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CRITICALITY SAFETY EVALUATION FOR K BASINS SANDFILTERS

by

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ABSTRACT

This criticality safety evaluation concludes that K Basins sandfilters operation does not require the presence of a criticality alarm system (CAS) due to the physical form and isotopic distribution of the fissionable material contained in it.

The K Basins sandfilters are used to filter water skimmed from the basin water surface. Particulates and contaminants are mechanically captured in the sandfilter medium (sand). As the particulates accumulate, the pressure drop across the sandfilter increases, requiring periodic backwashes into the sandfilter backwash pit to permit continued operation. In practice, addition of material is limited to approximately a three months (normal) or six months (maximum) accumulation, then a periodic backwash would be performed. Criticality of the sandfilter backwash pit is considered in a separate CSER (Erickson 1994).

NCNP-4.2, a three-dimensional Monte Carlo code that is standard for criticality calculations, was used for this criticality evaluation of the sandfilter.

Contingencies considered for normal and off-normal sandfilter operation included addition of fissile material, change of moderation, uranium-plutonium segregation, and heterogeneous distribution of fissile material. Parametric studies of unrealistic situations calculated extreme accumulation of fissile material, heterogeneous distribution of fissile material and loss of neutron absorbers.

No realistic normal or off-normal scenarios were determined which could compromise criticality safety and result in a $k_{eff} \geq 0.98$. The conclusion is that, due to the physical form and isotopic distribution of the fissionable material, there is no possibility of a nuclear criticality in the sandfilter. For this reason, there is no need for criticality alarm systems for K Basins sandfilters.

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1.0 INTRODUCTION

The purpose of this evaluation is to verify operation of K Basins sandfilters does not require the presence of an operational criticality alarm system (CAS).

The sandfilter k_{eff} 's were calculated for three normal or off-normals:

- Addition of Material - homogeneously distributed in sandfilter medium
- Moderation - sandfilter dryout with fixed fissile inventory
- Uranium, Plutonium Heterogeneity - thin layer on sand filter media top

The sandfilter reactivity was calculated for five parametric studies:

- Plutonium Segregation - $PuO_2 + H_2O$ distributed in sandfilter medium
- Moderation - sandfilter dryout with fixed fissile inventory
- Plutonium Heterogeneity - thin layer on sand filter media top
- Loss of Neutron Absorbers - 0.947 wt% ^{235}U uranium considered
- Loss of Neutron Absorbers - 1.250 wt% ^{235}U uranium considered

The analysis is based on conservative assumptions regarding material composition and quantity. The analyzed composition of the sand in the sandfilter was combined with the measured uranium and plutonium isotopic composition in the criticality calculations. The sandfilter contains other constituents including fission products, activation products, and corrosion products from the stored spent fuel and other materials in the basin for which no credit was taken. The presence of these other constituents in the analysis would provide an additional safety margin. In addition to ignoring the presence of these other materials, parametric studies considered plutonium separated from uranium, and unexposed uranium, both 0.947 and 1.250 wt% ^{235}U , in the sandfilter medium.

2.0 DESCRIPTION OF SYSTEM AND FACILITY

2.1 K BASINS SANDFILTERS

The K Basins sandfilters are used to filter contaminants from the basin water. Basin water is skimmed from the surface of the basin and pumped through the sandfilter. Particulates in the water from different sources, including corroded fuel, are mechanically captured in the sandfilter matrix. As the particulates accumulate, the pressure drop across the sandfilter increases, requiring periodic backwashing to remove these particulates and permit continued operation. The backwash water is pumped into the sandfilter backwash pit. The criticality of the sandfilter backwash pit is covered in a separate report (Erickson 1994).

The sandfilter (Figure 1) is approximately 241.3 cm (95 in.) high, and 198.12 cm (78 in.) outside diameter (Baker Filtration Co. Drawing 950-011 Rev. B). The sandfilter is neutronically isolated from the rest of the basin by 30.48 cm (12 in.) concrete walls and a 15.24 cm (6 in.) concrete roof and

Figure 1. Sand Filter Dimensions

Figure 1. Sandfilter Dimensions

**NOTE: Top View Is
Rotated From Side View**

Taken From:
Baker Filtration Co.
Drawing #950-011
Revision B

concrete floor slab (Drawings H-1-34595 and H-1-34596). The MCNP model of the sandfilter (Figure 2) was modified to use MCNP surface definitions, this means that the top and bottom of the sandfilter tank were modeled as ellipsoids.

2.2 100K BASIN SANDFILTER MEDIUM

The sandfilter medium is lapis lustre dried sands which is mostly SiO_2 with some Al_2O_3 and other oxides present. See Appendix B for material details. The specific gravity of this crystal is 2.61 g/cm^3 , yet in sand form, the density is approximately 1.61 g/cm^3 (100 lbs/ft^3). The difference between these two densities for the analysis was assumed to be the void fraction which can be filled with H_2O and UO_2 or PuO_2 . This void fraction is $(1.00 - (1.61/2.61)) = 0.383$.

The filling of the bottom of the sandfilter is with 1062 L (37.5 ft^3) of concrete, while the sand medium fills the sandfilter tank from there up to measured levels (see Appendix C).

3.0 REQUIREMENTS DOCUMENTATION

There are no unique requirements applicable to this evaluation

4.0 METHODOLOGY

MCNP-4.2 (Briesmeister 1990, Carter 1994, LANL 1986) was used for this evaluation. This code is under configuration control and has been tested extensively with experimental data of homogeneous low-enriched uranium oxide-water systems. The code consistently reproduced the measured data. The computed results are within the uncertainties of the experimental points. The validation is found in WHC-SD-NR-CSER-001 (Wittekind 1992).

MCNP-4.2 is a Monte Carlo code, using continuous energy group ENDF/B-V cross sections.

MCNP was used for k_{eff} calculations of the sandfilter medium with UO_2 and/or PuO_2 present. MCNP was used to calculate k_{eff} for an explicit representation of the sandfilter using different UO_2 and PuO_2 compositions. Figure 1 shows the sandfilter geometry as described by the manufacturer, and in relation to surrounding structures as installed in the K Basins. Figure 2 shows the MCNP model of the sandfilter. One difference is that the rounded top and rounded bottom were modeled as ellipsoids, but an effort was made to conserve volumes. Another difference is that the five-sided concrete enclosure is modeled as the simpler four-sided concrete enclosure.

MCNP calculations were performed on a WHC SGI workstation in the Science and Engineering Computational Center (SECC). MCNP-4.2 is code configuration controlled on the workstations of the SECC.

5.0 DISCUSSION OF CONTINGENCIES

Geometry - The geometry of the sandfilter tank was assumed to be unchanged. The tank is 0.635 cm (1/4 in.) thick, and is surrounded by 30.48 cm (1 ft) of concrete on five sides, the roof is only 15.24 cm (6 in.) thick concrete. No change in the location of the concrete walls or shape of the sandfilter tank were postulated. Beyond design basis accidents, such as a crane drop of a heavy weight, which compromise sandfilter integrity were not calculated. Any compromise of integrity would disperse the sandfilter medium, increasing neutron leakage and decreasing the reactivity. The sandfilter has 1062 L (37.5 ft³) of concrete in the bottom, and then is filled with lapis lustre dried sands to measured levels (Appendix C). Geometry of the fissile material was varied from homogeneous in the sandfilter medium to concentrated in a thin layer on the top of the sandfilter medium. Different neutron reflectors outside the sandfilter tank are shown to have no significant effect on MCNP calculated k_{eff} .

Moderation - The models employed in this evaluation used a range of moderation in order to determine optimum moderation and maximum reactivity. Non-optimal moderation conditions required more fissile material to become more reactive. Different moderations were achieved by (1) dryout, that is removing H₂O for a fixed UO₂ and PuO₂ inventory, and (2) adding UO₂ and PuO₂ which displaced H₂O in the fixed volume void between the sand grains.

Uranium-Plutonium Separation - There is no known mechanism in the basin or the sandfilter that could be separating the uranium from the plutonium in the sandfilter, or in the KE or KW basin. The wide range of different uranium to plutonium (U/Pu) weight ratios, e.g., U/Pu = 100, 200, 300, 400 and 500, were calculated to cover gross uncertainties in analytical chemistry measurements. The expected U/Pu ratio (Appendices G, H, and I) is approximately 455. The U/Pu = 0 ratio is not considered credible, as it represents the extreme when all uranium has been separated from plutonium, and was only considered in parametric study calculations.

Addition of material - The sandfilter continually removes particulates from the basin water, so addition of material is routine. The results presented in the analysis include the time to accumulate this quantity of fissile material, uranium oxide with plutonium oxide together or separately. This addition of material is calculated as if periodic backflushes to remove the particulates were not performed. In practice, addition of material is limited to approximately a three months (normal) or six months (maximum) accumulation, after which a periodic backwash would be performed.

Loss of neutron absorbers - Neutron absorption in the stainless steel tank and sand in the sandfilter medium was included in the analysis. The loss of the sand medium or disappearance of the stainless steel tank were not considered credible and therefore are not a contingency. Loss of neutron absorption was considered by decreasing the U/Pu ratio.

The normal cases considered will include addition of material, since this is the normal mode of operation, and limited uranium-plutonium separation because of uncertainties in reported analytical chemistry measurements. The off-normal cases will be sandfilter dryout, and fissile material heterogeneity in the sandfilter medium both of which include the effect of moderation

change. The loss of neutron absorbers to the ratio of $U/Pu = 0$, and unirradiated uranium, both 0.947 wt% ^{235}U and 1.250 wt% ^{235}U are considered so unlikely that these calculations are in the category of parametric studies of what is required in order to violate the criticality safety limit of $k_{eff} \leq 0.98$.

6.0 EVALUATION AND RESULTS

5.1 ACCUMULATION OF FISSILE ISOTOPES

The concentration of fissile isotopes in KE and KW basin water is measured and reported in $^{239/240}Pu$ $\mu Ci/L$. The plutonium (and uranium) isotope ratios and the uranium to plutonium ratio are both needed to convert this reported activity to grams of fissile isotopes. The plutonium and uranium isotope ratios were also measured, so this plutonium activity can be converted to grams of plutonium and grams of uranium.

Table 1 shows the uranium and plutonium isotope ratios for the KE basin measured by PNL in 1993. These isotope ratios, as shown in Appendix J, are used to convert the $^{239/240}Pu$ activity into grams of plutonium per liter.

Table 1. Uranium and Plutonium Isotopic Analysis Results.

Uranium		Plutonium	
Isotope	Mass%	Isotope	Mass%
U^{234}	0.007	Pu^{238}	0.075
U^{235}	0.694	Pu^{239}	86.010
U^{236}	0.079	Pu^{240}	12.599
U^{238}	99.220	Pu^{241}	1.101
		Pu^{242}	0.216

ORIGEN2 calculations (Appendices G, H, and I; and Hedengren 1987) for N Reactor MKIV fuel at 12 wt% ^{240}Pu exposure are consistent with these isotope ratios. The U/Pu ratio calculated in Appendix G from ORIGEN2 results (12 wt% ^{240}Pu and 20 to 25 years decay) is around 455. Most of the fuel now stored in the KE basin is known to consist of high exposure MKIV fuel assemblies with approximately 12 wt% ^{240}Pu .

The sandfilter flow rate varies between a maximum of 400 gpm and a minimum of 300 gpm. The $^{239/240}Pu$ activity at the sandfilter inlet ($1.55E-2$ $\mu Ci/L$) and outlet ($6.77E-3$ $\mu Ci/L$) was reported and is included as Appendix D. The average removal efficiency is: $[1 - (6.77E-3 \mu Ci/L / 1.55E-2 \mu Ci/L)] \times 100\% = 56.3$ percent. The removal in pCi/L is: $(1.55E-2 \mu Ci/L - 6.77E-3 \mu Ci/L) \times 1E6 pCi/\mu Ci = 8.73E+3 pCi/L$.

The maximum nominal plutonium accumulation rate is $8.73E+3 pCi/L / 8.197E+10 pCi (^{239}Pu + ^{240}Pu) / g Pu \times 400 gpm \times (231 in^3/gal \times (2.54 cm/in)^3 \times 1E-3 L/cm^3) \times (60 m/h \times 24 h/d \times 365.25 d/yr) = 84.82 g Pu/yr = 0.08482 kg Pu/yr$.

Conservatively, a sandfilter removal efficiency of 100% was assumed and the KE basin water concentration of $1.09E+4 pCi/L$ (measurement of 5/29/92) was used. Using 86.010 wt% ^{239}Pu and 12.599 wt% ^{240}Pu (PNL measurements in 1993),

an activity of $8.197\text{E}+10$ pCi ($^{239}\text{Pu}+^{240}\text{Pu}$)/g Pu, calculates to a concentration of $0.133\text{E}-6$ g Pu/L as shown in Appendix J. Conservatively, this was rounded up to $0.150\text{E}-6$ g Pu/L which converts to 0.119 kg Pu/yr accumulation rate. The time to accumulate UO_2 and PuO_2 is tabulated according to the 0.119 kg Pu/yr accumulation rate in the KE basin. Plutonium concentrations in the KW basin is from one to three orders of magnitude lower than the KE basin. Therefore the 0.119 kg Pu/yr accumulation rate is conservative for both basins.

6.2 NORMAL SITUATION

For this analysis of the sandfilter several conservative assumptions were made about the materials in the sandfilter.

- Only uranium (UO_2), and/or plutonium (PuO_2), are present in the water saturated sandfilter medium. Fission products, activation products, iron or aluminum from basin canisters, and other neutron absorbing materials are not included in the MCNP model.
- The density of the mixtures in the sandfilter is given in many of the following tables. It is the average density of the sand, water, UO_2 , and PuO_2 . The density for the mixtures increased from 1.988 g/cm³ (sand and water only) to > 4.8 g/cm³ as UO_2 and/or PuO_2 replaced water in the voids of the sand grains.
- The hydrogen to uranium (H/U) and hydrogen to plutonium (H/Pu) atom ratios were varied over a wide range of values and included the optimum moderation where the k_{eff} reached a maximum for a fixed quantity of fissile isotopes.
- U/Pu weight ratios of 100, 200, 300, 400, and 500 were considered. Measured values of the U/Pu ratio are in excess of 300 and the expected U/Pu ratio (Appendices G, H, and I) is approximately 455.

This analysis used the measured isotopic concentrations with different U/Pu proportions. UO_2 - PuO_2 - H_2O -sand mixtures for a wide range of H/(U+Pu) ratios were calculated.

Normal situation material accumulation considered the sandfilter modeled with sand, H_2O and different proportions of UO_2 and PuO_2 . The UO_2 and PuO_2 concentration are increased to search for a reactivity increase as a function of the quantity of fissile material. Because of the limited void space in the sand, the H/U atom ratio is changed as the water is displaced. Normal situation calculations considered neutron reflection effects of water and concrete around the sandfilter as well as neutron absorption effects of the steel sandfilter tank.

The off-normal conditions considered dryout, where the sand medium loses water. The off-normal conditions also considered heterogeneous geometry where fissile material is varied from homogeneous distribution to a thin layer at the top of the sandfilter medium.

Parametric studies used a U/Pu ratio of zero where the irradiated plutonium separated from uranium, and unirradiated uranium, MKIV 0.947 wt%

^{235}U and MKIA outer 1.250 wt% ^{235}U as the fissile material. These cases are not realistic or possible, but were calculated to see what was necessary for $k_{\text{eff}} \geq 0.98$.

Table 2 shows MCNP calculations for the normal situation as a function of H/(U+Pu) atom ratio and U/Pu weight ratio at the measured isotope ratios. In addition to the k_{eff} values, the dependent variables are the sandfilter mixture density, the mass of plutonium in the sandfilter, and the time required for this plutonium to accumulate. This total accumulation time is the time without a sandfilter backwash and conservatively using 0.150E-6 g Pu/L at an average 400 gpm that is captured uniformly throughout the sandfilter medium. ORIGEN2 calculations are consistent with U/Pu weight ratio of 455. The U/Pu weight ratios of 100, 200, 300, 400, and 500 were employed for conservative MCNP calculations (highest k_{eff}).

Table 2 MCNP k_{eff} calculations made with KE basin measured uranium and plutonium isotope ratios show that the sandfilter does not compromise criticality safety ($k_{\text{eff}} \geq 0.98$), even with continuous accumulation of uranium and plutonium over much longer times than backwashes would be performed and the UO_2 and PuO_2 would be washed into the sandfilter backwash pit. In practice, addition of material is limited to approximately a three months (normal) or six months (maximum) accumulation, after which a periodic backwash would be performed. Even when the U/Pu ratio is 100 (unrealistically low, U/Pu = 455 is expected) and the time without sandfilter backwashes exceeds 200 years, greater than facility life, the k_{eff} remains below the criticality safety limit of $k_{\text{eff}} \leq 0.98$.

The effect of the five-sided concrete structure being modeled as a standard four-sided concrete structure is next considered with MCNP calculations. Table 3 results demonstrate that the concrete reflector is not significant. The cylinder cases have 30.48 cm (1 ft.) of concrete in a cylinder around the sand filter with the area around the sandfilter equal to the four-sided MCNP model, the five-sided physical situation, and some extreme models on both sides of these two cases. One case of no concrete walls present does indicate the reflection effect of the 30.48 cm (1 ft.) concrete. The cases of flooding the concrete enclosure with water, or even filling it with concrete are both included in Table 3.

Using the case of the cylindrical model of the four-sided MCNP model, consider how many calculations fall within one, two and three standard deviations of this specific case: $0.9380 \pm (0.9380 \times 0.0022) = 0.9380 \pm 0.0021$. The one standard deviation range, or k_{eff} , from 0.9401 to 0.9359 includes 4 of the 7 other different concrete configurations. Statistically, we would expect 5 out of 7 (68.26%) within one standard deviation. The two standard deviation range, or k_{eff} , from 0.9422 to 0.9338 includes 7 of the 7 other different concrete configurations. Statistically, we would expect 7 out of 7 (95.46%) within two standard deviations. This exercise demonstrates that the location of the 30.48 cm (1 ft.) concrete wall is not significant, and that the four-sided MCNP model of the five-sided physical situation concrete wall is reasonable and satisfactory.

