part 8 - Empty block
******************************
NEST 1
*      MAT size -   x y z
1 BOX   0         12 6 6
*
*******************************
* Part 9 - Above columns
*******************************
NEST 1
1 BOX  0 12 6 4
*
******************************
* Part 10 - Can in -x, -y column
******************************
NEST 2
*
*      ORIGIN      x      y      z  MAT      param1 param2 param3
1 ZROD ORIGIN 1.9818 1.9818      0  1        1.7098 5.4368
2 BOX                               0            12      6      6
*
******************************
* Part 11 - Can in +x, -y column
******************************
NEST 2
*
*      ORIGIN      x      y      z  MAT      param1 param2 param3
1 ZROD ORIGIN 10.0182 1.9818     0  1        1.7098 5.4368
2 BOX                               0            12      6      6
*
******************************
* Part 12 - Can in -x, +y column
******************************
NEST 2
*
*      ORIGIN      x      y      z  MAT      param1 param2 param3
1 ZROD ORIGIN 1.9818 4.0182      0  1        1.7098 5.4368
2 BOX                               0            12      6      6
*
******************************
* Part 13 - Can in +x, +y column
******************************
NEST 2
*
*      ORIGIN      x      y      z  MAT      param1 param2 param3
1 ZROD ORIGIN 10.0182 4.0182     0  1        1.7098 5.4368
2 BOX                               0            12      6      6
*
*
********************
* UNIT 4
********************
*
* Superhistory option using 10 generation per superhistory
* and nu multiplication factor = 1.0
SUPERHIST  10  1.0
* First stage  Last stage  N per stage  time  Std dev.   Source
     -2           100         500          140   STDV .003     -1
*
* Starting source
MULTIFISS
STD
REGION 1 IN PART 3 /
REGION 1 IN PART 4 /
REGION 1 IN PART 5 /
REGION 1 IN PART 6 /
END
CODE 3
PWC
*  Top left corner     Top right corner   Bottom left corner
*  x      y      z      x      y     z      x      y      z
*  x-y plot. at extra can height
 -32    42     20     32    42    20    -32    -42     20
 -32    42     28     32    42    28    -32    -42     28
END
```

MONK6B input file cbatch2.inp

```
*
* File Name        :cbatch2.inp
```

```
* Description     :PFP Vault 4 cubicle
* Author          :Karl Hillesland
* Date            :Feb 10, 1997
*
* CSER 96-025, rev. 1
*
* Code           :Monk 6B
*****************************
* Inner cans moved towards corners at 45 degrees
*   overbatched can in second position from bottom, front row
*****************************
*
FISSION
******************************************************
*       MATERIAL DATA AND MAIN CONTROL DATA          *
******************************************************
* Material #     Material Name                Symbol *
*    1           Plutonium Oxide                P    *
*    2           Water                          W    *
*    3           Concrete                       C    *
******************************************************
* Number of Materials          Number of Nuclides
          3                           6
NUCNAMES
*
* PuO2 at 5.5 g Pu/cm3 with H2O mixed in (H/Pu = 2)
ATOM  6.65   PU239 1.0   HINH2O 2.0  O 3.0
*
* Water
ATOM  1.00       HINH2O  2.0   O  1.0
*
* Concrete from "Bulk Shield Design for Neutron Energies Below 50 MeV"
* L. L. Carter, Nuclear Technology/Fusion Vol. 3, March 1983
ATOM  2.258  HINH2O 0.0642  O 0.5916  SI 0.2405  CA 0.0738  FE 0.0299
*
INCHES
*
**************************
* Part 1 - Global
************************
NEST 2
*      ORIGIN      x      y       z  MAT         param1 param2 param3
1  BOX ORIGIN    -32    -42       0   P2          64     84     109
2  BOX ORIGIN    -32    -42       0    0          64     84     109
ALBEDO    1 1 0 1 1 0
PERIODIC  XY
************************
* Part 2 - Array of cubicles
************************
ARRAY   2 2 1
6 5 3 4
*
************************
* Part 3 - +y side, empty cubicle, door closed
************************
NEST  5
*      ORIGIN      x      y       z  MAT      param1 param2 param3
*  Vault
1  BOX ORIGIN      4      4       8  P16        24     12    100
*  Walls and door
```