Table 2. MCNP k_{eff} Calculations for UO_2 and PuO_2 in Sandfilter
Sand Voids Homogeneously Filled With UO_2 - PuO_2 - H_2O

H (U+Pu)	Density g/cm ³	$k_{eff} \pm \sigma/k_{eff}$ *	Sand Filter Plutonium, kg	Accumulation Time**,yr	U/Pu***
0	5.835	0.4486 ± 0.0032	106.	891.	100
5	3.350	0.9354 ± 0.0024	37.7	315.	100
10	2.816	0.9380 ± 0.0021	22.9	192.	100
25	2.368	0.7778 ± 0.0018	10.5	88.0	100
200	2.040	0.2152 ± 0.0018	1.44	12.0	100
1,000	1.999	0.0500 ± 0.0017	0.291	2.44	100
10,000	1.989	0.0052 ± 0.0020	0.0292	0.244	100
0	5.835	0.4038 ± 0.0031	53.5	447.7	200
5	3.350	0.8471 ± 0.0024	18.9	158.5	200
10	2.815	0.8113 ± 0.0021	11.5	96.3	200
25	2.368	0.6201 ± 0.0018	5.28	44.2	200
200	2.040	0.1497 ± 0.0018	0.723	6.05	200
1,000	1.999	0.0336 ± 0.0017	0.146	1.22	200
10,000	1.989	0.0035 ± 0.0020	0.0147	0.123	200
0	5.835	0.3869 ± 0.0034	35.7	299.	300
5	3.350	0.8025 ± 0.0024	12.6	106.	300
10	2.815	0.7444 ± 0.0024	7.68	64.3	300
25	2.368	0.5500 ± 0.0020	3.53	29.5	300
200	2.040	0.1259 ± 0.0018	0.483	4.040	300
1,000	1.999	0.0279 ± 0.0020	0.976	0.817	300
10,000	1.989	0.0029 ± 0.0016	0.00978	0.0819	300
0	5.835	0.3742 ± 0.0035	26.8	224.	400
5	3.350	0.7677 ± 0.0025	9.49	79.4	400
10	2.815	0.7067 ± 0.0021	5.76	48.3	400
25	2.368	0.5102 ± 0.0021	2.65	22.2	400
200	2.040	0.1136 ± 0.0019	0.362	3.03	400
1,000	1.999	0.0252 ± 0.0019	0.0732	0.613	400
10,000	1.989	0.0026 ± 0.0018	0.00734	0.0615	400
0	5.835	0.3675 ± 0.0036	21.5	179.	500
5	3.350	0.7487 ± 0.0021	7.60	63.6	500
10	2.815	0.6798 ± 0.0025	4.61	38.6	500
25	2.368	0.4880 ± 0.0019	2.12	17.7	500
200	2.040	0.1062 ± 0.0019	0.290	2.43	500
1,000	1.999	0.0235 ± 0.0017	0.0586	0.491	500
10,000	1.989	0.0024 ± 0.0017	0.00588	0.0492	500

*The MCNP code presents the statistical uncertainty of its results as σ/k_{eff} .
The standard deviation of k_{eff} , σ , is calculated as in following example:

$$0.7677 \pm (0.7677 \times 0.0025) = 0.7677 \pm 0.0019$$

**Conservatively, the 0.119 kg Pu/yr accumulation rate was used.

In practice, material addition is limited to three months (normal),
six months (maximum) accumulation.

***The expected U/Pu ratio (Appendices G, H, and I) is approximately 455.

Table 3. MCNP k_{eff} Calculations for Sandfilter Concrete Reflection
 Variation of Concrete Wall Neutron Reflector
 Sand Voids Homogeneously Filled With UO_2 - PuO_2 - H_2O , No Dryout
 Sand Filter Plutonium 22.9 kg, Accumulation Time 192. yr,
 $H/(U+Pu)=10$, $U/Pu=100$,
 Average Density of Sand Filter Contents 2.816 g/cm^3 (sand, H_2O , UO_2 , PuO_2)

$k_{eff} \pm \sigma/k_{eff}$	Situation
0.9380 ± 0.0022	Four-sided configuration base case
0.9381 ± 0.0023	Cylinder = base case air space
0.9392 ± 0.0022	Cylinder = Five-sided configuration air space
0.9357 ± 0.0023	Cylinder = 4/3 air space of base case
0.9350 ± 0.0022	Cylinder = 5/3 air space of base case
0.9408 ± 0.0022	Cylinder = 2/3 air space of base case
0.9399 ± 0.0018	Cylinder = 1/3 air space of base case
0.9397 ± 0.0022	Cylinder = 0/3 air space of base case
0.9406 ± 0.0020	Base case + Water fills air space
0.9384 ± 0.0023	Base case + Concrete fills air space
0.9381 ± 0.0022	Base case and air replaced concrete walls

The four-sided MCNP model of the five-sided physical situation 30.48 cm (1 ft.) concrete wall has very little discernable effect on the calculated k_{eff} . Also, filling the air space with water or concrete or removing the concrete walls altogether has little, if any, discernable effect on MCNP calculated k_{eff} of this large 196.85 cm (77.5 in.) diameter sandfilter.

Table 4 calculates the effect of the steel sandfilter tank in absorbing neutrons and reducing the neutron reflection of 30.48 cm (1 ft.) concrete.

Table 4. MCNP k_{eff} Calculations for Sandfilter Without Stainless Steel
 Air Replaces Stainless Steel Sandfilter Tank
 Sand Voids Homogeneously Filled With UO_2 - PuO_2 - H_2O , No Dryout
 Sandfilter Plutonium 22.9 kg, Accumulation Time 192 yr,
 $U/Pu=100$, $H/(U+Pu)=10$
 Average Density of Sand Filter Contents 2.816 g/cm^3 (sand, H_2O , UO_2 , PuO_2)

$k_{eff} \pm \sigma/k_{eff}$	Situation
0.9380 ± 0.0022	Four-sided configuration base case
0.9366 ± 0.0020	Base case, Air replace SS 316 tank
0.9406 ± 0.0020	Base case + Water fills air space
0.9371 ± 0.0022	Water fills Air space, Air replace SS316
0.9384 ± 0.0023	Base case + Concrete fills air space
0.9426 ± 0.0019	Concrete in Air space, Air replace SS316
0.9381 ± 0.0022	Base case and air replaced concrete walls
0.9310 ± 0.0020	Air replaces concrete walls and SS316 tank

There is little, if any, discernable effect on MCNP calculated k_{eff} when the neutron absorption in the stainless steel tank is removed. The sand filled with UO_2 - PuO_2 - H_2O system is not noticeably affected by neutron absorption or reflection conditions on its boundary. The 196.85 cm (77.5 in.) diameter sandfilter is relatively unaffected by outside material.

6.3 OFF-NORMAL SITUATIONS AND DRYOUT OF SANDFILTER

Table 5 considers the off-normal situation of dryout. A fixed uranium and plutonium material inventory is maintained while the H_2O in the sand void is reduced to zero to search for the optimum moderation, revealed as a peak in MCNP reactivity. The fissile material is homogeneously distributed in the sandfilter in these MCNP calculations. The time to accumulate column assumes that no periodic sandfilter backwashes are performed for the full accumulation time. $H/(U+Pu) = 5$ from Table 2 was used as the starting point because these represented the maximum in calculated k_{eff} .

Table 5. DRYOUT, Off-Normal, MCNP k_{eff} for UO_2 and PuO_2 in Sandfilter
 $H/(U+Pu) = 5$ from Table 2, then Water Loss Lowers $H/(U+Pu)$

$\frac{H}{(U+Pu)}$	Density g/cm ³	$k_{eff} \pm \sigma/k_{eff}$	Sand Filter Plutonium, kg	Accumulation Time, yr	U/Pu
5.0	3.350	0.9354 ± 0.0023	37.7	315.	100
4.0	3.285	0.8921 ± 0.0027	37.7	315.	100
3.0	3.236	0.8225 ± 0.0026	37.7	315.	100
2.0	3.186	0.7129 ± 0.0031	37.7	315.	100
1.0	3.136	0.5542 ± 0.0037	37.7	315.	100
0.0	3.086	0.3781 ± 0.0043	37.7	315.	100
5.0	3.350	0.8471 ± 0.0024	18.9	158.	200
4.0	3.293	0.8160 ± 0.0025	18.9	158.	200
2.0	3.193	0.6660 ± 0.0027	18.9	158.	200
0.0	3.093	0.3343 ± 0.0041	18.9	158.	200
5.0	3.350	0.8025 ± 0.0024	12.6	106.	300
4.0	3.295	0.7726 ± 0.0022	12.6	106.	300
2.0	3.195	0.6294 ± 0.0031	12.6	106.	300
0.0	3.095	0.3159 ± 0.0040	12.6	106.	300
5.0	3.350	0.7677 ± 0.0025	9.49	79.4	400
4.0	3.296	0.7374 ± 0.0025	9.49	79.4	400
2.0	3.196	0.6164 ± 0.0032	9.49	79.4	400
0.0	3.097	0.3064 ± 0.0041	9.49	79.4	400
5.0	3.350	0.7407 ± 0.0021	7.60	63.6	500
4.0	3.297	0.7252 ± 0.0025	7.60	63.6	500
2.0	3.197	0.5979 ± 0.0028	7.60	63.6	500
0.0	3.097	0.2942 ± 0.0043	7.60	63.6	500

Table 6 calculates the dryout off-normal, for a reduced fixed fissile quantity at U/Pu weight ratio = 100, over a range of $H/(U+Pu)$ atom ratios.

This plutonium quantity is still large in comparison to calculated plutonium inventories (Appendix D), and the sandfilter backwash time of three to six month is short compared to the over 20 year accumulation time.

Table 6. DRYOUT, Off-Normal, MCNP k_{eff} for UO_2 and PuO_2 in Sandfilter
Water Loss Lowers $H/(U+Pu)$, $U/Pu = 100$, Plutonium 0.001 g/cm^3
Sand Filter Plutonium 2.54 kg, Accumulation Time 21.3 yr

$\frac{H}{(U+Pu)}$	Density g/cm^3	$k_{eff} \pm \sigma/k_{eff}$
0	1.702	0.1585 ± 0.0061
5	1.719	0.2397 ± 0.0044
10	1.736	0.2934 ± 0.0038
30	1.803	0.3820 ± 0.0029
50	1.870	0.3939 ± 0.0022
68	1.931	0.3813 ± 0.0019
83	1.981	0.3672 ± 0.0019
100	2.038	0.3513 ± 0.0019
112	2.079	0.3385 ± 0.0019

The results of Table 5 and 6 show that the reactivity may increase with dryout, but that k_{eff} remains below Table 2 calculated k_{eff} 's for the same $H/(U+Pu)$ ratio. Table 2 contains the maximum possible k_{eff} 's which do not compromise the criticality safety limit, $k_{eff} \leq 0.98$.

Tables 7, and 8 consider the off-normal situation of non-homogeneous distribution of uranium/plutonium in the sandfilter. A fixed uranium and plutonium material inventory is maintained while the spatial distribution in the sand is reduced to a thin upper layer on top. The heavy metal is mixed with sand and water filling all remaining void space. MCNP calculations searched for the optimum moderation and geometry, revealed as a peak in k_{eff} . The time to accumulate column assumes that no periodic sandfilter backwashes are performed for the full accumulation time. This plutonium quantity is still large in comparison to calculated plutonium inventories (Appendix D), and the sandfilter backwash time of three to six month is short compared to the over 20 year accumulation time.

Table 7. DISTRIBUTION, Off-Normal, MCNP k_{eff} for UO_2 and PuO_2 in Sandfilter
 UO_2 and PuO_2 Concentrate in Layer at Top of Sandfilter
Water Loss Lowers $H/(U+Pu)$, $U/Pu=100$, Plutonium 0.001 g/cm^3
Sand Filter Plutonium 2.54 kg, Accumulation Time 21.3 yr

$\frac{H}{(U+Pu)}$	Density g/cm^3	$k_{eff} \pm \sigma/k_{eff}$	U/Pu Layer Thickness, cm
0	5.835	0.3847 ± 0.0044	2.260
5	3.350	0.4265 ± 0.0038	6.382
8	2.970	0.4547 ± 0.0039	8.858
15	2.582	0.5013 ± 0.0030	14.629
25	2.368	0.5234 ± 0.0033	22.877
40	2.235	0.5118 ± 0.0028	35.251
75	2.124	0.4222 ± 0.0020	64.117
112	2.080	0.3392 ± 0.0018	94.615

Table 8. DISTRIBUTION, Off-Normal, MCNP k_{eff} for U/Pu = 400
 UO_2 and PuO_2 Concentrated in a Layer at Top of Sandfilter
 Water Loss Lowers H/(U+Pu), Plutonium 0.001 g/cm³
 Sand Filter Plutonium 2.54 kg, Accumulation Time 21.3 yr

H (U+Pu)	Density g/cm ³	$k_{eff} \pm \sigma/k_{eff}$	U/Pu Layer Thickness, cm
0	5.835	0.4045 $\pm$ 0.0040	8.973
3	3.824	0.5122 $\pm$ 0.0032	18.800
5	3.350	0.5651 $\pm$ 0.0029	25.351
8	2.969	0.6004 $\pm$ 0.0026	35.177
11	2.755	0.6025 $\pm$ 0.0027	45.005
14	2.618	0.5904 $\pm$ 0.0022	54.832
17	2.522	0.5701 $\pm$ 0.0022	64.656
20	2.452	0.5474 $\pm$ 0.0018	74.485
23	2.398	0.5227 $\pm$ 0.0019	84.311
26	2.353	0.5017 $\pm$ 0.0019	94.615

The results of Table 7 and 8 show a reactivity increase with transition from homogeneous geometry to a thin dry layer of sand and uranium/plutonium oxide and that the maximum k_{eff} remains below the Table 2 calculated k_{eff} for the same H/(U+Pu) ratio. For example, the Table 7, U/Pu=100, maximum occurs at H/(U+Pu)=25 where k_{eff} is 0.5234, and this is less than Table 2, U/Pu=100, at H/(U+Pu)=25 where k_{eff} is 0.7778. Similarly, the Table 8, U/Pu=400, maximum occurs at H/(U+Pu)=11 where k_{eff} is 0.6025, and this is less than Table 2, U/Pu=400, at H/(U+Pu)=10 where k_{eff} is 0.7067. Table 2, the continuous addition of material k_{eff} values represent the maximum calculated k_{eff} values at any H/(U+Pu) for particular U/Pu ratios. The dryout, H/(U+Pu)=0, case is specifically excluded from this discussion because these k_{eff} results are lower than the optimally moderated cases with the same amount of fissile material or less. Since the Table 2 maximum $k_{eff} \leq 0.98$, this shows that no dryout or heterogeneous distribution would compromise criticality safety.

6.4 PARAMETRIC STUDIES WITH LOSS OF NEUTRON ABSORBERS

Table 9 shows MCNP parametric study calculations for measured plutonium isotope ratios, 0.0 U/Pu weight ratio, and different total accumulation times. This total accumulation time is the time without a sandfilter backwash and all of the measured plutonium concentration is captured uniformly throughout the sandfilter medium.

Table 9 shows that for the unrealistic parametric study of uranium entirely removed from the plutonium, U/Pu = 0.0, the accumulation of over 15,700 grams of plutonium requires over 132. years without a sandfilter backwash to approach $k_{eff} \geq 0.95$ (note: this is a plutonium system, not a low enriched uranium system where $k_{eff} \geq 0.98$ would be used) and compromise criticality safety. This is a parametric study to identify what would be necessary to cause a criticality in the sandfilter and has no relation to reality. Appendix D reports a sandfilter sampling interpretation indicating less than 225 g plutonium in the sandfilter.

Table 9. PARAMETER SURVEY, MCNP k_{eff} for PuO_2 in Sandfilter
No Uranium, $U/Pu=0$, Sand Voids Homogeneously Filled With PuO_2-H_2O

$\frac{H}{(U+Pu)}$	Density g/cm ³	$k_{eff} \pm \sigma/k_{eff}$	Sand Filter Plutonium, kg	Accumulation Time, yr
0	5.835	2.3482 ± 0.0013	10,750.	90,000.
5	3.409	1.6378 ± 0.0015	3,971.	33,200.
25	2.392	1.3709 ± 0.0020	1,127.	9,440.
200	2.044	1.4136 ± 0.0021	155.1	1,300.
1,000	1.999	1.1851 ± 0.0016	31.4	263.
1,500	1.996	1.0417 ± 0.0012	20.9	175.
2,000	1.994	0.9241 ± 0.0014	15.7	132.
2,500	1.993	0.8256 ± 0.0014	12.6	105.
3,000	1.992	0.7509 ± 0.0015	10.5	87.8
3,500	1.991	0.6827 ± 0.0017	8.99	75.2
4,000	1.990	0.6286 ± 0.0015	7.86	65.8
6,000	1.990	0.4716 ± 0.0016	5.24	43.9
8,000	1.990	0.3800 ± 0.0018	3.93	32.9
10,000	1.989	0.3185 ± 0.0018	3.15	26.3
20,000	1.989	0.1737 ± 0.0017	1.57	13.2
50,000	1.988	0.0739 ± 0.0015	0.630	5.27
100,000	1.988	0.0376 ± 0.0019	0.315	2.64
250,000	1.988	0.0153 ± 0.0019	0.126	1.05

Table 2 results can be combined with those of Table 9 results to state that when the U/Pu ratio ≥ 100 , then the concentration of uranium and plutonium in the KE basin analysis cannot compromise the criticality safety limit, $k_{eff} \leq 0.98$. If the $U/Pu < 100$, then 15,700 grams of plutonium is required to reach the criticality safety limit, $k_{eff} \leq 0.98$. The 15,700 grams of plutonium would require more than 132 years without a sandfilter backwash to accumulate, at the present plutonium concentration in KE basin.

Tables 10 and 11 calculate the parametric study of $U/Pu = 0$ for the off-normal situation of dryout of the sandfilter. These results give further support that the maximum k_{eff} is calculated for the continuous addition of material situation, Table 9 for $U/Pu = 0$.

Table 10. PARAMETER SURVEY, DRYOUT, MCNP k_{eff} for 0.001 g/cm³ Pu in Sandfilter
 No Uranium, U/Pu = 0.0, Water Loss Changed H/Pu
 Sand Filter Plutonium 2.54 kg, Accumulation Time 21 yr

H/Pu	Density g/cm ³	$k_{eff} \pm \sigma/k_{eff}$
0	1.602	0.1642 $\pm$ 0.0050
5	1.602	0.1655 $\pm$ 0.0050
10	1.602	0.1683 $\pm$ 0.0050
50	1.604	0.1742 $\pm$ 0.0056
100	1.605	0.1859 $\pm$ 0.0050
500	1.618	0.2395 $\pm$ 0.0051
1,000	1.633	0.2848 $\pm$ 0.0037
2,500	1.680	0.3287 $\pm$ 0.0031
3,800	1.719	0.3403 $\pm$ 0.0023
5,000	1.758	0.3344 $\pm$ 0.0022
6,500	1.805	0.3219 $\pm$ 0.0020
8,200	1.859	0.3045 $\pm$ 0.0017
10,000	1.914	0.2869 $\pm$ 0.0019

Table 11. PARAMETER SURVEY, DRYOUT, MCNP k_{eff} for 0.010 g/cm³ Pu in Sandfilter
 No Uranium, U/Pu = 0.0, Water Loss Changed H/Pu
 Sand Filter Plutonium 25.4 kg, Accumulation Time 210 yr

H/Pu	Density g/cm ³	$k_{eff} \pm \sigma/k_{eff}$
0	1.602	0.4288 $\pm$ 0.0051
5	1.604	0.4448 $\pm$ 0.0046
10	1.605	0.4616 $\pm$ 0.0045
50	1.618	0.5728 $\pm$ 0.0039
100	1.633	0.7163 $\pm$ 0.0036
500	1.758	1.0839 $\pm$ 0.0023
680	1.814	1.1172 $\pm$ 0.0019
830	1.861	1.1310 $\pm$ 0.0018
1,000	1.914	1.1214 $\pm$ 0.0016
1,118	1.950	1.1215 $\pm$ 0.0017
1,236	1.987	1.1144 $\pm$ 0.0018

Table 12 considers the parametric study of non-homogeneous distribution of plutonium in the sandfilter. A fixed plutonium inventory is maintained while the spatial distribution in the sand is reduced to a thin upper layer on top. The plutonium oxide is mixed with sand and water filling all remaining void space. MCNP calculations searched for the optimum moderation, revealed as a peak in k_{eff} . The time to accumulate column assumes that no periodic sandfilter backwashes are performed for the full accumulation time. The heterogeneous distribution of U/Pu = 0 fissile material calculated k_{eff} falls below the Table 9 continuous addition of material values. This is a parametric study to identify what would be necessary to cause a criticality in the sandfilter and has no relation to reality.

Table 12. PARAMETER SURVEY, DISTRIBUTION, MCNP k_{eff} for PuO_2 in Sandfilter No Uranium, U/Pu = 0, Plutonium Concentrated in a Layer at Top of Sand Media Sand Filter Plutonium 2.54 kg, Accumulation Time 21 yr

H/Pu	Density g/cm ³	$k_{eff} \pm \sigma/k_{eff}$	Pu Layer Thickness, cm
0	5.835	0.3513 ± 0.0046	0.022
5	3.409	0.3638 ± 0.0051	0.061
10	2.859	0.3662 ± 0.0049	0.099
25	2.392	0.3704 ± 0.0042	0.213
75	2.133	0.3821 ± 0.0051	0.595
200	2.044	0.4001 ± 0.0043	1.551
500	2.011	0.4270 ± 0.0042	3.843
1,500	1.996	0.4881 ± 0.0031	11.485
4,000	1.991	0.4708 ± 0.0025	30.591
9,000	1.989	0.3294 ± 0.0018	68.818
10,500	1.989	0.2973 ± 0.0018	80.255

The results of Table 12 show reactivity increase with transition from homogeneous geometry to a thin dry layer of sand and plutonium oxide. The heterogeneous distribution peak k_{eff} value for a H/Pu ratio falls is less than the Table 9, continuous accumulation of fissile material, k_{eff} . Table 9 calculated k_{eff} values are shown to be maximum k_{eff} values for any H/Pu ratio.

Table 13 shows MCNP calculations for unexposed uranium (0.947 wt% ^{235}U) and various H/U atom ratios. The concentration of unexposed uranium in the water is conservatively assumed to be $0.750E-4$ g U/L, 500 times the plutonium concentration of $0.150E-6$ g Pu/L. At 400 gpm, the uranium accumulation rate is 59.7 kg U/yr with no sandfilter backwashes. This is a parametric study to identify what would be necessary to challenge the criticality safety limit, $k_{eff} \leq 0.98$. The high H/U atom ratio calculations, even though there is no potential for criticality, are closest to normal operation for less than 3 months since a sandfilter backwash.

Table 13. PARAMETER SURVEY, MCNP k_{eff} for 0.947 wt% ^{235}U in Sandfilter NO Plutonium, Sand Voids Filled Completely With UO_2-H_2O , No Dryout

H/U	Density g/cm ³	$k_{eff} \pm \sigma/k_{eff}$	Sand Filter Uranium, kg	Accumulation Time, yr
0	5.835	0.3744 ± 0.0035	10,700.	180.
1	4.805	0.5997 ± 0.0028	7,870.	132.
2	4.211	0.6970 ± 0.0023	6,210.	104.
5	3.349	0.7363 ± 0.0022	3,800.	63.6
8	2.969	0.6999 ± 0.0022	2,740.	45.9
10	2.815	0.6667 ± 0.0021	2,310.	38.7
20	2.451	0.5251 ± 0.0018	1,290.	21.6
50	2.188	0.3100 ± 0.0019	558.	9.33
100	2.091	0.1838 ± 0.0017	286.	4.79
200	2.040	0.1018 ± 0.0019	145.	2.43
500	2.009	0.0436 ± 0.0018	58.5	0.979
1,000	1.999	0.0224 ± 0.0021	29.3	0.491
5,000	1.990	0.0046 ± 0.0018	5.88	0.0984
10,000	1.989	0.0023 ± 0.0018	2.94	0.0492

Table 13 k_{eff} calculations with the unirradiated (0.947 wt% ^{235}U) UO_2 - H_2O -sand system show the reactivity increase of this system is not sufficient to challenge the criticality safety limit of $k_{eff} \leq 0.98$. In practice, addition of material is limited to approximately a three months (normal) or six months (maximum) accumulation.

Table 14 shows MCNP calculations for unexposed uranium (1.25 wt% ^{235}U) and the H/U atom ratio varied. The concentration of unexposed uranium in the water is conservatively assumed to be $0.750\text{E-}4$ g U/L, at 400 gpm, the uranium accumulation rate is 59.736 kg U/yr with no sandfilter backwashes. This is a parametric study to identify what would be necessary to cause a criticality in the sandfilter. The high H/U atom ratio calculations, even though there is no potential for criticality, are the closest to normal operation at less than 3 months since a sandfilter backwash.

Table 14. PARAMETER SURVEY, MCNP k_{eff} for 1.25 wt% ^{235}U in Sandfilter NO Plutonium, Sand Voids Filled Completely With UO_2 - H_2O , No Dryout

H/U	Density g/cm ³	$k_{eff} \pm \sigma/k_{eff}$	Sand Filter Uranium, kg	Accumulation Time, yr
0	5.835	0.4076 ± 0.0036	10,700.	180.
1	4.806	0.6557 ± 0.0026	7,870.	132.
2	4.211	0.7653 ± 0.0026	6,210.	104.
5	3.350	0.8357 ± 0.0018	3,800.	63.7
8	2.969	0.8008 ± 0.0019	2,740.	45.9
10	2.815	0.7688 ± 0.0021	2,310.	38.7
20	2.452	0.6265 ± 0.0018	1,290.	21.7
50	2.188	0.3872 ± 0.0018	558.	9.34
100	2.091	0.2351 ± 0.0019	286.	4.80
200	2.040	0.1321 ± 0.0020	145.	2.43
500	2.009	0.0571 ± 0.0020	58.5	0.980
1,000	1.999	0.0293 ± 0.0020	29.4	0.491
5,000	1.990	0.0060 ± 0.0019	5.88	0.0985
10,000	1.989	0.0030 ± 0.0017	2.94	0.0492

The k_{eff} calculations in Table 14 made with the unirradiated (1.25 wt% ^{235}U) UO_2 - H_2O -sand system show the reactivity increase of this system is not sufficient to challenge the criticality safety limit, $k_{eff} \leq 0.98$. In practice, addition of material is limited to approximately a three months (normal) or six months (maximum) accumulation, then a periodic backwash would be performed.

Any irradiation of the 1.25 wt% ^{235}U material, without chemical separation of the resulting U/Pu ratio, would lower the k_{eff} below the Table 14 calculated values. Any blending of the 1.25 wt% ^{235}U MKIA outer uranium with the 0.947 wt% MKIA inner and MKIV uranium would also lower the calculated k_{eff} below the Table 14 k_{eff} results. The fact that $k_{eff} \leq 0.98$ for all Table 14 results envelops all possible irradiated compositions at KE and KW basins as long as there is no plutonium separation from uranium.

Table 14 results demonstrate that, where there is no plutonium separation from uranium, there are no plutonium quantity limits necessary in

order to satisfy the criticality safety limit, $k_{eff} \leq 0.98$ for the sandfilter. These Table 14 results for the 1.250 wt% ^{235}U bound the 0.947 wt% ^{235}U Table 13 results so that both KE and KW basin sandfilters are considered.

7.0 DESIGN FEATURES AND ADMINISTRATIVELY CONTROLLED LIMITS AND REQUIREMENTS

There are no unique design features, administratively controlled limits, or requirements applicable to this evaluation.

The maintenance of criticality safety, as described, is predicated on measured KE basin plutonium isotope ratios and a U/Pu weight ratio greater than 100, then there are no mass limits on fissile material in the sandfilter. The irradiation of uranium in the KE and KW basins are consistent with U/Pu weight ratio of 455, and there is no demonstrated uranium plutonium separation occurring in KE or KW basin. If the U/Pu weight is less than 100, then the total plutonium quantity in the sandfilter needs to be less than 15,700 g. At the present plutonium concentration in the KE basin water, this would require over 132 years without a sandfilter backwash to accumulate. Sandfilter backwashes are routinely performed every three months, and at a maximum of about six months. Based on these considerations, it is not necessary to establish any sampling program to assure compliance with these criticality requirements.

8.0 SUMMARY AND CONCLUSIONS

The analysis based on the assumptions discussed in this document shows that under normal operating conditions and off-normal operating conditions, a criticality ($k_{eff} > 1.00$) is not credible. For off-normal conditions, fissile material accumulations, reduced uranium to plutonium ratio, and change of moderation due to dryout with fixed fissile inventory were considered.

Regarding the need for a Criticality Alarm System (CAS), WHC-CM-4-29, the Nuclear Criticality Safety Manual, states (Section 11.0, Item 5.1):

"A CAS shall be installed and maintained operational for all fissionable material facilities and for fissionable material outside the core of nuclear reactor facilities, unless one of the following criteria is met:

1. A CAS is not required when a documented safety analysis shows that it is not needed due to the physical form and isotopic distribution of fissionable material. Such analyses shall be approved by the independent safety review organization.
2. A CAS is not required when intervening shielding ensures that the maximum calculated dose in occupied locations will not exceed 25 rems whole body exposure or equivalent from the maximum accident of concern. Detection without facility evacuation is required in accordance with Item 5.2.2 of this section.
3. A CAS is not required when fissionable material packaging/shipping requirements have been complied with, and the material is either awaiting transport or in route in sealed, approved shipping containers."

No CAS is necessary because of criterion 1. above. Criticality analysis has determined that no realistic situation could result in a criticality due to the physical form and isotopic distribution of fissionable material.

The analysis discusses a number of possible contingencies (geometry, moderation, material addition, uranium-plutonium segregation, and loss of neutron absorbers) and discards all but the accumulation of fissile material. The analysis ignores the presence of neutron absorbers except those shown to be present in the sandfilter medium or in the uranium or plutonium, for example ^{240}Pu . With the addition of the fission products and other materials found from chemical analyses of sandfilter medium, at actual densities and concentrations, the sandfilter is safely subcritical under all conditions of moderation even for extremely large quantities of fissile material. Sandfilter changeout would be dictated by other than criticality concerns well in advance of any significant plutonium buildup.

9.0 REFERENCES

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- Drawing 950-011, *Filter System HRM-78 w/ Single Lever*, Baker Filtration Company, Huntington Beach, California, 23 March 1978.
- Drawing H-1-34595 Revision 1, *Structural Plans, Sections and Details*, dated March 7, 1979.
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- Erickson, D. G., March 1994, WHC-SD-NR-CSER-014, *Criticality Safety Evaluation Report for the 100 KE Basin for Sandfilter Backwash Pit*, Westinghouse Hanford Company, Richland, Washington.
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- LANL, 1986, *MCNP - A General Purpose Monte Carlo Code for Neutron and Photon Transport, Version 3A*, LA-7396, Rev. 2, Los Alamos National Laboratory, J. F. Briesmeister (Editor).
- WHC-CN-4-29, *Nuclear Criticality Safety Manual*, Criticality Engineering Analysis, Sept. 15, 1988.
- Wittekind, W. D., 1992, WHC-SD-NR-CSER-001, *K Basin Criticality Evaluation for Irradiated Fuel Canisters in Sludge*, Westinghouse Hanford Company, Richland, Washington.

APPENDIX A.

REVIEWER'S COMMENTS

The criticality safety evaluation review was provided by S. J. Altschuler, who provided this reviewer comment:

A previous study using the EGGNIT code* showed that for an infinite $\text{PuO}_2\text{-H}_2\text{O-SiO}_2$ mixture, the most reactive system was for $\text{H/Pu}=0$, complete dryness. Silicon was chosen because of its low (160 mb) neutron absorption cross-section. Hydrogen, with its 330 mb cross-section, acts more as a poison than a moderator or reflector. The maximum "safe" ($k_{\text{eff}}=0.95$) concentration under these conditions was 0.70 g Pu/L. The volume of the sandfilter is taken as 6000 liters which would allow a safe accumulation of 4.2 kg Pu. Assuming a flow of 400 gpm with an activity of $1.09\text{E}+4$ pCi/L, this will take 29 years at 144 g Pu/yr (attributing all the activity to ^{239}Pu) and the system will still be safely subcritical.

*S. J. Altschuler and P. C. Doto, "Minimum Criticality Safety Limits for Nuclear Waste," Trans. Am. Nuc. Soc., 64, p. 339 (Nov. 1991).

APPENDIX B.

LAPIS LUSTRE DRIED SANDS ANALYSIS

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TO: GENE WOODRUFF
WESTINGHOUSE HANFORD

FROM: KEN ADAMS

5352 Research Drive
Huntington Beach
California 92649
telephone
(714) 898-3474
fx
(714) 893-8927/(714)
telex
678446

LAPIS LUSTRE DRIED SANDS

Color:	Gray to Amber
Unit Weight:	100 Lbs. per Cu. Ft.
Specific Gravity:	2.51
MOH Hardness:	6
Acid Solubility:	0.1% (AWWA B100-80, Sec. 5.3)
Absorption:	0.5%

Chemical Analysis (Dry Basis):

Aluminum as Al_2O_3	8.53%
Calcium as CaO	0.57%
Chlorine as Cl	0.018%
Fluorine as F	0.01%
Iron as Fe_2O_3	0.61%
Magnesium as MgO	0.18%
Potassium as K_2O	3.17%
Combined Silica as SiO_2	81.52%
Sodium as Na_2O	1.53%
Sulfur as SO_2	0.08%
Titanium as TiO_2	0.01%
Loss on Ignition	0.44%
Asbestos	None

APPENDIX C.

MEMO, 105KE SAND FILTER SAND DEPTH CALCULATIONS,
L. D. Alwardt to G. L. Bennett, November 18, 1993

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**Westinghouse
Hanford Company**

WHC-SD-NR-CSER-013 Rev. 0

**Internal
Memo**

From: Safety Technical Support and K Basins Engineering
Phone: 373-1591 X0-44 and 373-3581 X5-34
Date: November 18, 1993
Subject: 105KE SAND FILTER SAND DEPTH CALCULATIONS

93LOAMJL.002

To: G. L. Bennett X3-68

cc: C. L. Bennett X0-44
J. Greenborg H0-35
R. J. Kuhta X5-34
T. J. Ruane X3-61
J. P. Schmidt X0-41
R. L. Simons X0-35
S. A. Slinn X5-06
H. Toffer H0-38
W. D. Whittekind H0-38
LDA:MJL File/LB

Based on information obtained on November 9, 1993 during the performance of Operating Procedure 59-43-7 to sample the 105KE sand filter, Safety Technical Support has performed a calculation to determine the current height of working media sand. During the performance of OP 59-43-7 two measurements were taken. The first measurement was the distance from the top rim of the inspection plate port (lower side) to the top of the working media. The distance to the top of the sand was measured to be 25 inches. The second measurement was the distance from the same reference point on the inspection plate port to the floor on the inside of the sand filter concrete enclosure structure. The distance to the floor was measured to be 87.75 inches.

Information on Baker Filtration Company drawing 950-011, Revision B, was used to calculate the thickness of the working media layer. Due to the lack of complete dimension information on the drawing two assumptions were required. The first assumption is that the line that is 3.5 inches above the top of the concrete layer is at the same elevation as the centerline of the effluent piping, which is shown as 2'-5" above the working elevation of the basin. The 2'-5" elevation for the effluent piping centerline was physically verified subsequent to the sand filter sampling. The second assumption is that the working elevation of the basin and the elevation of the floor inside the sand filter concrete enclosure structure are equivalent. With those assumptions, a working media depth of 1'-8" as shown on the drawing would correspond to an elevation of 4'-5" above the floor. The information obtained during sampling indicates that the top of the working media is 5'-2 3/4" (87.75" - 25") above the floor. Assuming that the depth of the support media is 7.5 inches as shown on the drawing, that corresponds to a working media depth of 29.75 inches.

G. L. Bennett
Page 2
November 18, 1993

93LDAMJL.002

Baker Filtration drawing 950-011, revision B, shows a working media mass of 8700 pounds for a height of 20 inches. With a depth of 29.75 inches, the mass of working media sand is equal to approximately 12,940 pounds.

K Basins Engineering has reviewed the information contained in this memo and concurs with the validity of the assumptions and calculations.

L.D. Alwardt
Safety Technical Support

M.J. Langevin
K Basins Engineering

Concurrence:

C.L. Bennett, Manager
Safety Technical Support

Date 11-18-93

R.J. Kuhta, Manager
Auxiliary Plant Engineering

Date 11-18-93

Attachment

SAND FILTER DIMENSIONS

TAKEN FROM:
BAKER FILTRATION CO.
DRAWING # 950-011
REVISION B

- APPENDIX D.

MEMO, 100 K SANDFILTER SAMPLING RECOMMENDATIONS,
L. D. Alwardt to V. L. Hoefer, December 21, 1993

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Fix (back up to Fix)

Westinghouse
Hanford Company

WHC-SD-NR-CSE-013 Rev. 0

Internal
Memo

From: Safety Technical Support
Phone: 373-3325 X0-44
Date: December 21, 1993
Subject: 100 K SANDFILTER SAMPLING RECOMMENDATIONS

93LDA.011

To: V. L. Hoefer X0-42

cc: M. A. Jensen X0-44
M. A. Green X0-35
M. J. Langevin X5-34
J. D. Mathews X3-68
T. J. Ruane X3-61
J. P. Schmidt X0-41
CLB:LDA File/LB

Reference: Internal Memo, C. L. Bennett to G. L. Bennett,
"Projected Plutonium in the 105 KE Sandfilter," dated
October 20, 1993.