```
2  BOX ORIGIN      0      0       8   3          32    24     100
*  Hallway
3  BOX ORIGIN      0      0       8   0          32     42    100
*  Floor
4  BOX ORIGIN      0      0       0   3          32     42    108
*  Top reflector
5  BOX ORIGIN      0      0       0   2          32     42    109
*
************************
* Part 4 - +y side, empty cubicle, door closed
************************
NEST  5
*      ORIGIN      x      y       z  MAT      param1 param2 param3
*  Vault
1  BOX ORIGIN      4      4       8   P7         24     12    100
*  Walls and door
2  BOX ORIGIN      0      0       8   3          32    24     100
*  Hallway
3  BOX ORIGIN      0      0       8   0          32     42    100
*  Floor
4  BOX ORIGIN      0      0       0   3          32     42    108
*  Top reflector
5  BOX ORIGIN      0      0       0   2          32     42    109
*
****************************
* Part 5 - -y side empty cubicle, doors closed
****************************
NEST  5
*      ORIGIN   x  y  z  ROTATE  x   y  z  theta  MAT
*  Vault
1  BOX ORIGIN  28 -4  8  ROTATE 90  90  0    180    P7
                                                 24     12     100
*
*      ORIGIN      x      y       z  MAT      param1 param2 param3
*  Walls and door
2  BOX ORIGIN      0    -24       8   3          32    24     100
*  Hallway
3  BOX ORIGIN      0    -42       8   0          32     42    100
*  Floor
4  BOX ORIGIN      0    -42       0   3          32     42    108
*  Top reflector
5  BOX ORIGIN      0    -42       0   2          32     42    109
*
****************************
* Part 6 - -y side filled cubicle, doors closed
****************************
NEST  5
*      ORIGIN   x  y  z  ROTATE  x   y  z  theta  MAT
*  Vault
1  BOX ORIGIN  28 -4  8  ROTATE 90  90  0    180    P7
                                                 24     12     100
*
*      ORIGIN      x      y       z  MAT      param1 param2 param3
*  Walls and door
2  BOX ORIGIN      0    -24       8   3          32    24     100
*  Hallway
3  BOX ORIGIN      0    -42       8   0          32     42    100
*  Floor
4  BOX ORIGIN      0    -42       0   3          32     42    108
*  Top reflector
```

```
5  BOX ORIGIN      0    -42      0    2          32      42   109
*
*****************************
* Part 7 - vault interior, filled
*****************************
ARRAY 2 2 17
*  Note that these are all "upside down" because
*  the array goes -x +x then -y +y
*  13 cans
    (8 8
     8 8)*2

    10 11
     8 8

     8 8
    12 13

    10 11
     8 8

     8 8
    12 13

    10 11
     8 8

     8 8
    12 13

    10 8
     8 8

     8 8
     8 8

    (8 8
     8 8)*6

     9 9
     9 9
*
*****************************
* Part 8 - Empty block
*****************************
NEST 1
*       MAT size -   x y z
1 BOX   0          12 6 6
*
*****************************
* Part 9 - Above columns
*****************************
NEST 1
1 BOX  0 12 6 4
*
*****************************
* Part 10 - Can in -x, -y column
*****************************
NEST 2
*
```