Attached is an updated (see reference) calculation for plutonium
accumulation in the 105 KE sandfilter based on recent sand and basin
water analyses. This calculation provides a justification for
continued operation of the sandfilter past the next scheduled
sandfilter sample date.

If you have any questions, please contact L. D. Alwardt at 373-1591.

Concurrence:

L. D. Alwardt, Principal Engineer
Safety Technical Support

C. L. Bennett, Manager
Safety Technical Support

ymf--

Attachment

Updated 105KE Sand Filter Plutonium Deposition Calculation

The information in this updated calculation reflects data obtained from 105KE sand filter sampling performed on November 9, 1993. Two analyses of the 105KE sand filter sample (#R4565) taken on November 9, 1993 yielded Pu-239/240 specific activities of $5.68\text{E-}01$ and $6.25\text{E-}01$ $\mu\text{Ci/gram}$ of sample. From Baker Filtration Company drawing #950-011, revision B, and the component list for a model 2 HRB-78 filter, the height of the working media is 20 inches and the weight of the working media is 8,700 pounds ($3.95\text{E+}06$ grams). However, based on sand height measurements taken during 105KE sand filter sampling on November 9, 1993, the height of the filter media has been calculated to be 29.75 inches. This corresponds to a working media weight of approximately 12,940 pounds ($5.87\text{E+}06$ grams).

Using the greater of the two sample activities the amount of Pu calculated to be in the 105KE sand filter as of November 9, 1993 is as follows:

$$\begin{aligned}\text{Pu in sand filter} &= 5.87\text{E+}06 \text{ g} * 6.25\text{E-}01 \mu\text{Ci/g} * 1\text{E-}06 \text{ Ci}/\mu\text{Ci} \\ &\quad * 12.2 \text{ g Pu/Ci Pu-239/240} \\ &= 44.8 \text{ g Pu}\end{aligned}$$

Following is a table of available sample data since July 1993 for center of basin (sand filter inlet) and ion exchange module inlet (sand filter outlet).

Date	SF Inlet (Center of Basin) Pu-239/240 Spec. Activity	SF Outlet (IXM Inlet) Pu-239/240 Spec. Activity
7/06/93	$1.52\text{E-}02 \mu\text{Ci/l}$	$1.03\text{E-}02 \mu\text{Ci/l}$
7/13/93	$1.74\text{E-}02 \mu\text{Ci/l}$	$1.10\text{E-}02 \mu\text{Ci/l}$
7/20/93	$2.20\text{E-}02 \mu\text{Ci/l}$	$1.18\text{E-}02 \mu\text{Ci/l}$
7/28/93	$1.64\text{E-}02 \mu\text{Ci/l}$	$8.32\text{E-}03 \mu\text{Ci/l}$
8/03/93	$1.87\text{E-}02 \mu\text{Ci/l}$	$1.20\text{E-}02 \mu\text{Ci/l}$
8/11/93	$1.20\text{E-}02 \mu\text{Ci/l}$	$7.11\text{E-}03 \mu\text{Ci/l}$
8/18/93	$9.00\text{E-}03 \mu\text{Ci/l}$	$8.21\text{E-}03 \mu\text{Ci/l}$
8/25/93	$1.04\text{E-}02 \mu\text{Ci/l}$	$4.30\text{E-}03 \mu\text{Ci/l}$
9/01/93	Not Available	$5.18\text{E-}03 \mu\text{Ci/l}$
9/08/93	$9.31\text{E-}03 \mu\text{Ci/l}$	$4.41\text{E-}03 \mu\text{Ci/l}$
9/15/93	$1.11\text{E-}02 \mu\text{Ci/l}$	$4.64\text{E-}03 \mu\text{Ci/l}$
9/22/93	$1.13\text{E-}02 \mu\text{Ci/l}$	$3.84\text{E-}03 \mu\text{Ci/l}$
10/06/93	$1.08\text{E-}02 \mu\text{Ci/l}$	$5.37\text{E-}03 \mu\text{Ci/l}$
10/13/93	$2.44\text{E-}02 \mu\text{Ci/l}$	Not Available
10/20/93	$2.64\text{E-}02 \mu\text{Ci/l}$	Not Available
10/27/93	$3.90\text{E-}02 \mu\text{Ci/l}$	Not Available
11/03/93	$1.56\text{E-}02 \mu\text{Ci/l}$	$7.21\text{E-}03 \mu\text{Ci/l}$
11/10/93	$8.90\text{E-}03 \mu\text{Ci/l}$	$7.68\text{E-}03 \mu\text{Ci/l}$

¹ Internal Memo 93LDAMJL.002, 105KE SAND FILTER SAND DEPTH CALCULATIONS, Safety Technical Support and K Basins Engineering to G.L. Bennett, dated November 16, 1993

The time-weighted average sand filter inlet activity is $1.55\text{E-}02 \mu\text{Ci/l}$. The time-weighted average sand filter outlet activity is $6.77\text{E-}03 \mu\text{Ci/l}$. The time-weighted average removal efficiency is 56.2 percent.

Potential sand filter plutonium accumulation for three different operational scenarios will be addressed in this calculation. The first scenario assumes continued operation of the 105KE sand filter with the current average basin water Pu-239/240 specific activity until February 8, 1994 (three months after the last sand filter sample²). The second scenario assumes that due to sludge pumping to complete cleanup of the discharge chute area basin water Pu-239/240 concentrations will rise to values seen in late 1992/early 1993 when sludge pumping was occurring. The third scenario assumes the plutonium accumulation from scenario 2 and calculates the number of days of operation after February 8, 1994 required for the sand filter to accumulate 200 grams of plutonium using the average Pu-239/240 specific activity from scenario 1 for the period after February 8, 1993.

Scenario 1

Pu in sand filter as of November 9, 1993 = 44.8 g Pu
 Pu accumulation in sand filter = $400 \text{ gal/min} * 60 \text{ min/hr} * 24 \text{ hours/day}$
 (11/9/93-2/8/94) $* 91 \text{ days} * 3.785 \text{ l/gal} * 1.55\text{E-}02 \mu\text{Ci/l}$
 $* 1\text{E-}06 \text{ Ci}/\mu\text{Ci} * 12.2 \text{ g Pu/Ci Pu-239/240}$
 $* .562$
 = 44.8 g Pu + 21.1 g Pu
 = 65.9 g Pu

Scenario 2

Sludge pumping and discharge chute cleanout is planned to recommence prior to 105KE sand filter sampling in early February, 1994. Center of basin sample data for the period 10/6/92 through 1/12/93 (the general period during which sludge pumping was occurring) was reviewed to estimate the Pu-239/240 specific activity expected during final discharge chute cleanout. The average center of basin Pu-239/240 specific activity during the period 10/6/92 through 1/12/93 was $6.94\text{E-}02 \mu\text{Ci/l}$ and the highest specific activity was $1.16\text{E-}01 \mu\text{Ci/l}$. The average Pu-239/240 specific activity will be used and for conservatism that value will be assumed to exist for the entire period between 11/9/93 and 2/8/94.

Pu in sand filter as of November 9, 1993 = 44.8 g Pu
 Pu accumulation in sand filter = $400 \text{ gal/min} * 60 \text{ min/hr} * 24 \text{ hours/day}$
 (11/9/93-2/8/94) $* 91 \text{ days} * 3.785 \text{ l/gal} * 6.94\text{E-}02 \mu\text{Ci/l}$
 $* 1\text{E-}06 \text{ Ci}/\mu\text{Ci} * 12.2 \text{ g Pu/Ci Pu-239/240}$
 $* .562$
 = 44.8 g Pu + 94.4 g Pu
 = 139.2 g Pu

² Internal Memo 93LDA.010, 100 K SANDFILTER SAMPLING RECOMMENDATIONS, Safety Technical Support to V.L. Hoefer, dated December 20, 1993

Scenario 3

Pu in sand filter as of February 8, 1994 = 139.2 g Pu
(from Scenario 2)

Time to accumulate 60.8 g Pu = $60.8 \text{ g Pu} / (400 \text{ gal/min} * 60 \text{ min/hr} * 24 \text{ hours/day} * 3.785 \text{ l/gal} * 1.55\text{E-}02 \text{ } \mu\text{Ci/l} * 1\text{E-}06 \text{ Ci/} \mu\text{Ci} * 12.2 \text{ g Pu/Ci Pu-239/240} * .562$

= 262 days from February 8, 1994

Summary

The calculations for the above scenarios provide confidence that the 105KE sand filter can be operated safely within the Operations Safety Requirements limit of 225 grams plutonium past the next scheduled sampling on or before February 8, 1994. Since closure of the Unreviewed Safety Question associated with the 105KE North Loadout Pit is not anticipated prior to February 8, 1994 backwashing of the 105KE sand filter is not anticipated prior to sand filter sampling. Experience has shown that the plutonium deposition calculated from sand filter sampling is less than the value calculated from basin water specific activity due to the conservative assumptions used. A time cushion after sampling is needed due to the time required to receive sample results back from the analysis facility.

APPENDIX E.

KE SANDFILTER ANALYSIS OF NOVEMBER 9, 1993

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LE STATUS REPORT FOR R 4565. 105 KE BASIN 0115KBS TIME: 12/13/93 10: 8
 PATCHED: 11/11/93 13:44 SAMPLE HAS NOT BEEN SLURPED SANDFilter
 DELVED: 11/16/93 8: 0 SAMPLED 9 NOVEMBER 1993

EXT.	DETER.	RESULTS OR STATUS	OUT OF GOOD RANGE?	GOOD ANS?	CHARGE CODE
****	*****	*****	***	***	*****
3700	ACD DGST	2.74850E 01 G/L	N	Y	E14156
3725	AT	1.94000E 00 uCi/G Rec	N	Y	E14156
3740	U	1.42000E-02 G/G Rec	N	Y	E14156
3781	Fu239/40	5.68000E-01 uCi/G Rec	N	Y	E14156
3782	Am241	OUT FOR RERUN			E14156
3782	Am241	2.73000E-01 uCi/G Rec	N	Y	E14156
3800	ACD DGST	2.91270E 01 G/L	N	Y	E14156
3825	AT	1.78000E 00 uCi/G Rec	N	Y	E14156
3840	U	1.23000E-02 G/G Rec	N	Y	E14156
3881	Fu239/40	5.25000E-01 uCi/G Rec	N	Y	E14156
3882	Am241	OUT FOR RERUN			E14156
3882	Am241	3.57000E 00 uCi/G Rec	N	Y	E14156
3710	R S WT%	9.97000E 01 WT% SOLIDS	N	Y	E14156
3810	R S WT%	9.96000E 01 WT% SOLIDS	N	Y	E14156

END OF REPORT

APPENDIX F.

CALCULATION OF U/Pu WEIGHT RATIO AND TOTAL PLUTONIUM FROM SANDFILTER ANALYSIS

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CALCULATION OF URANIUM TO PLUTONIUM WEIGHT RATIO AND TOTAL PLUTONIUM

Situation:

- 1) The uranium concentration, gU/G, is measured.
- 2) The ($^{239}\text{Pu} + ^{240}\text{Pu}$) activity in $\mu\text{Ci/G}$ is measured.
- 3) The plutonium isotopic composition (mass %) is known.
- 4) The ^{241}Am activity in $\mu\text{Ci/G}$ is measured.

Note: Capital "G" is being explicitly used here to designate "g of sample."

- 5) The sandfilter sand quantity is $5.87\text{E}+6$ grams (Appendix D).

Analytical Chemistry Results for KE Sandfilter (Appendix E):

- 1) U: $1.42\text{E}-2$ gU/G, $1.23\text{E}-2$ gU/G or $(1.325\text{E}-2 \pm 9.5\text{E}-4)$ gU/G
- 2) Pu: $5.68\text{E}-1$ $\mu\text{Ci/G}$, $5.25\text{E}-1$ $\mu\text{Ci/G}$ or $(5.965\text{E}-1 \pm 2.85\text{E}-2)$ $\mu\text{CiPu/G}$
- 3) ^{241}Am : $2.73\text{E}-1$ $\mu\text{Ci/G}$, $3.57\text{E}0$ $\mu\text{Ci/G}$ or (1.9215 ± 1.6485) $\mu\text{Ci}^{241}\text{Am/G}$

Plutonium isotope ratios are (from other KE analyses):

^{238}Pu	0.0745658	mass%
^{239}Pu	86.0096250	mass%
^{240}Pu	12.5987204	mass%
^{241}Pu	1.1008806	mass%
^{242}Pu	0.2162082	mass%

From this, it was shown (Appendix J): $8.197\text{E}+4$ $\mu\text{Ci}(^{239}\text{Pu}+^{240}\text{Pu}) = 1$ g Pu.

Additional Necessary Information:

N_A Avagadro's Number	6.022045×10^{23} atoms/gram-mole	$(6.022045\text{E}+23)$
μCi Definition	$1 \mu\text{Ci} = 3.7 \times 10^{10}$ dis/s	$(3.7\text{E}+4)$

Isotope	AW(Atomic Weight)	$t_{1/2}$ (half-life) yr
^{241}Am	241.056823	432.7

Calculation of U/Pu weight ratio:

$$\text{gU/G} + \{ [\mu\text{Ci}(^{239}\text{Pu}+^{240}\text{Pu})/\text{G}] + [\mu\text{Ci}(^{239}\text{Pu}+^{240}\text{Pu})/\text{gPu}] \} = \text{gU/G} + \text{gPu/G} = \text{U/Pu}$$

$$\frac{\text{U}}{\text{Pu}} = \frac{(1.325\text{E}-2 \pm 9.5\text{E}-4) \text{ gU/G}}{(5.965\text{E}-1 \pm 2.85\text{E}-2) \mu\text{CiPu/G} / 8.197\text{E}+4 \mu\text{Ci}(^{239}\text{Pu}+^{240}\text{Pu})/\text{gPu}}$$

$$= \frac{(1.325\text{E}-2 \pm 9.5\text{E}-4) \text{ gU/G}}{(7.277\text{E}-6 \pm 3.477\text{E}-7) \text{ gPu/G}} = 1821 \pm 157$$

This result demonstrates the degree of accuracy and precision expected from this type of chemical analysis.

The uncertainty was calculated from:

$$(A \pm \delta A)/(B \pm \delta B) = (A/B) \pm (A/B) \times \text{SQRT}((\delta A/A)^2 + (\delta B/B)^2)$$

Calculation of Plutonium mass in the sandfilter:

$$([\mu\text{Ci}(^{239}\text{Pu}+^{240}\text{Pu})/\text{G}] + [\mu\text{Ci}(^{239}\text{Pu}+^{240}\text{Pu})/\text{gPu}]) \times \text{G} = \text{gPu/G} \times \text{G} = \text{gPu}$$

$$\text{Pu} = (5.965\text{E}-1 \pm 2.85\text{E}-2) \mu\text{CiPu/G} / 8.197\text{E}+4 \mu\text{Ci}(^{239}\text{Pu}+^{240}\text{Pu})/\text{gPu} \times 5.87\text{E}+6 \text{ g}$$

$$= (7.277\text{E}-6 \pm 3.477\text{E}-7) \text{ gPu/G} \times 5.87\text{E}+6 \text{ g} = 42.7 \pm 2.0 \text{ gPu}$$

CALCULATION OF ²⁴¹AMERICIUM TO PLUTONIUM WEIGHT RATIO

Calculation of ²⁴¹Am/Pu weight ratio:

$$\{[\mu\text{Ci}^{241}\text{Am/G}] + [\mu\text{Ci}^{241}\text{Am/g}^{241}\text{Am}]\} + \{[\mu\text{Ci}^{239}\text{Pu} + ^{240}\text{Pu})/\text{G}] + [\mu\text{Ci}^{239}\text{Pu} + ^{240}\text{Pu})/\text{gPu}]\}$$

$$= \text{g}^{241}\text{Am/G} + \text{gPu/G} = ^{241}\text{Am/Pu}$$

first:

$$\frac{6.022045\text{E}+23 \text{ atoms/g-mole} \times \ln(2) \text{ dis/s/atom}}{241.056823 \text{ g } ^{241}\text{Am/g-mole}} \times \frac{1 \mu\text{Ci } ^{241}\text{Am}}{3.7\text{E}+4 \text{ dis/s}}$$

$$= 3.427\text{E}+6 \mu\text{Ci}^{241}\text{Am/g}^{241}\text{Am}$$

$$\frac{^{241}\text{Am}}{\text{Pu}} = \frac{(1.9215 + 1.6485) \mu\text{Ci}^{241}\text{Am/G} / 3.427\text{E}+6 \mu\text{Ci}^{241}\text{Am/g}^{241}\text{Am}}{(5.965\text{E}-1 \pm 2.85\text{E}-2) \mu\text{CiPu/G} / 8.197\text{E}+4 \mu\text{Ci}^{239}\text{Pu} + ^{240}\text{Pu})/\text{gPu}}$$

$$= \frac{(5.606\text{E}-7 \pm 4.810\text{E}-7) \text{ g}^{241}\text{Am/G}}{(7.277\text{E}-6 \pm 3.477\text{E}-7) \text{ gPu/G}} = 0.077 \pm 0.066 ^{241}\text{Am/Pu}$$

The ORIGEN2 calculation for ²⁴¹Am/Pu at 12 wt% ²⁴⁰Pu, 20 years decay is:

$$(4.763\text{E}+1 \text{ g } ^{241}\text{Am} / \text{MT}) / (2.196\text{E}+3 \text{ g Pu} / \text{MT}) = 0.021 ^{241}\text{Am/Pu}$$

The range of $0.077 \pm 0.066 ^{241}\text{Am/Pu}$ is 0.143 to 0.011,
which includes $0.021 ^{241}\text{Am/Pu}$

This result demonstrates the degree of accuracy and precision expected from this type of chemical analysis.

APPENDIX G.