```
*       ORIGIN      x       y        z  MAT       param1 param2 param3
1 ZROD ORIGIN 1.9818 1.9818         0  1         1.7098 5.4368
2 BOX                                  0            12      6      6
*
*****************************
* Part 11 - Can in +x, -y column
*****************************
NEST 2
*
*       ORIGIN      x       y        z  MAT       param1 param2 param3
1 ZROD ORIGIN 10.0182 1.9818        0  1         1.7098 5.4368
2 BOX                                  0            12      6      6
*
*****************************
* Part 12 - Can in -x, +y column
*****************************
NEST 2
*
*       ORIGIN      x       y        z  MAT       param1 param2 param3
1 ZROD ORIGIN 1.9818 4.0182         0  1         1.7098 5.4368
2 BOX                                  0            12      6      6
*
*****************************
* Part 13 - Can in +x, +y column
*****************************
NEST 2
*
*       ORIGIN      x       y        z  MAT       param1 param2 param3
1 ZROD ORIGIN 10.0182 4.0182        0  1         1.7098 5.4368
2 BOX                                  0            12      6      6
*
*****************************
* Part 14 - Can in -x, +y column, bottom of overbatched can
*****************************
NEST 2
*
*       ORIGIN      x       y        z  MAT       param1 param2 param3
1 ZROD ORIGIN 1.9818 4.0182         0  1         1.7098      6
2 BOX                                  0            12      6      6
*
*
*****************************
* Part 15 - Can in -x, +y column, top of overbatched can
*****************************
NEST 2
*
*       ORIGIN      x       y        z  MAT       param1 param2 param3
1 ZROD ORIGIN 1.9818 4.0182         0  1         1.7098  1.982
2 BOX                                  0            12      6      6
*
*****************************
* Part 16 - vault interior, filled
*****************************
ARRAY 2 2 17
*  Note that these are all "upside down" because
*  the array goes -x +x then -y +y
*  13 cans
    (8 8
     8 8)*2
```

```
    10 11
     8 8

     8 8
    12 13

    10 11
     8 8

     8 8
    14 13

    10 11
    15 8

     8 8
    12 13

    10 8
     8 8

     8 8
     8 8

    (8 8
     8 8)*6

     9 9
     9 9
*
*******************
* UNIT 4
*******************
*
* Superhistory option using 10 generation per superhistory
* and nu multiplication factor = 1.0
SUPERHIST  10  1.0
* First stage  Last stage  N per stage  time  Std dev.   Source
    -2          100        500         140   STDV .003     -1
*
* Starting source
MULTIFISS
STD
REGION 1 IN PART 3 /
REGION 1 IN PART 4 /
REGION 1 IN PART 5 /
REGION 1 IN PART 6 /
REGION 1 IN PART 14 /
REGION 1 IN PART 15 /
END
CODE 3
PWC
*  Top left corner     Top right corner   Bottom left corner
*  x     y      z      x     y      z      x     y      z
*  x-y plot. at extra can height
 -32    42     20     32    42     20    -32   -42     20
 -32    42     28     32    42     28    -32   -42     28
END
```

MONK6B input file owag.inp

```
*
* File Name        :owagon.inp
* Description      :PFP Vault 4 cubicle
* Author           :Karl Hillesland
* Date             :Nov 22, 1996
*
* CSER 96-025
*
* Code            :Monk 6B
*****************************
* Can level with center can in back column, no person, doors open
*****************************
*
FISSION
*******************************************************
*        MATERIAL DATA AND MAIN CONTROL DATA          *
*******************************************************
* Material #      Material Name                Symbol *
*    1            Plutonium Oxide                P    *
*    2            Water                          W    *
*    3            Concrete                       C    *
*******************************************************
* Number of Materials         Number of Nuclides
       3                              6
NUCNAMES
*
* PuO2 at 5 g Pu/cm3 with H2O mixed in (H/Pu = 2)
ATOM  6.65   PU239 1.0   HINH2O 2.0  O 3.0
*
* Water
ATOM  1.00       HINH2O  2.0   O  1.0
*
* Concrete from "Bulk Shield Design for Neutron Energies Below 50 MeV"
* L. L. Carter, Nuclear Technology/Fusion Vol. 3, March 1983
ATOM  2.258  HINH2O 0.0642  O 0.5916  SI 0.2405  CA 0.0738  FE 0.0299
*
INCHES
*
**************************
* Part 1 - Global
*************************
NEST 2
*      ORIGIN      x       y       z  MAT         param1 param2 param3
1  BOX ORIGIN    -32     -42      0   P2           64     84     109
2  BOX ORIGIN    -32     -42      0    0           64     84     109
ALBEDO    1 1 0 1 1 0
PERIODIC  XY
*************************
* Part 2 - Array of cubicles
*************************
ARRAY   2 2 1
6 5 3 4
*
*************************
* Part 3 - +y side. empty cubicle. door closed
*************************
NEST  5
```