CALCULATIONS ON ORIGEN2 OUTPUT FOR 12.8 Wt% ²⁴⁰Pu MKIV

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SELECTED ORIGEN2 RESULTS WITH SPREADSHEET CALCULATIONS
 Irradiation to 12.8 wt% ^{240}Pu , Decay times to 50 years
 ORIGEN2 output is grams per Metric Ton of Initial Heavy Metal
 Spreadsheet results are dimensionless, except the % for the ^{240}Pu Wt%

	DISCHARGE	5 yr	10 yr	15 yr	20 yr	25 yr	30 yr	35 yr	40 yr	45 yr	50 yr
PU240	282.5	282.4	282.2	282.1	281.9	281.8	281.7	281.5	281.4	281.2	281.1
PU241	77.18	60.67	47.69	37.49	29.47	23.17	18.21	14.32	11.25	8.846	6.954
AM241	0.8228	17.26	30.04	39.96	47.63	53.53	58.04	61.45	64.01	65.90	67.26
U	994700	994700	994700	994700	994700	994700	994700	994700	994700	994700	994700
NP	77.63	42.88	43.07	43.35	43.70	44.10	44.54	45.01	45.51	46.02	46.54
PU	2209	2229	2216	2205	2196	2189	2184	2180	2176	2173	2171
TOTAL	996900	996900	996900	996900	996900	996900	996900	996900	996900	996900	996900
^{240}Pu Wt%	12.789	12.669	12.735	12.794	12.837	12.873	12.898	12.913	12.932	12.941	12.948
U/Pu	450.3	446.3	448.9	451.1	453.0	454.4	455.4	456.3	457.1	457.8	458.2
Am/Pu	0.0004	0.0077	0.0136	0.0181	0.0217	0.0245	0.0266	0.0282	0.0294	0.0303	0.0310
$\frac{^{241}\text{Am}}{^{241}\text{Am} + ^{241}\text{Pu}}$	0.0105	0.2215	0.3865	0.5159	0.6178	0.6979	0.7612	0.8110	0.8505	0.8817	0.9063
^{241}Pu Wt%	3.4939	2.7218	2.1521	1.7002	1.3420	1.0585	0.8338	0.6569	0.5170	0.4071	0.3203
$^{241}\text{Pu}/^{240}\text{Pu}$	0.2732	0.2148	0.1690	0.1329	0.1045	0.0822	0.0646	0.0509	0.0400	0.0315	0.0247

The exposure or burnup for this ORIGEN2 calculation was selected to match the exposure or burnup representative of KE basin sludge analyses. These spreadsheet calculations were performed on the ORIGEN2 results which are included in Appendix I. The calculated values for the ^{240}Pu wt%, the U/Pu ratio, the $^{241}\text{Am}/\text{Pu}$ ratio, and the $\frac{^{241}\text{Am}}{^{241}\text{Am} + ^{241}\text{Pu}}$ ratio can all be seen to change with decay time. The 14.40 year half-life of ^{241}Pu which decays into ^{241}Am is the best method to ascertain the effective time since irradiation and reactor discharge.

These calculations, and taking 20 to 25 years of decay time, form the basis for the statement that the U/Pu ratio is approximately 455.

APPENDIX H.

ORIGEN2 INPUT FOR 12.8 Wt% ²⁴⁰Pu MKIV

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```

-1
-1
-1
TIT N-REACTOR Composite (Inner+Outer) MKIV: (12.6 PERCENT PU 240)
LIP 0 0 0
LIB 0 1 2 3 421 422 423 9 3 0 1 42
RDA 1 METRIC TON U(0.947 PCT ENRICHED) FOR MK IV OUTER FUEL
INP -1 1 -1 -1 1 1
RDA 1 METRIC TON U(0.947 PCT ENRICHED) FOR MK IV FUEL
INP -2 1 -1 -1 1 1
RDA 1 METRIC TON U(0.947 PCT ENRICHED) FOR MK IV AVE. FUEL
INP -3 1 -1 -1 1 1
RDA TRACE IMPURITIES IN A METRIC TON OF URANIUM
INP -4 1 -1 -1 1 1
RDA 1 METRIC TON ZIRCALOY
INP -5 1 -1 -1 1 1
RDA
BAS ONE METRIC TON OF URANIUM, MARK IV FUEL
RDA CREATE A VECTOR WITH ONE METRIC TON OF MK IV (OUTER) FUEL
MOV -1 1 0 1.0 URANIUM VECTOR
RDA ADD TRACE IMPURITIES IN URANIUM
ADD -4 1 0 1.0
RDA ADD 140.7 LB ZIRCALOY / SHORT TON URANIUM
ADD -5 1 0 0.07035 FRACTION BY WEIGHT
RDA
RDA NOTE: BURNUP IS MWD/SHORT TON; FUEL WEIGHT IS METRIC TON
RDA IRRADIATE MK IV FOR 3000MWD/TON (85 PCT CAPACITY FACTOR)
RDA
RDA IRRADIATE MK IV OUTER.
BUP
IRP 30.0 11.88 1 2 4 2 BURN 30.0 DAYS, TOTAL 30.0 DAYS
DEC 36.0 2 3 4 0 DECAY 6.0 DAYS
IRP 66.0 11.88 3 4 4 0 BURN 30.0 DAYS, TOTAL 60.0 DAYS
DEC 72.0 4 5 4 0 DECAY 6.0 DAYS
IRP 102.0 11.88 5 6 4 0 BURN 30.0 DAYS, TOTAL 90.0 DAYS
DEC 108.0 6 7 4 0 DECAY 6.0 DAYS
IRP 138.0 11.88 7 8 4 0 BURN 30.0 DAYS, TOTAL 120.0 DAYS
DEC 144.0 8 9 4 0 DECAY 6.0 DAYS
IRP 174.0 11.88 9 10 4 0 BURN 30.0 DAYS, TOTAL 150.0 DAYS
DEC 180.0 10 11 4 0 DECAY 6.0 DAYS
IRP 210.0 11.88 11 12 4 0 BURN 30.0 DAYS, TOTAL 180.0 DAYS
DEC 216.0 12 2 4 0 DECAY 6.0 DAYS
IRP 246.0 11.88 2 3 4 0 BURN 30.0 DAYS, TOTAL 210.0 DAYS
DEC 252.0 3 4 4 0 DECAY 6.0 DAYS
IRP 282.0 11.88 4 5 4 0 BURN 30.0 DAYS, TOTAL 240.0 DAYS
DEC 288.0 5 6 4 0 DECAY 6.0 DAYS
IRP 318.0 11.88 6 7 4 0 BURN 30.0 DAYS, TOTAL 270.0 DAYS
BUP
MOV 7 -7 0 1.0 SAVE RESULTS.
MOV 1 -8 0 1.0 SAVE INITIAL VECTOR.
RDA
STP 2
2 922350 0.00947E+6 922380 0.99006E+6 0 0.0
2 922340 0.00007E+6 922360 0.00040E+6 0 0.0
0

```



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2 922350 0.00947E+6 922380 0.99006E+6 0 0.0
2 922340 0.00007E+6 922360 0.00040E+6 0 0.0
0
2 922350 0.00947E+6 922380 0.99006E+6 0 0.0
2 922340 0.00007E+6 922360 0.00040E+6 0 0.0
0
4 130000 75. 500000 1.45E+4 260000 1350. 240000 1000. ZIRCALOY
4 280000 550. 60000 275. 920000 2.5 400000 0.9814E+5 ZIRCALOY
4 50000 0.5 480000 0.5 270000 10. 290000 50. ZIRCALOY
4 720000 200. 10000 25. 820000 100. 120000 20. ZIRCALOY
4 250000 50. 420000 50. 70000 80. 140000 100. ZIRCALOY
4 110000 20. 220000 50. 740000 50. 230000 50. ZIRCALOY
0
4 400000 65. 290000 75. 480000 0.25 40000 10. IMPURITIES IN
4 130000 800. 10000 2. 140000 125. 280000 100. 1 METRIC TON
4 250000 25. 120000 25. 260000 350. 240000 65. OF
4 50000 2.25 70000 75. 60000 550. 0 0.0 URANIUM
0
RDA
LIB 0 1 2 3 411 412 413 9 3 0 1 41
RDA
RDA CREATE A VECTOR WITH ONE METRIC TON OF MK IV (INNER) FUEL
MOV -2 1 0 1.0 URANIUM VECTOR
RDA ADD TRACE IMPURITIES IN URANIUM
ADD -4 1 0 1.0
RDA ADD 140.7 LB ZIRCALOY / SHORT TON URANIUM
ADD -5 1 0 0.07035 FRACTION BY WEIGHT
RDA IRRADIATE MK IV INNER.
BUP
IRP 30.0 9.13 1 2 4 2 BURN 30.0 DAYS, TOTAL 30.0 DAYS
DEC 36.0 2 3 4 0 DECAY 6.0 DAYS
IRP 66.0 9.13 3 4 4 0 BURN 30.0 DAYS, TOTAL 60.0 DAYS
DEC 72.0 4 5 4 0 DECAY 6.0 DAYS
IRP 102.0 9.13 5 6 4 0 BURN 30.0 DAYS, TOTAL 90.0 DAYS
DEC 108.0 6 7 4 0 DECAY 6.0 DAYS
IRP 138.0 9.13 7 8 4 0 BURN 30.0 DAYS, TOTAL 120.0 DAYS
DEC 144.0 8 9 4 0 DECAY 6.0 DAYS
IRP 174.0 9.13 9 10 4 0 BURN 30.0 DAYS, TOTAL 150.0 DAYS
DEC 180.0 10 11 4 0 DECAY 6.0 DAYS
IRP 210.0 9.13 11 12 4 0 BURN 30.0 DAYS, TOTAL 180.0 DAYS
DEC 216.0 12 2 4 0 DECAY 6.0 DAYS
IRP 246.0 9.13 2 3 4 0 BURN 30.0 DAYS, TOTAL 210.0 DAYS
DEC 252.0 3 4 4 0 DECAY 6.0 DAYS
IRP 282.0 9.13 4 5 4 0 BURN 30.0 DAYS, TOTAL 240.0 DAYS
DEC 288.0 5 6 4 0 DECAY 6.0 DAYS
IRP 318.0 9.13 6 7 4 0 BURN 30.0 DAYS, TOTAL 270.0 DAYS
BUP
RDA COMBINE FOR COMPOSITE
RDA VECTOR
RDA 1 INNER INITIAL
RDA -8 OUTER INITIAL
RDA 7 INNER FINAL
RDA -7 OUTER FINAL
RDA
MOV 1 -6 0 0.317

```

```

ADD      -8 -6 0 0.683
MOV      -6 1 0 1.0
RDA
MOV      7 2 0 0.317
ADD      -7 2 0 0.683
RDA
DEC      5.0      2 3 5 1
DEC      10.0     3 4 5 0
DEC      15.0     4 5 5 0
DEC      20.0     5 6 5 0
DEC      25.0     6 7 5 0
DEC      30.0     7 8 5 0
DEC      35.0     8 9 5 0
DEC      40.0     9 10 5 0
DEC      45.0    10 11 5 0
DEC      50.0    11 12 5 0
CUT      5 1.E-05 7 1.E-05 9 1.E-05 10 1.E-05 27 1.0 -1
HED      1 CHARGE
HED      2 DISCHARGE
OPTA     8 8 8 8 4 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTL     8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTF     8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OUT      12 1 -1 0
RDA
STP      4
END

```

APPENDIX I.

ORIGEN2 OUTPUT FOR 12.8 Wt% ²⁴⁰Pu MKIV

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1
 0 ***** OUTPUT UNIT = 6 PAGE 1 *****

 ***** ORIGEN2: A REVISED AND UPDATED VERSION OF THE ORIGEN COMPUTER CODE *****

INTRODUCTION

THIS TEXT IS INTENDED TO BE A BRIEF OUTLINE OF THE ORIGEN2 COMPUTER CODE, WHICH IS A REVISED AND UPDATED VERSION OF THE ORIGEN DOCUMENTED IN REPORT ORNL-4628 (MAY 1973). INCLUDED WERE ARE A BRIEF DESCRIPTION OF THE FUNCTIONS OF ORIGEN2, A LISTING OF THE MAJOR DATA SOURCES, A LISTING OF THE PUBLISHED DOCUMENTATION CONCERNING ORIGEN2, AND AN OUTLINE OF THE ORIGEN2 OUTPUT ORGANIZATION. ORIGEN2 IS AVAILABLE FROM THE ORNL RADIATION SHIELDING INFORMATION CENTER (RSIC) AT THE FOLLOWING ADDRESS:

CODES COORDINATOR
 RADIATION SHIELDING INFORMATION CENTER
 BLDG. 6025
 OAK RIDGE NATIONAL LABORATORY
 OAK RIDGE, TENNESSEE 37830
 PHONE: (615) 576-6176

QUESTIONS CONCERNING ORIGEN2 SHOULD BE ADDRESSED TO RSIC.

-DESCRIPTION

ORIGEN2 IS A REVISION AND UPDATE OF THE ORIGEN COMPUTER CODE. SPECIFICALLY, THE INPUT, OUTPUT, CONTROL, AND DATA BASE ASPECTS OF ORIGEN HAVE BEEN SIGNIFICANTLY REVISED AND UPDATED TO REFLECT CURRENT INFORMATION AND NEEDS. IT SHOULD BE NOTED THAT THE MATHEMATICAL METHODS USED TO SOLVE THE NUCLEIDE BUILDUP, DEPLETION, AND DECAY EQUATIONS ARE ESSENTIALLY UNCHANGED FROM THAT IN ORIGEN. ORIGEN2 IS A COMPUTER CODE DESIGNED TO CALCULATE THE COMPOSITION AND CHARACTERISTICS OF NUCLEAR MATERIALS AS A FUNCTION OF DECAY TIME AND THE CHANGES THE MATERIALS UNDERGO DURING VARIOUS FUEL CYCLE OPERATIONS. INPUT AND OUTPUT FEATURES HAVE BEEN DESIGNED TO FACILITATE FLEXIBILITY IN THE TYPE OF CASES THAT CAN BE CONSIDERED AND IN CONTROLLING THE DETAIL OF THE OUTPUT. FOR FURTHER INFORMATION, THE USER IS REFERRED TO THE DOCUMENTATION LISTED BELOW.

-MAJOR DATA SOURCES

VIRTUALLY ALL ASPECTS OF THE DATA INPUT TO ORIGEN2 HAVE BEEN UPDATED OR REVISED TO REFLECT CURRENT INFORMATION. THE PRINCIPAL SOURCES OF CROSS SECTION DATA WERE THE ENDF/B-IV, ENDF/B-V, AND LENDL COMPILATIONS. DECAY AND PHOTON INFORMATION WERE PRIMARILY BASED ON THE EVALUATED NUCLEAR STRUCTURE DATA FILE (ENSDF) AT ORNL AND ENDF/B-IV. DATA CONCERNING REACTOR AND FUEL CHARACTERISTICS WERE OBTAINED FROM REFERENCE SAFETY ANALYSIS REPORTS AND, WHERE POSSIBLE, THE COMMERCIAL REACTOR VENDORS.

-DOCUMENTATION

THE FOLLOWING ITEMS CONSTITUTE THE ORIGEN2 DOCUMENTATION PUBLISHED AS OF THE DATE OF THIS CODE PACKAGE:

- A.G. CROFF, "ORIGEN2 - A REVISED AND UPDATED VERSION OF THE OAK RIDGE ISOTOPE GENERATION AND DEPLETION CODE", ORNL-5621 (JULY 1980).
- A.G. CROFF, "A USER'S MANUAL FOR THE ORIGEN2 COMPUTER CODE", ORNL/TM-7175 (JULY 1980).
- A.G. CROFF, M.A. BJERKE, G.W. MORRISON, AND L.M. PETRIE, "REVISED URANIUM-PLUTONIUM CYCLE PWR AND BWR MODELS FOR THE ORIGEN COMPUTER CODE", ORNL/TM-6051 (SEPTEMBER 1978).
- A.G. CROFF AND M.A. BJERKE, "ALTERNATIVE FUEL CYCLE PWR MODELS FOR THE ORIGEN COMPUTER CODE", ORNL/TM-7005 (FEB 1980).
- A.G. CROFF, R.L. MAESE, AND H.B. GOVE, "UPDATED DECAY AND PHOTON LIBRARIES FOR THE ORIGEN CODE", ORNL/TM-6055 (FEB 1979).
- A.G. CROFF, "ORIGEN2: A REVISED AND UPDATED VERSION OF ORIGEN", TRANS. AM. NUCL. SOC., VOL. 34, P. 349-50 (JUNE 1980).

1
 0 ***** OUTPUT UNIT = 6 PAGE 2 *****

 ***** ORIGEN2: A REVISED AND UPDATED VERSION OF THE ORIGEN COMPUTER CODE *****

ORGANIZATION OF ORIGEN2 OUTPUT

PAST EXPERIENCE HAS INDICATED THAT MANY USERS ENCOUNTER CONSIDERABLE DIFFICULTY IN FINDING THE DESIRED INFORMATION IN A ORIGEN2 OUTPUT WHICH IS SOMETIMES RATHER MASSIVE. THIS SECTION IS INTENDED AS A BRIEF OUTLINE OF THE ORGANIZATION OF ORIGEN2 OUTPUT. FOR DETAILS REFER TO THE USER'S MANUAL (ORNL/TM-7175, SECT. 8.2). THE ORIGEN2 OUTPUT IS EXTREMELY HIERARCHICAL, AND IS ORGANIZED AS FOLLOWS:

0 CARD INPUT ECHO
 MISCELLANEOUS INPUT DATA (NEUTRON YIELDS, REPROCESSING LOSSES, ELEMENT CHEMICAL TOXICITIES
 LISTING OF ORIGEN2 COMMANDS CURRENTLY BEING EXECUTED
 LISTING OF ORIGEN2 DATA LIBRARIES (IF SPECIFIED)
 DECAY LIBRARY
 ACTIVATION PRODUCTS
 ACTINIDES
 FISSION PRODUCTS
 CROSS SECTION/FISSION PRODUCT YIELD LIBRARY
 ACTIVATION PRODUCTS, ACTINIDES, AND FISSION PRODUCTS
 PHOTON LIBRARY
 ACTIVATION PRODUCTS, ACTINIDES, AND FISSION PRODUCTS
 OUTPUT 1
 REACTIVITY AND BURUP DATA
 ACTIVATION PRODUCT TABLES
 GRAM TABLES (NUCLIDE, ELEMENT, NUCLIDE SUMMARY, ELEMENT SUMMARY)
 CURIE TABLES (NUCLIDE, ELEMENT, NUCLIDE SUMMARY, ELEMENT SUMMARY)
 ETC. (DEPENDING ON THE OUTPUT OPTIONS SPECIFIED, MANY OF THESE TABLES MAY BE OMITTED)

ACTINIDE TABLES
 SAME SUBHEADINGS POSSIBLE AS UNDER ACTIVATION PRODUCT TABLES
 FISSION PRODUCT TABLES
 SAME SUBHEADINGS POSSIBLE AS UNDER ACTIVATION PRODUCT TABLES
 NEUTRON PRODUCTION RATE TABLES: (ALPHA,N) AND SPONTANEOUS FISSION
 PHOTON TABLES
 ACTIVATION PRODUCTS (SUMMATION AND PRINCIPAL CONTRIBUTORS)
 ACTINIDES (SUMMATION AND PRINCIPAL CONTRIBUTORS)
 FISSION PRODUCTS (SUMMATION AND PRINCIPAL CONTRIBUTORS)

OUTPUT 2
 SAME GENERAL CONTENT AND ORDER AS OUTPUT 1

OUTPUT N
 SAME GENERAL CONTENT AND ORDER AS OUTPUT 1
 TABLE OF CONTENTS (UNIT 12) FOR THE ABOVE (UNIT 6) OUTPUT
 VARIABLE CROSS SECTION INFORMATION OUTPUT (UNIT 16)
 DEBUGGING AND OTHER INTERNAL INFORMATION OUTPUT (UNIT 15)

0 THE SCENARIO LISTED ABOVE CONSTITUTES A TYPICAL ORIGEN2 OUTPUT FOR MANY CASES. ONE POSSIBLE MODIFICATION IS THE USE OF AN
 STP COMMAND TO EXECUTE AN ADDITIONAL SET OF INSTRUCTIONS AFTER THE FIRST SET HAS BEEN EXECUTED. IF THIS IS DONE, THE OUTPUT
 WILL BEGIN WITH "MISCELLANEOUS INPUT DATA" IF NSTP=1, "ORIGEN2 COMMANDS CURRENTLY BEING EXECUTED" IF NSTP=2, OR "OUTPUT 1"
 FOR NSTP=3. ANOTHER OFTEN-USED OPTION IS TO EMPLOY BOTH THE PRIMARY (UNIT 6) AND ALTERNATE (UNIT 11) OUTPUT UNITS. IF BOTH
 ARE ROUTED TO PAPER, THE TABLE OF CONTENTS FOR UNIT 11, WHICH IS ON UNIT 13, WILL IMMEDIATELY FOLLOW THE DEBUGGING AND
 INTERNAL INFORMATION (UNIT 15) OUTPUT. THE "OUTPUT N" TABLES FOR UNIT 11 WILL BE PRINTED FOLLOWING THE TABLE OF CONTENTS.

1 LISTING OF INPUT DATA ON UNIT = 5

INPUT UNIT	WRITE UNIT	CARD NUMBER	CARD IMAGE
5	50	1	-1
5	50	2	-1
5	50	3	-1
5	50	4	TIT H-REACTOR Composite (Inner+Outer) MKIV: (12.6 PERCENT PU 240)
5	50	5	LIP 0 0 0
5	50	6	LIB 0 1 2 3 421 422 423 9 3 0 1 42
5	50	7	RDA 1 METRIC TON U(0.947 PCT ENRICHED) FOR MK IV OUTER FUEL

```

5 50 8 INP -1 1 -1 -1 1 1
5 50 9 RDA 1 METRIC TON U(0.947 PCT ENRICHED) FOR MK IV FUEL
5 50 10 IMP -2 1 -1 -1 1 1
5 50 11 RDA 1 METRIC TON U(0.947 PCT ENRICHED) FOR MK IV AVE. FUEL
5 50 12 INP -3 1 -1 -1 1 1
5 50 13 RDA TRACE IMPURITIES IN A METRIC TON OF URANIUM
5 50 14 IMP -4 1 -1 -1 1 1
5 50 15 RDA 1 METRIC TON ZIRCALOY
5 50 16 IMP -5 1 -1 -1 1 1
5 50 17 RDA
5 50 18 DAS ONE METRIC TON OF URANIUM, MARK IV FUEL
5 50 19 RDA CREATE A VECTOR WITH ONE METRIC TON OF MK IV (OUTER) FUEL
5 50 20 MOV -1 1 0 1.0 URANIUM VECTOR
5 50 21 RDA ADD TRACE IMPURITIES IN URANIUM
5 50 22 ADD -4 1 0 1.0
5 50 23 RDA ADD 140.7 LB ZIRCALOY / SHORT TON URANIUM
5 50 24 ADD -5 1 0 0.07035 FRACTION BY WEIGHT
5 50 25 RDA
5 50 26 RDA NOTE: BURNUP IS MW/SHORT TON; FUEL WEIGHT IS METRIC TON
5 50 27 RDA IRRADIATE MK IV FOR 3000MW/TON (85 PCT CAPACITY FACTOR)
5 50 28 RDA
5 50 29 RDA IRRADIATE MK IV OUTER.
5 50 30 BUP
5 50 31 INP 30.0 11.88 1 2 4 2 BURN 30.0 DAYS, TOTAL 30.0 DAYS
5 50 32 DEC 36.0 2 3 4 0 DECAY 6.0 DAYS
5 50 33 IRP 66.0 11.88 3 4 4 0 BURN 30.0 DAYS, TOTAL 60.0 DAYS
5 50 34 DEC 72.0 4 5 4 0 DECAY 6.0 DAYS
5 50 35 IRP 102.0 11.88 5 6 4 0 BURN 30.0 DAYS, TOTAL 90.0 DAYS
5 50 36 DEC 108.0 6 7 4 0 DECAY 6.0 DAYS
5 50 37 IRP 138.0 11.88 7 8 4 0 BURN 30.0 DAYS, TOTAL 120.0 DAYS
5 50 38 DEC 144.0 8 9 4 0 DECAY 6.0 DAYS
5 50 39 IRP 174.0 11.88 9 10 4 0 BURN 30.0 DAYS, TOTAL 150.0 DAYS
5 50 40 DEC 180.0 10 11 4 0 DECAY 6.0 DAYS
5 50 41 IRP 210.0 11.88 11 12 4 0 BURN 30.0 DAYS, TOTAL 180.0 DAYS
5 50 42 DEC 216.0 12 2 4 0 DECAY 6.0 DAYS
5 50 43 IRP 246.0 11.88 2 3 4 0 BURN 30.0 DAYS, TOTAL 210.0 DAYS
5 50 44 DEC 252.0 3 4 4 0 DECAY 6.0 DAYS
5 50 45 IRP 282.0 11.88 4 5 4 0 BURN 30.0 DAYS, TOTAL 240.0 DAYS
5 50 46 DEC 288.0 5 6 4 0 DECAY 6.0 DAYS
5 50 47 IRP 318.0 11.88 6 7 4 0 BURN 30.0 DAYS, TOTAL 270.0 DAYS
5 50 48 BUP
5 50 49 MOV 7 -7 0 1.0 SAVE RESULTS.

```

1
LISTING OF INPUT DATA ON UNIT = 5

PAGE 4

INPUT UNIT	WRITE UNIT	CARD NUMBER	CARD IMAGE
5	50	50	MOV 1 -8 0 1.0 SAVE INITIAL VECTOR.
5	50	51	RDA
5	50	52	STP 2
5	50	53	2 922350 0.00947E+6 922380 0.99006E+6 0 0.0
5	50	54	2 922340 0.00007E+6 922360 0.00040E+6 0 0.0
5	50	55	0
5	50	56	2 922350 0.00947E+6 922380 0.99006E+6 0 0.0
5	50	57	2 922340 0.00007E+6 922360 0.00040E+6 0 0.0
5	50	58	0
5	50	59	2 922350 0.00947E+6 922380 0.99006E+6 0 0.0

```

5 50 60 2 922340 0.00007E+6 922360 0.00040E+6 0 0.0
5 50 61 0
5 50 62 4 130000 75. 500000 1.45E+4 260000 1350. 240000 1000. ZIRCALOY
5 50 63 4 280000 550. 60000 275. 920000 2.5 400000 0.9814E+6 ZIRCALOY
5 50 64 4 50000 0.5 400000 0.5 270000 10. 290000 50. ZIRCALOY
5 50 65 4 720000 200. 10000 25. 820000 100. 120000 20. ZIRCALOY
5 50 66 4 250000 50. 420000 50. 70000 80. 140000 100. ZIRCALOY
5 50 67 4 110000 20. 220000 50. 740000 50. 230000 50. ZIRCALOY
5 50 68 0
5 50 69 4 400000 65. 290000 75. 480000 0.25 40000 10. IMPURITIES IN
5 50 70 4 130000 800. 10000 2. 140000 125. 280000 100. 1 METRIC TON
5 50 71 4 250000 25. 120000 25. 260000 350. 240000 65. OF
5 50 72 4 50000 2.25 70000 75. 60000 550. 0 0.0 URANIUM
5 50 73 0
5 50 74 RDA
5 50 75 LIB 0 1 2 3 411 412 413 9 3 0 1 41
5 50 76 RDA
5 50 77 RDA CREATE A VECTOR WITH ONE METRIC TON OF NK IV (INNER) FUEL
5 50 78 MOV -2 1 0 1.0 URANIUM VECTOR
5 50 79 RDA ADD TRACE IMPURITIES IN URANIUM
5 50 80 ADD -4 1 0 1.0
5 50 81 RDA ADD 140.7 LB ZIRCALOY / SHORT TON URANIUM
5 50 82 ADD -5 1 0 0.07035 FRACTION BY WEIGHT
5 50 83 RDA IRRADIATE NK IV INNER.
5 50 84 BLP
5 50 85 IRP 30.0 9.13 1 2 4 2 BURN 30.0 DAYS, TOTAL 30.0 DAYS
5 50 86 DEC 36.0 2 3 4 0 DECAY 6.0 DAYS
5 50 87 IRP 66.0 9.13 3 4 4 0 BURN 30.0 DAYS, TOTAL 60.0 DAYS
5 50 88 DEC 72.0 4 5 4 0 DECAY 6.0 DAYS
5 50 89 IRP 102.0 9.13 5 6 4 0 BURN 30.0 DAYS, TOTAL 90.0 DAYS
5 50 90 DEC 108.0 6 7 4 0 DECAY 6.0 DAYS
5 50 91 IRP 130.0 9.13 7 8 4 0 BURN 30.0 DAYS, TOTAL 120.0 DAYS
5 50 92 DEC 144.0 8 9 4 0 DECAY 6.0 DAYS
5 50 93 IRP 174.0 9.13 9 10 4 0 BURN 30.0 DAYS, TOTAL 150.0 DAYS
5 50 94 DEC 180.0 10 11 4 0 DECAY 6.0 DAYS
5 50 95 IRP 210.0 9.13 11 12 4 0 BURN 30.0 DAYS, TOTAL 180.0 DAYS
5 50 96 DEC 216.0 12 2 4 0 DECAY 6.0 DAYS
5 50 97 IRP 246.0 9.13 2 3 4 0 BURN 30.0 DAYS, TOTAL 210.0 DAYS
5 50 98 DEC 252.0 3 4 4 0 DECAY 6.0 DAYS
5 50 99 IRP 282.0 9.13 4 5 4 0 BURN 30.0 DAYS, TOTAL 240.0 DAYS

```

LISTING OF INPUT DATA ON UNIT = 5

PAGE 5

INPUT UNIT	WRITE UNIT	CARD NUMBER	CARD IMAGE
5	50	100	DEC 285.0 5 6 4 0 DECAY 6.0 DAYS
5	50	101	IRP 318.0 9.13 6 7 4 0 BURN 30.0 DAYS, TOTAL 270.0 DAYS
5	50	102	BLP
5	50	103	RDA COMBINE FOR COMPOSITE
5	50	104	RDA VECTOR
5	50	105	RDA 1 INNER INITIAL
5	50	106	RDA -8 OUTER INITIAL
5	50	107	RDA 7 INNER FINAL
5	50	108	RDA -7 OUTER FINAL
5	50	109	RDA
5	50	110	MOV 1 -6 0 0.317
5	50	111	ADD -8 -6 0 0.683

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[illegible]

GROUP FRACTIONAL RECOVERIES									
GROUP	SET NUMBER	SET NUMBER	SET NUMBER	SET NUMBER	SET NUMBER	SET NUMBER	SET NUMBER	SET NUMBER	SET NUMBER
1	1	2	3	4	5	6	7	8	9
2	10	11	12	13	14	15	16	17	18
3	19	20	21	22	23	24	25	26	27
4	28	29	30	31	32	33	34	35	36
5	37	38	39	40	41	42	43	44	45
6	46	47	48	49	50	51	52	53	54
7	55	56	57	58	59	60	61	62	63
8	64	65	66	67	68	69	70	71	72
9	73	74	75	76	77	78	79	80	81
10	82	83	84	85	86	87	88	89	90
11	91	92	93	94	95	96	97	98	99
12	100	101	102	103	104	105	106	107	108
13	109	110	111	112	113	114	115	116	117
14	118	119	120	121	122	123	124	125	126
15	127	128	129	130	131	132	133	134	135
16	136	137	138	139	140	141	142	143	144
17	145	146	147	148	149	150	151	152	153
18	154	155	156	157	158	159	160	161	162
19	163	164	165	166	167	168	169	170	171
20	172	173	174	175	176	177	178	179	180
21	181	182	183	184	185	186	187	188	189
22	190	191	192	193	194	195	196	197	198
23	199	200	201	202	203	204	205	206	207
24	208	209	210	211	212	213	214	215	216
25	217	218	219	220	221	222	223	224	225
26	226	227	228	229	230	231	232	233	234
27	235	236	237	238	239	240	241	242	243
28	244	245	246	247	248	249	250	251	252
29	253	254	255	256	257	258	259	260	261
30	262	263	264	265	266	267	268	269	270
31	271	272	273	274	275	276	277	278	279
32	280	281	282	283	284	285	286	287	288
33	289	290	291	292	293	294	295	296	297
34	298	299	300	301	302	303	304	305	306
35	307	308	309	310	311	312	313	314	315
36	316	317	318	319	320	321	322	323	324
37	325	326	327	328	329	330	331	332	333
38	334	335	336	337	338	339	340	341	342
39	343	344	345	346	347	348	349	350	351
40	352	353	354	355	356	357	358	359	360
41	361	362	363	364	365	366	367	368	369
42	370	371	372	373	374	375	376	377	378
43	379	380	381	382	383	384	385	386	387
44	388	389	390	391	392	393	394	395	396
45	397	398	399	400	401	402	403	404	405
46	406	407	408	409	410	411	412	413	414
47	415	416	417	418	419	420	421	422	423
48	424	425	426	427	428	429	430	431	432
49	433	434	435	436	437	438	439	440	441
50	442	443	444	445	446	447	448	449	450
51	451	452	453	454	455	456	457	458	459
52	460	461	462	463	464	465	466	467	468
53	469	470	471	472	473	474	475	476	477
54	478	479	480	481	482	483	484	485	486
55	487	488	489	490	491	492	493	494	495
56	496	497	498	499	500	501	502	503	504
57	505	506	507	508	509	510	511	512	513
58	514	515	516	517	518	519	520	521	522
59	523	524	525	526	527	528	529	530	531
60	532	533	534	535	536	537	538	539	540
61	541	542	543	544	545	546	547	548	549
62	550	551	552	553	554	555	556	557	558
63	559	560	561	562	563	564	565	566	567
64	568	569	570	571	572	573	574	575	576
65	577	578	579	580	581	582	583	584	585
66	586	587	588	589	590	591	592	593	594
67	595	596	597	598	599	600	601	602	603
68	604	605	606	607	608	609	610	611	612
69	613	614	615	616	617	618	619	620	621
70	622	623	624	625	626	627	628	629	630
71	631	632	633	634	635	636	637	638	639
72	640	641	642	643	644	645	646	647	648
73	649	650	651	652	653	654	655	656	657
74	658	659	660	661	662	663	664	665	666
75	667	668	669	670	671	672	673	674	675
76	676	677	678	679	680	681	682	683	684
77	685	686	687	688	689	690	691	692	693
78	694	695	696	697	698	699	700	701	702
79	703	704	705	706	707	708	709	710	711
80	712	713	714	715	716	717	718	719	720
81	721	722	723	724	725	726	727	728	729
82	730	731	732	733	734	735	736	737	738
83	739	740	741	742	743	744	745	746	747
84	748	749	750	751	752	753	754	755	756
85	757	758	759	760	761	762	763	764	765
86	766	767	768	769	770	771	772	773	774
87	775	776	777	778	779	780	781	782	783
88	784	785	786	787	788	789	790	791	792
89	793	794	795	796	797	798	799	800	801
90	802	803	804	805	806	807	808	809	810
91	811	812	813	814	815	816	817	818	819
92	820	821	822	823	824	825	826	827	828
93	829	830	831	832	833	834	835	836	837
94	838	839	840	841	842	843	844	845	846
95	847	848	849	850	851	852	853	854	855
96	856	857	858	859	860	861	862	863	864
97	865	866	867	868	869	870	871	872	873
98	874	875	876	877	878	879	880	881	882
99	883	884	885	886	887	888	889	890	891
100	892	893	894	895	896	897	898	899	900

[illegible][illegible][illegible]

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OUTPUT UNIT = 6

N-REACTOR Composite (Inner+Outer) MKIV: (12.6 PERCENT PU 240)

111 0

 

817. 817 0

0 RDY 0 RDY

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001 0

0 004 0004

1 METRIC TON (0.947 PCT ENRICHED) FOR MK IV OUTER FUEL

1. The first step is to identify the problem or question that needs to be answered. This involves understanding the context and the specific requirements of the task.