```
*      ORIGIN      x      y      z  MAT      param1 param2 param3
*  Vault
1  BOX ORIGIN     4      4      8    0          24     12    100
*  Walls and door
2  BOX ORIGIN     0      0      8    3          32    24     100
*  Hallway
3  BOX ORIGIN     0      0      8    0          32     42    100
*  Floor
4  BOX ORIGIN     0      0      0    3          32     42    108
*  Top reflector
5  BOX ORIGIN     0      0      0    2          32     42    109
*
*************************
* Part 4 - +y side, full cubicle, door open
*************************
CLUSTER 8
*      ORIGIN      x      y      z  MAT          param1 param2 param3
*  Vault
1  BOX ORIGIN     4      4      8   P14          24     12      100
*  -y Wall
2  BOX ORIGIN     0      0      8    3           32      4      100
*  -x Wall
3  BOX ORIGIN     0      4      8    3            4     20      100
*  +x Wall
4  BOX ORIGIN    28      4      8    3            4     20      100
*  Floor
5  BOX ORIGIN     0      0      0    3           32     42        8
*  Top Water Reflector
6  BOX ORIGIN     0      0    108    2           32     42        1
*  Wagon
7  BOX ORIGIN     4     16     26   P17          18     19.5      6
*  Total
8  BOX ORIGIN     0      0      0    0           32     42      109
*
****************************
* Part 5 - -y side empty cubicle, doors closed
****************************
NEST  5
*      ORIGIN   x  y  z  ROTATE  x    y  z  theta  MAT
*  Vault
1  BOX ORIGIN  28 -4  8  ROTATE 90   90  0    180    0
                                             24       12     100
*
*      ORIGIN      x      y      z  MAT      param1 param2 param3
*  Walls and door
2  BOX ORIGIN     0    -24      8    3          32    24     100
*  Hallway
3  BOX ORIGIN     0    -42      8    0          32     42    100
*  Floor
4  BOX ORIGIN     0    -42      0    3          32     42    108
*  Top reflector
5  BOX ORIGIN     0    -42      0    2          32     42    109
*
****************************
* Part 6 - -y side filled cubicle, doors closed
****************************
NEST  5
*      ORIGIN   x  y  z  ROTATE  x    y  z  theta  MAT
*  Vault
1  BOX ORIGIN  28 -4  8  ROTATE 90   90  0    180    P7
```

```
                                                 24       12     100
*
*      ORIGIN      x      y      z  MAT      param1 param2 param3
*  Walls and door
2  BOX ORIGIN     0    -24      8    3          32    24     100
*  Hallway
3  BOX ORIGIN     0    -42      8    0          32     42    100
*  Floor
4  BOX ORIGIN     0    -42      0    3          32     42    108
*  Top reflector
5  BOX ORIGIN     0    -42      0    2          32     42    109
*
*****************************
* Part 7 - vault interior, filled
*****************************
ARRAY 2 2 17
*  Note that these are all "upside down" because
*  the array goes -x +x then -y +y
   (8 8
    8 8)*2

  (10 11
    8 8

    8 8
   12 13)*7

    9 9
    9 9
*
*****************************
* Part 8 - Empty block
*****************************
NEST 1
*      MAT size -  x y z
1 BOX   0         12 6 6
*
*****************************
* Part 9 - Above columns
*****************************
NEST 1
1 BOX  0 12 6 4
*
*****************************
* Part 10 - Can centered in -x, -y column
*****************************
NEST 2
*
*      ORIGIN       x       y       z  MAT      param1 param2 param3
1 ZROD ORIGIN   2.25    2.25      0  1        1.7098 5.4368
2 BOX                                 0            12      6      6
*
*****************************
* Part 11 - Can centered in +x, -y column
*****************************
NEST 2
*
*      ORIGIN       x       y       z  MAT      param1 param2 param3
1 ZROD ORIGIN   9.75    2.25      0  1        1.7098 5.4368
2 BOX                                 0            12      6      6
```