1 1 1- 1- 1 1-

1 METRIC TON (90.947 PCT ENRICHED) FOR MK IV FUEL

 

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7 0 INP *INP      -2 1 -1 -1 1 1
8 0 RDA *RDA      1 METRIC TON U(0.947 PCT ENRICHED) FOR MK IV AVE. FUEL
9 0 INP *INP      -3 1 -1 -1 1 1
10 0 RDA *RDA      TRADE IMPURITIES IN A METRIC TON OF URANIUM
11 0 INP *INP      -4 1 -1 -1 1 1
12 0 RDA *RDA      1 METRIC TON ZIRCALOY
13 0 INP *INP      -5 1 -1 -1 1 1
14 0 RDA *RDA
15 0 BAS *BAS      ONE METRIC TON OF URANIUM, MARK IV FUEL
16 0 RDA *RDA      CREATE A VECTOR WITH ONE METRIC TON OF MK IV (OUTER) FUEL
17 0 MOV *MOV      -1 1 0 1.0 URANIUM VECTOR
18 0 RDA *RDA      ADD TRACE IMPURITIES IN URANIUM
19 0 ADD *ADD      -4 1 0 1.0
20 0 RDA *RDA      ADD 140.7 LB ZIRCALOY / SHORT TON URANIUM
21 0 ADD *ADD      -5 1 0 0.07035 FRACTION BY WEIGHT
22 0 RDA *RDA
23 0 RDA *RDA      NOTE: BURNUP IS MW/SHORT TON; FUEL WEIGHT IS METRIC TON
24 0 RDA *RDA      IRRADIATE MK IV FOR 3000MW/TON (85 PCT CAPACITY FACTOR)
25 0 RDA *RDA
26 0 RDA *RDA      IRRADIATE MK IV OUTER.
27 0 BUP *BUP
28 0 IRP *IRP      30.0 11.88 1 2 4 2 BURN 30.0 DAYS, TOTAL 30.0 DAYS
29 0 DEC *DEC      36.0 2 3 4 0 DECAY 6.0 DAYS
30 0 IRP *IRP      66.0 11.88 3 4 4 0 BURN 30.0 DAYS, TOTAL 60.0 DAYS
31 0 DEC *DEC      72.0 4 5 4 0 DECAY 6.0 DAYS
32 0 IRP *IRP      102.0 11.88 5 6 4 0 BURN 30.0 DAYS, TOTAL 90.0 DAYS
33 0 DEC *DEC      108.0 6 7 4 0 DECAY 6.0 DAYS
34 0 IRP *IRP      138.0 11.88 7 8 4 0 BURN 30.0 DAYS, TOTAL 120.0 DAYS
35 0 DEC *DEC      144.0 8 9 4 0 DECAY 6.0 DAYS
36 0 IRP *IRP      174.0 11.88 9 10 4 0 BURN 30.0 DAYS, TOTAL 150.0 DAYS
37 0 DEC *DEC      180.0 10 11 4 0 DECAY 6.0 DAYS
38 0 IRP *IRP      210.0 11.88 11 12 4 0 BURN 30.0 DAYS, TOTAL 180.0 DAYS
39 0 DEC *DEC      216.0 12 2 4 0 DECAY 6.0 DAYS
40 0 IRP *IRP      246.0 11.88 2 3 4 0 BURN 30.0 DAYS, TOTAL 210.0 DAYS
41 0 DEC *DEC      252.0 3 4 4 0 DECAY 6.0 DAYS
42 0 IRP *IRP      282.0 11.88 4 5 4 0 BURN 30.0 DAYS, TOTAL 240.0 DAYS
43 0 DEC *DEC      288.0 5 6 4 0 DECAY 6.0 DAYS
44 0 IRP *IRP      318.0 11.88 6 7 4 0 BURN 30.0 DAYS, TOTAL 270.0 DAYS
45 0 BUP *BUP
46 0 MOV *MOV      7 -7 0 1.0 SAVE RESULTS.
47 0 MOV *MOV      1 -8 0 1.0 SAVE INITIAL VECTOR.
48 0 RDA *RDA
49 0 STP *STP      2

```

OSUM OF YIELDS FOR EACH FISSION ISOTOPE: 0.0000E+00 0.0000E+00 2.0001E+00 2.0002E+00 2.0006E+00 2.0003E+00
 ISOTOPIES FOR WHICH YIELDS ARE EXPLICITLY ACCOUNTED FOR: 922350 922380 942390 942410

OUTPUT UNIT = 6

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```

1 0 RDA *RDA
2 0 LIB *LIB      0 1 2 3 411 412 413 9 3 0 1 41
3 0 RDA *RDA
4 0 RDA *RDA      CREATE A VECTOR WITH ONE METRIC TON OF MK IV (INNER) FUEL
5 0 MOV *MOV      -2 1 0 1.0 URANIUM VECTOR
6 0 RDA *RDA      ADD TRACE IMPURITIES IN URANIUM
7 0 ADD *ADD      -4 1 0 1.0
8 0 RDA *RDA      ADD 140.7 LB ZIRCALOY / SHORT TON URANIUM
9 0 ADD *ADD      -5 1 0 0.07035 FRACTION BY WEIGHT
10 0 RDA *RDA      IRRADIATE MK IV INNER.
11 0 BUP *BUP

```

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*N-REACTOR Composite (Inner+Outer) HKIV: (12.6 PERCENT PU 240)

POWER= 8.11404E+00 MW, BURNUP= 2.19079E+03 MWD, FLUX= 1.28E+14 N/CM**2-SEC
 REACTIVITY AND BURNUP DATA
 BASIS=ONE METRIC TON OF URANIUM, MARK IV FUEL

	CHARGE	DISCHARGE	5.0YR	10.0YR	15.0YR	20.0YR	25.0YR	30.0YR	35.0YR	40.0YR	45.0YR	50.0YR
TIME, SEC	0.00E+00	2.75E+07	1.58E+08	3.16E+08	4.73E+08	6.31E+08	7.89E+08	9.47E+08	1.10E+09	1.26E+09	1.42E+09	1.58E+09
NEUT. FLUX	0.00E+00	1.31E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SP POW,MW	0.00E+00	8.11E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BURNUP,MWD	0.00E+00	2.43E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K INFINITY	0.00000	1.20083	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
NEUT PROD	0.00E+00	4.22E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
NEUT DESTN	0.00E+00	3.51E+03	4.44E+03	4.44E+03	4.44E+03	4.44E+03	4.44E+03	4.44E+03	4.44E+03	4.44E+03	4.44E+03	4.44E+03
TOT BURNUP	0.00E+00	2.19E+03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AVG N FLUX	0.00E+00	1.28E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AVG SP POW	0.00E+00	8.11E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

SIZE OF NMAX(1): NMAX= 1 #= 876 NMAX= 2 #= 432 NMAX= 3 #= 142 NMAX= 4 #= 49 NMAX= 5 #= 91 NMAX= 6 #= 53
 NMAX= 7 #= 46 NMAX= 8 #= 0 NMAX= 9 #= 0 NMAX=10 #= 0 NMAX=11 #= 0 NMAX=12 #= 0

THE NUMBER OF NON-ZERO TERMS IN A=6435
 THE NUMBER OF NON-ZERO FISSION PRODUCT YIELDS=3242
 ILITE= 688 ACT= 129 IFP= 879 ITOT=1696
 THE NUMBER OF N-ZERO NATURAL ABUNDANCES= 437
 THE NUMBER OF NON-ZERO PHOTON YIELDS= 0
 THE MAXIMUM NUMBER OF TERMS IN AP= 3409

TOTAL 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
 OUTPUT UNIT = 6 PAGE 17

*N-REACTOR Composite (Inner+Outer) MKIV: (12.6 PERCENT PU 240)

ACTINIDES+DAUGHTERS

POWER= 8.11404E+00 MW, BURNUP= 2.19079E+03 MWD, FLUX= 1.28E+14 N/CM**2-SEC
 5 SUMMARY TABLE: CONCENTRATIONS, GRAMS
 ONE METRIC TON OF URANIUM, MARK IV FUEL

	CHARGE	DISCHARGE	5.0YR	10.0YR	15.0YR	20.0YR	25.0YR	30.0YR	35.0YR	40.0YR	45.0YR	50.0YR
U234	7.000E+01	6.452E+01	6.468E+01	6.478E+01	6.491E+01	6.502E+01	6.514E+01	6.525E+01	6.535E+01	6.546E+01	6.555E+01	6.565E+01
U235	9.470E+03	6.906E+03	6.906E+03	6.906E+03	6.906E+03	6.907E+03	6.907E+03	6.907E+03	6.907E+03	6.908E+03	6.908E+03	6.908E+03
U236	4.000E+02	8.361E+02	8.362E+02	8.364E+02	8.365E+02	8.367E+02	8.368E+02	8.370E+02	8.371E+02	8.372E+02	8.374E+02	8.375E+02
U238	9.901E+05	9.868E+05	9.868E+05	9.868E+05	9.868E+05	9.868E+05	9.868E+05	9.868E+05	9.868E+05	9.868E+05	9.868E+05	9.868E+05
NP237	0.000E+00	4.088E+01	4.288E+01	4.307E+01	4.335E+01	4.370E+01	4.410E+01	4.454E+01	4.501E+01	4.551E+01	4.602E+01	4.654E+01
NP239	0.000E+00	3.667E+01	9.321E+00	9.316E+00	9.312E+00	9.307E+00	9.303E+00	9.299E+00	9.294E+00	9.290E+00	9.286E+00	9.281E+00
PU239	0.000E+00	1.840E+03	1.876E+03	1.876E+03	1.876E+03	1.875E+03	1.875E+03	1.875E+03	1.875E+03	1.874E+03	1.874E+03	1.874E+03
PU240	0.000E+00	2.825E+02	2.824E+02	2.822E+02	2.821E+02	2.819E+02	2.818E+02	2.817E+02	2.815E+02	2.814E+02	2.812E+02	2.811E+02
PU241	0.000E+00	7.718E+01	6.067E+01	4.769E+01	3.749E+01	2.947E+01	2.317E+01	1.821E+01	1.432E+01	1.125E+01	8.846E+00	6.954E+00
AM241	0.000E+00	8.228E+01	1.726E+01	3.004E+01	3.996E+01	4.763E+01	5.353E+01	5.804E+01	6.145E+01	6.401E+01	6.590E+01	6.726E+01
SUNTOT	1.000E+06	9.969E+05	9.969E+05	9.969E+05	9.969E+05	9.969E+05	9.969E+05	9.969E+05	9.969E+05	9.969E+05	9.969E+05	9.969E+05
OTOTAL	1.000E+06	9.969E+05	9.969E+05	9.969E+05	9.969E+05	9.969E+05	9.969E+05	9.969E+05	9.969E+05	9.969E+05	9.969E+05	9.969E+05

OUTPUT UNIT = 6 PAGE 18

*N-REACTOR Composite (Inner+Outer) MKIV: (12.6 PERCENT PU 240)

ACTINIDES+DAUGHTERS

POWER= 8.11404E+00 MW, BURNUP= 2.19079E+03 MWD, FLUX= 1.28E+14 N/CM**2-SEC
 5 SUMMARY TABLE: CONCENTRATIONS, GRAMS
 ONE METRIC TON OF URANIUM, MARK IV FUEL

CHARGE	DISCHARGE	5.0YR	10.0YR	15.0YR	20.0YR	25.0YR	30.0YR	35.0YR	40.0YR	45.0YR	50.0YR
U	1.000E+00	9.947E+05	9.947E+05	9.947E+05	9.947E+05	9.947E+05	9.947E+05	9.947E+05	9.947E+05	9.947E+05	9.947E+05
WP	0.000E+00	7.743E+01	4.288E+01	4.335E+01	4.370E+01	4.410E+01	4.454E+01	4.501E+01	4.551E+01	4.602E+01	4.654E+01
PU	0.000E+00	2.209E+03	2.229E+03	2.246E+03	2.263E+03	2.280E+03	2.298E+03	2.316E+03	2.335E+03	2.354E+03	2.373E+03
AN	0.000E+00	9.681E-01	1.734E+01	3.017E+01	4.009E+01	4.775E+01	5.365E+01	5.816E+01	6.131E+01	6.402E+01	6.730E+01
SUMTOT	1.000E+06	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05
OTOTAL	1.000E+06	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05

CUMULATIVE TABLE TOTALS

AP+FP	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ACT+FP	1.000E+06	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05
AP+ACT+FP	1.000E+06	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05	9.949E+05

OUTPUT UNIT = 6

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M-REACTOR Composite (Inner-Outer) NKIV: (12.6 PERCENT PU 240)

(ALPHA,N) NEUTRON SOURCE, NEUTRONS/SEC

BASIS=ONE METRIC TON OF URANIUM, MARK IV FUEL

CHARGE	DISCHARGE	5.0YR	10.0YR	15.0YR	20.0YR	25.0YR	30.0YR	35.0YR	40.0YR	45.0YR	50.0YR
U234	2.430E+02	2.240E+02	2.240E+02	2.253E+02	2.258E+02	2.263E+02	2.268E+02	2.273E+02	2.278E+02	2.283E+02	2.288E+02
U235	7.486E+00	5.459E+00	5.459E+00	5.459E+00	5.459E+00	5.459E+00	5.459E+00	5.459E+00	5.459E+00	5.459E+00	5.459E+00
U236	1.047E+02	1.047E+02	1.047E+02	1.047E+02	1.047E+02	1.047E+02	1.047E+02	1.047E+02	1.047E+02	1.047E+02	1.047E+02
U238	0.000E+00	5.308E+04	5.308E+04	5.308E+04	5.308E+04	5.308E+04	5.308E+04	5.308E+04	5.308E+04	5.308E+04	5.308E+04
U239	0.000E+00	8.332E+04	8.332E+04	8.332E+04	8.332E+04	8.332E+04	8.332E+04	8.332E+04	8.332E+04	8.332E+04	8.332E+04
PU240	0.000E+00	4.879E+04	4.879E+04	4.879E+04	4.879E+04	4.879E+04	4.879E+04	4.879E+04	4.879E+04	4.879E+04	4.879E+04
AN241	0.000E+00	2.710E+03	5.683E+04	9.894E+04	1.316E+05	1.560E+05	1.763E+05	1.911E+05	2.024E+05	2.108E+05	2.156E+05
CH242	0.000E+00	5.221E+05	3.862E+02	1.533E+02	1.533E+02	1.533E+02	1.533E+02	1.533E+02	1.533E+02	1.533E+02	1.533E+02
CH244	0.000E+00	1.064E+04	8.798E+03	7.266E+03	6.000E+03	4.955E+03	4.092E+03	3.379E+03	2.791E+03	2.305E+03	1.903E+03

TOTALS

TABLE

ACTUAL

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OUTPUT UNIT = 6

R-REACTOR Composite (Inner-Outer) NKIV: (12.6 PERCENT PU 240)

SPONTANEOUS FISSION NEUTRON SOURCE, NEUTRONS/SEC

BASIS=ONE METRIC TON OF URANIUM, MARK IV FUEL

CHARGE	DISCHARGE	5.0YR	10.0YR	15.0YR	20.0YR	25.0YR	30.0YR	35.0YR	40.0YR	45.0YR	50.0YR
U238	1.322E+04	1.318E+04	1.318E+04	1.318E+04	1.318E+04	1.318E+04	1.318E+04	1.318E+04	1.318E+04	1.318E+04	1.318E+04
U239	0.000E+00	8.127E+03	7.971E+03	7.663E+03	7.367E+03	7.082E+03	6.809E+03	6.545E+03	6.293E+03	6.049E+03	5.816E+03
U240	0.000E+00	2.798E+05	2.798E+05	2.798E+05	2.798E+05	2.798E+05	2.798E+05	2.798E+05	2.798E+05	2.798E+05	2.798E+05
U242	0.000E+00	1.308E+04	1.308E+04	1.308E+04	1.308E+04	1.308E+04	1.308E+04	1.308E+04	1.308E+04	1.308E+04	1.308E+04
CH242	0.000E+00	2.538E+06	1.877E+03	7.551E+02	7.210E+02	7.047E+02	6.888E+02	6.733E+02	6.581E+02	6.433E+02	6.288E+02
CH244	0.000E+00	1.319E+06	1.090E+06	9.002E+05	7.434E+05	6.139E+05	5.070E+05	4.187E+05	3.457E+05	2.855E+05	2.350E+05

TOTALS

TABLE

ACTUAL

OVERALL

TOTALS

TABLE

ACTUAL

1.359E+04	4.893E+06	1.662E+06	1.508E+06	1.381E+06	1.273E+06	1.182E+06	1.106E+06	1.041E+06	9.849E+05	9.408E+05	9.019E+05
1.359E+04	4.893E+06	1.662E+06	1.508E+06	1.381E+06	1.273E+06	1.182E+06	1.106E+06	1.041E+06	9.849E+05	9.408E+05	9.019E+05

APPENDIX J.

CALCULATION OF PLUTONIUM CONCENTRATION FROM ($^{239}\text{Pu} + ^{240}\text{Pu}$) pCi/L

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CALCULATION OF PLUTONIUM CONCENTRATION FROM ($^{239}\text{Pu} + ^{240}\text{Pu}$) pCi/L

Situation:

- 1) The ($^{239}\text{Pu} + ^{240}\text{Pu}$) activity in pCi/L in water is known.
- 2) The plutonium isotopic composition (mass %) is also known.

Analytical Chemistry Result (of 29 May 1992):

- 1) $1.09\text{E}+4$ pCi/L is basin water activity of ($^{239}\text{Pu} + ^{240}\text{Pu}$).

Plutonium isotope ratios are:

2) ^{238}Pu	0.0745658	mass%
^{239}Pu	86.0096250	mass%
^{240}Pu	12.5987204	mass%
^{241}Pu	1.1008806	mass%
^{242}Pu	0.2162082	mass%

Additional Necessary Information:

N_A Avagadro's Number	6.022045×10^{23} atoms/gram-mole	($6.022045\text{E}+23$)
pCi Definition	1 pCi = 3.7×10^{-2} dis/s	($3.7\text{E}-2$)

Isotope	AW(Atomic Weight)	$t_{1/2}$ (half-life) yr
^{239}Pu	239.052157	24,100
^{240}Pu	240.053808	6,560

Calculation:

$$\begin{aligned} & (^{239}\text{Pu grams}) \times (\text{atoms/gram}) \times (\text{pCuries/atom}) = ^{239}\text{Pu pCi/g Pu} \\ & (^{240}\text{Pu grams}) \times (\text{atoms/gram}) \times (\text{pCuries/atom}) = ^{240}\text{Pu pCi/g Pu} \\ & ^{239}\text{Pu pCi/g Pu} + ^{240}\text{Pu pCi/g Pu} = (^{239}\text{Pu} + ^{240}\text{Pu}) \text{ pCi/g Pu} \end{aligned}$$

Example for $^{239}\text{Pu} + ^{240}\text{Pu}$:

$$\begin{aligned} & \frac{.860096250 \text{ g } ^{239}\text{Pu}}{1 \text{ g Pu}} \times \frac{6.022045\text{E}+23 \text{ atoms/g-mole}}{239.052157 \text{ g } ^{239}\text{Pu/g-mole}} \times \frac{\ln(2) \text{ dis/s/atom}}{24,100 \times 365.25 \times 24 \times 60 \times 60} \times \frac{1 \text{ pCi } ^{239}\text{Pu}}{3.7\text{E}-2 \text{ dis/s}} \\ & = 5.337\text{E}+10 \text{ pCi } ^{239}\text{Pu/g Pu} \end{aligned}$$

$$\begin{aligned} & \frac{.125987204 \text{ g } ^{240}\text{Pu}}{1 \text{ g Pu}} \times \frac{6.022045\text{E}+23 \text{ atoms/g-mole}}{240.053808 \text{ g } ^{240}\text{Pu/g-mole}} \times \frac{\ln(2) \text{ dis/s/atom}}{6,560 \times 365.25 \times 24 \times 60 \times 60} \times \frac{1 \text{ pCi } ^{240}\text{Pu}}{3.7\text{E}-2 \text{ dis/s}} \\ & = 2.860\text{E}+10 \text{ pCi } ^{240}\text{Pu/g Pu} \end{aligned}$$

$$5.337\text{E}+10 \text{ pCi } ^{239}\text{Pu/g Pu} + 2.860\text{E}+10 \text{ pCi } ^{240}\text{Pu/g Pu} = 8.197\text{E}+10 \text{ pCi } (^{239}\text{Pu} + ^{240}\text{Pu})/\text{g Pu}$$

$$1.09\text{E}+4 \text{ pCi } (^{239}\text{Pu} + ^{240}\text{Pu})/\text{L} / 8.197\text{E}+10 \text{ pCi } (^{239}\text{Pu} + ^{240}\text{Pu})/\text{g Pu} = 1.330\text{E}-7 \text{ g Pu/L}$$

CALCULATION OF PLUTONIUM ACCUMULATION FROM g Pu/L

Situation:

- 1) Assumed: $1.50\text{E-}7$ g Pu/L concentration in water.
- 2) Assumed: The sandfilter flow rate is 400 gpm.