```
*
******************************
* Part 12 - Can centered in -x, +y column
******************************
NEST 2
*
*      ORIGIN      x      y       z  MAT      param1 param2 param3
1 ZROD ORIGIN   2.25   3.75      0  1        1.7098 5.4368
2 BOX                               0            12      6      6
*
******************************
* Part 13 - Can centered in +x, +y column
******************************
NEST 2
*
*      ORIGIN      x      y       z  MAT      param1 param2 param3
1 ZROD ORIGIN   9.75   3.75      0  1        1.7098 5.4368
2 BOX                               0            12      6      6
*
******************************
* Part 14 - vault interior, filled
******************************
ARRAY 2 2 17
*  Note that these are all "upside down" because
*  the array goes -x +x then -y +y
    (8 8
     8 8)*2

   (10 11
     8 8

     8 8
    12 13)*3

    15 11
    16 8

     8 8
    12 13

   (10 11
     8 8

     8 8
    12 13)*3

     9 9
     9 9
*
******************************
* Part 15 - Can centered in -x, -y column, with extra can level
******************************
CLUSTER 3
*
*      ORIGIN      x      y       z  MAT      param1 param2 param3
1 ZROD ORIGIN 2.4285 2.5846      0  1        1.7098 5.4368
2 ZROD ORIGIN 4.0715 5.6654      0  1        1.7098 5.4368
  OVERLAP  1   3   1
3 BOX                               0            12      6      6
  OVERLAP  1   2   2
```

```
*
******************************
* Part 16 - Empty space, with extra can added
******************************
CLUSTER 2
*
*      ORIGIN      x       y       z  MAT      param1 param2 param3
1 ZROD ORIGIN 4.0715  -0.3346     0  1        1.7098 5.4368
  OVERLAP  1  2  1
2 BOX                                0            12      6      6
  OVERLAP  1  1  2
*
*******************************
* Part 17 - Fixed Array Wagon
*******************************
ARRAY  2 3 1
(18)*6
********************************
* Part 18 - A can in the wagon
********************************
NEST 2
*      ORIGIN      x      y       z  MAT      param1 param2 param3
1 ZROD ORIGIN      4     4.5      0  1        1.7098 5.4368
2 BOX                                0             9    6.5      6
*
*******************
* UNIT 4
*******************
*
* Superhistory option using 10 generation per superhistory
* and nu multiplication factor = 1.0
SUPERHIST  10  1.0
* First stage  Last stage  N per stage  time  Std dev.   Source
     -2          100        1000          240   STDV .003     -1
*
* Starting source
MULTIFISS
STD
REGION 1 IN PART 4 /
REGION 1 IN PART 6 /
REGION 1 IN PART 15 /
REGION 2 IN PART 15 /
REGION 1 IN PART 16 /
REGION 7 IN PART 4 /
END
CODE 3
PWC
*  Top left corner      Top right corner    Bottom left corner
*  x      y      z      x      y      z      x      y      z
*  x-y plot, at extra can height
 -32     42     58     32     42     58    -32    -42     58
 -32     42     28     32     42     28    -32    -42     28
END
```

9/4/97

DISTRIBUTION SHEET

To Distribution	**From** Criticality and Shielding	**Page** 1 **of** ~~47~~ ~~48~~ 1 KN ~~KEH~~ 8/27/97 **Date** 6/26/97
Project Title/Work Order Addendum 1 to CSER 96-025: PFP Storage of 9.25/9.5 inch Tall, 4.4 kg Pu Cans on Existing Vault 4 Pedestals		**EDT No.** 621288 **ECN No.** N/A

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