Calculation:

(gPu/liter) x (gallons/minute) x (liter/gallon) x (minutes/year) = grams Pu/yr

$$1.50\text{E-}7\text{g Pu/L} \times 400\text{ gpm} \times (231\text{ in}^3/\text{gal} \times (2.54\text{ cm/in})^3 \times 1\text{E-}3\text{ l/cm}^3) \\ \times (60\text{ m/h} \times 24\text{ h/d} \times 365.25\text{ d/yr}) = 119.46\text{ g Pu/yr} = 0.11946\text{ kg Pu/yr}$$

APPENDIX K.

MCNP SAMPLE TABLE 2 INPUT FILE.

messages:

Sand Filter in KE, Table 2, Normal Situation Calculations

```

c      x axis, y axis, vertical z, U/Pu= 100., H/(U+Pu)= 0.
c      xx -xx yy -yy zz -zz rr -rr imp:n= $
1 1 -1.29e-3 7 -12 13 -18 19 -20 imp:n=1 $ air under floor
2 2 -2.370 7 -12 13 -18 20 -21 imp:n=1 $ concrete floor
3 2 -2.370 7 -12 13 -18 21 -22 imp:n=1 $ concrete slab
4 1 -1.29e-3 22 -23 2  -6 imp:n=1 $ air over slab
5 3 -7.800 23 -24 1  -2 imp:n=1 $ tank ss 316
6 3 -7.800 23 -27 5  -6 imp:n=1 $ tank ss 316
7 3 -7.800 27  -1 imp:n=1 $ concrete
8 2 -2.370 23 -24 -5 imp:n=1 $ concrete
9 2 -2.370 24 -25 -5 imp:n=1 $ coarse sand+Pu
10 6 -5.835 25 -26 -5 imp:n=1 $ working media+Pu
11 6 -5.835 26 -27 -5 imp:n=1 $ water
12 4 -1.000 27  -3 imp:n=1 $ water
13 4 -1.000 27 -28 4  -6 imp:n=1 $ air under roof
14 1 -1.29e-3 9 -10 15 -16 22 -28 6 imp:n=1 $ air inside concrete
15 1 -1.29e-3 8 -11 14 -17 22 -29 (-9:10:-15:16:28) imp:n=1 $ concrete
16 2 -2.370 7 -12 13 -18 22 -30 (-8:11:-14:17:29) imp:n=1 $ air
17 1 -1.29e-3 -7: 12:-13: 18:-19: 30 imp:n=0 $ outside world
18 0

```

```

1 sq 1500.400225 1500.400225 9687.480625 0.0 0.0 0.0 -14535098.11
0.0 0.0 52.07 $ inside tank bottom ellipsoid
2 sq 1549.9969 1549.9969 9812.8836 0.0 0.0 0.0 -15209939.16
0.0 0.0 52.07 $ outside tank bottom ellipsoid
3 sq 1500.400225 1500.400225 9687.480625 0.0 0.0 0.0 -14535098.11
0.0 0.0 174.31 $ inside tank top ellipsoid
4 sq 1549.9969 1549.9969 9812.8836 0.0 0.0 0.0 -15209939.16
0.0 0.0 174.31 $ outside tank top ellipsoid
5 cz 98.425 $ tank inside radius (38.75 in.)
6 cz 99.060 $ tank outside radius (39.00 in.)
7 px -250.00 $ -x of system
8 px -144.78 $ -x outside of concrete wall (-57.00 in.)
9 px -114.30 $ -x inside of concrete wall (-45.00 in.)
10 px 114.30 $ +x inside of concrete wall (45.00 in.)
11 px 144.78 $ +x outside of concrete wall (57.00 in.)
12 px 250.00 $ +x of system
13 py -250.00 $ -y of system
14 py -144.78 $ -y outside of concrete wall (-57.00 in.)
15 py -114.30 $ -y inside of concrete wall (-45.00 in.)
16 py 114.30 $ +y inside of concrete wall (45.00 in.)
17 py 144.78 $ +y outside of concrete wall (57.00 in.)
18 py 250.00 $ +y of system
19 pz -100.00 $ -z of system
20 pz -45.72 $ -z bottom of concrete floor (-18.00 in.)
21 pz -15.24 $ -z bottom of concrete slab (-6.00 in.)
22 pz 0.00 $ +z top of concrete slab (0.00 in.)
c pz 12.70 $ bottom tip of sandfilter (5.00 in.)
23 pz 52.07 $ 1 in. below 54 in section (20.50 in.)
24 pz 67.31 $ +z concrete level (26.50 in.)
25 pz 86.36 $ +z coarse sand level
c 25 pz 86.36 $ +z coarse sand level (34.00 in.)
26 pz 161.925 $ +z fine sand level (63.75 in.)
27 pz 194.31 $ 1 in. above 54 in section (76.50 in.)
c pz 213.68 $ top tip of sandfilter (92.00 in.)
28 pz 243.84 $ +z inside of concrete cover (96.00 in.)
29 pz 259.08 $ +z outside of concrete cover (102.00 in.)
30 pz 300.00 $ model top

```

```

kcode 1000 1.0 5 100
ksrc 0.00 0.00 76.00 $ source centered
0.00 0.00 86.00
0.00 0.00 96.00
0.00 0.00 106.00
0.00 0.00 116.00
0.00 0.00 126.00
0.00 0.00 136.00
0.00 0.00 146.00

```

	0.00	0.00	156.00	
	0.00	0.00	166.00	
	50.00	0.00	76.00	\$ source +X centered
	50.00	0.00	86.00	
	50.00	0.00	96.00	
	50.00	0.00	106.00	
	50.00	0.00	116.00	
	50.00	0.00	126.00	
	50.00	0.00	136.00	
	50.00	0.00	146.00	
	50.00	0.00	156.00	
	50.00	0.00	166.00	
	0.00	50.00	76.00	\$ source +Y centered
	0.00	50.00	86.00	
	0.00	50.00	96.00	
	0.00	50.00	106.00	
	0.00	50.00	116.00	
	0.00	50.00	126.00	
	0.00	50.00	136.00	
	0.00	50.00	146.00	
	0.00	50.00	156.00	
	0.00	50.00	166.00	
	-50.00	0.00	76.00	\$ source -X centered
	-50.00	0.00	86.00	
	-50.00	0.00	96.00	
	-50.00	0.00	106.00	
	-50.00	0.00	116.00	
	-50.00	0.00	126.00	
	-50.00	0.00	136.00	
	-50.00	0.00	146.00	
	-50.00	0.00	156.00	
	-50.00	0.00	166.00	
	0.00	-50.00	76.00	\$ source -Y centered
	0.00	-50.00	86.00	
	0.00	-50.00	96.00	
	0.00	-50.00	106.00	
	0.00	-50.00	116.00	
	0.00	-50.00	126.00	
	0.00	-50.00	136.00	
	0.00	-50.00	146.00	
	0.00	-50.00	156.00	
	0.00	-50.00	166.00	
m1	7016.50c	-0.80000		\$ air (1.29e-3 g/cc)
	8016.50c	-0.20000		
m2	26000.55c	-0.00312		\$ normal concrete (2.37 g/cm3)
	1001.50c	-0.00206		
	8016.50c	-0.69335		
	12000.50c	-0.00209		
	20000.50c	-0.24959		
	14000.50c	-0.18816		
	13027.50c	-0.00510		
	16032.50c	-0.00082		
	6000.50c	-0.05571		
mt2	poly.01t			\$ hydrogen in solid
m3	6000.50c	-0.00040		\$ stainless steel (7.80 g/cm3)
	25055.50c	-0.00100		
	14000.50c	-0.00500		
	12000.50c	-0.17000		
	24000.50c	-0.12000		
	42000.50c	-0.02500		
	15031.50c	-0.00023		
	16032.50c	-0.00015		
	26000.55c	-0.67822		
m4	1001.50c	0.66667		\$ water (1.000 g/cm3)
	8016.50c	0.33333		
mt4	litr.01t			\$ hydrogen in liquid
m5	1001.50c	-4.827e-03		\$ wet sand (2.706 g/cm3)
	8016.50c	-4.971e-01		\$ H/U=10
	92234.50c	-8.528e-06		\$ 234U .0074565 wt% U
	92235.50c	-7.935e-04		\$ 235U .6938084 wt% U
	92236.50c	-9.020e-05		\$ 236U .0788619 wt% U
	92238.50c	-1.135e-01		\$ 238U 99.2198732 wt% U
	94238.50c	-3.806e-07		\$ 238Pu .0745658 wt% Pu
	94239.55c	-4.388e-04		\$ 239Pu 86.0096250 wt% Pu
	94240.50c	-6.427e-05		\$ 240Pu 12.5987204 wt% Pu
	94241.50c	-5.616e-06		\$ 241Pu 1.1008806 wt% Pu
	94242.50c	-1.103e-06		\$ 242Pu .2162082 wt% Pu

	13027.50c	-5.163e-02	
	20000.50c	-2.064e-03	
	29000.50c	-7.962e-04	
	26000.50c	-8.831e-02	
	12000.50c	-6.416e-04	
	25055.50c	-6.628e-04	
	42000.50c	-4.580e-05	
	11023.50c	-4.636e-04	
	28000.50c	-1.325e-04	
	82000.50c	-4.012e-04	
	14000.50c	-2.370e-01	
	40000.50c	-6.029e-05	
	31000.50c	-9.121e-04	
mt5	lwtr.01t		\$ hydrogen in liquid
no	13027.50c	-1.254e-02	\$ U/Pu=100.
	20000.50c	-1.118e-03	\$ H/(U+Pu)=0.
	17000.50c	-4.942e-05	\$ dry sand (5.835 g/cm3)
	9019.50c	-2.746e-05	\$ Pu density= 3.6964e-2 g/cm3
	26000.55c	-1.172e-03	
	12000.50c	-2.980e-04	
	19000.50c	-7.222e-03	
	14000.50c	-1.044e-01	
	11023.50c	-3.320e-03	
	16032.50c	-1.098e-04	
	22000.50c	-1.373e-05	
	8016.50c	-2.302e-01	
	92234.50c	-4.358e-03	
	92235.50c	-4.339e-03	
	92236.50c	-5.023e-04	
	92238.50c	-6.282e-01	
	94238.50c	-4.728e-06	
	94239.50c	-5.443e-03	
	94240.50c	-8.009e-04	
	94241.50c	-7.079e-05	
	94242.50c	-1.385e-05	
mt7	13027.50c	-2.185e-02	\$ U/Pu=100.
	20000.50c	-1.947e-03	\$ H/(U+Pu)=5.
	17000.50c	-8.607e-05	\$ wet sand (3.350 g/cm3)
	9019.50c	-4.782e-05	\$ Pu density= 1.3088e-2 g/cm3
	26000.55c	-2.042e-03	
	12000.50c	-5.190e-04	
	19000.50c	-1.258e-02	
	14000.50c	-1.819e-01	
	11023.50c	-5.783e-03	
	16032.50c	-1.913e-04	
	22000.50c	-2.391e-05	
	8016.50c	-3.704e-01	
	1001.50c	-8.273e-03	
	92234.50c	-2.688e-05	
	92235.50c	-2.676e-03	
	92236.50c	-3.098e-04	
	92238.50c	-3.874e-01	
	94238.50c	-2.916e-06	
	94239.50c	-3.358e-03	
	94240.50c	-4.939e-04	
	94241.50c	-4.366e-05	
	94242.50c	-8.538e-06	
mt7	lwtr.01t		\$ hydrogen in liquid
no	13027.50c	-3.091e-02	\$ U/Pu=100.
	20000.50c	-2.734e-03	\$ H/(U+Pu)=25.
	17000.50c	-1.218e-04	\$ wet sand (2.368 g/cm3)
	9019.50c	-6.764e-05	\$ Pu density= 3.6521e-3 g/cm3
	26000.55c	-2.888e-03	
	12000.50c	-7.342e-04	
	19000.50c	-1.779e-02	
	14000.50c	-2.573e-01	
	11023.50c	-8.181e-03	
	16032.50c	-2.706e-04	
	22000.50c	-3.382e-05	
	8016.50c	-5.069e-01	
	1001.50c	-1.633e-02	
	92234.50c	-1.061e-05	
	92235.50c	-1.056e-03	
	92236.50c	-1.223e-04	
	92238.50c	-1.529e-01	
	94238.50c	-1.151e-06	
	94239.50c	-1.325e-03	

	94240.50e	-1.950e-04	
	94241.50e	-1.723e-05	
	94242.50e	-3.370e-06	
mt8	lutr.01t		\$ hydrogen in liquid
mt9	13027.50e	-3.588e-02	\$ U/Pu=100.
	20000.50e	-3.197e-03	\$ H/(U+Pu)=200.
	17000.50e	-1.413e-04	\$ wet sand (2.040 g/cm3)
	9019.50e	-7.852e-05	\$ Pu density= 4.9972e-4 g/cm3
	26000.55e	-3.353e-03	
	12000.50e	-8.522e-04	
	19000.50e	-2.065e-02	
	14000.50e	-2.987e-01	
	11023.50e	-9.496e-03	
	16032.50e	-3.141e-04	
	22000.50e	-3.926e-05	
	8015.50e	-5.818e-01	
	1001.50e	-2.079e-02	
	92234.50e	-1.685e-06	
	92235.50e	-1.678e-04	
	92236.50e	-1.942e-05	
	92238.50e	-2.429e-02	
	94238.50e	-1.828e-07	
	94239.50e	-2.105e-04	
	94240.50e	-3.097e-05	
	94241.50e	-2.737e-06	
	94242.50e	-5.353e-07	
mt9	lutr.01t		\$ hydrogen in liquid
mt10	13027.50e	-3.662e-02	\$ U/Pu=100.
	20000.50e	-3.263e-03	\$ H/(U+Pu)=1000.
	17000.50e	-1.443e-04	\$ wet sand (1.999 g/cm3)
	9019.50e	-8.015e-05	\$ Pu density= 1.0104e-4 g/cm3
	26000.55e	-3.422e-03	
	12000.50e	-8.699e-04	
	19000.50e	-2.105e-02	
	14000.50e	-3.049e-01	
	11023.50e	-9.693e-03	
	16032.50e	-3.206e-04	
	22000.50e	-4.008e-05	
	8016.50e	-5.930e-01	
	1001.50e	-2.141e-02	
	92234.50e	-3.478e-07	
	92235.50e	-3.463e-05	
	92236.50e	-4.008e-06	
	92238.50e	-5.013e-03	
	94238.50e	-3.773e-08	
	94239.50e	-4.345e-05	
	94240.50e	-6.391e-06	
	94241.50e	-5.649e-07	
	94242.50e	-1.105e-07	
mt10	lutr.01t		\$ hydrogen in liquid
mt11	13027.50e	-3.679e-02	\$ U/Pu=100.
	20000.50e	-3.279e-03	\$ H/(U+Pu)=10000.
	17000.50e	-1.450e-04	\$ wet sand (1.989 g/cm3)
	9019.50e	-8.053e-05	\$ Pu density= 1.0129e-5 g/cm3
	26000.55e	-3.439e-03	
	12000.50e	-8.741e-04	
	19000.50e	-2.118e-02	
	14000.50e	-3.064e-01	
	11023.50e	-9.739e-03	
	16032.50e	-3.221e-04	
	22000.50e	-4.027e-05	
	8016.50e	-5.957e-01	
	1001.50e	-2.157e-02	
	92234.50e	-3.503e-08	
	92235.50e	-3.488e-06	
	92236.50e	-4.037e-07	
	92238.50e	-5.049e-04	
	94238.50e	-3.800e-09	
	94239.50e	-4.376e-06	
	94240.50e	-6.437e-07	
	94241.50e	-5.690e-08	
	94242.50e	-1.113e-08	
mt11	lutr.01t		\$ hydrogen in liquid
totnu	1000.		
ctme			
print	30 40 60 110 126 140		

MCNP SAMPLE TABLE 9 INPUT FILE.

message:

Sand Filter in K2, Table 9, Parametric Study Calculations

```

c      x axis, y axis, vertical z, U/Pu= 0., H/(U+Pu)= 0.
c      xx -xx yy -yy zz -zz rr -rr imp:n= $
1 1 -1.29e-3 7 -12 13 -18 19 -20 imp:n=1 $ air under floor
2 2 -2.370 7 -12 13 -18 20 -21 imp:n=1 $ concrete floor
3 2 -2.370 7 -12 13 -18 21 -22 imp:n=1 $ concrete slab
4 1 -1.29e-3 22 -23 2 -6 imp:n=1 $ air over slab
5 3 -7.800 -23 1 -2 imp:n=1 $ tank ss 316
6 3 -7.800 23 -27 5 -6 imp:n=1 $ tank ss 316
7 3 -7.800 27 3 -4 imp:n=1 $ tank ss 316
8 2 -2.370 -23 -1 imp:n=1 $ concrete
9 2 -2.370 23 -24 -5 imp:n=1 $ concrete
10 6 -5.833 24 -25 -5 imp:n=1 $ coarse sand+Pu
11 6 -5.833 25 -26 -5 imp:n=1 $ working media+Pu
12 4 -1.000 26 -27 -5 imp:n=1 $ water
13 4 -1.000 27 -3 imp:n=1 $ water
14 1 -1.29e-3 27 -28 4 -6 imp:n=1 $ air under roof
15 1 -1.29e-3 9 -10 15 -16 22 -28 6 imp:n=1 $ air inside concrete
16 2 -2.370 8 -11 14 -17 22 -29 (-9:10:-15:16:28) imp:n=1 $ concrete
17 1 -1.29e-3 7 -12 13 -18 22 -30 (-8:11:-14:17:29) imp:n=1 $ air
18 0 -7: 12:-13: 18:-19: 30 imp:n=0 $ outside world

1 sq 1500.400225 1500.400225 9687.480625 0.0 0.0 0.0 -14535098.11
0.0 0.0 52.07 $ inside tank bottom ellipsoid
2 sq 1549.9969 1549.9969 9812.8836 0.0 0.0 0.0 -15209939.16
0.0 0.0 52.07 $ outside tank bottom ellipsoid
3 sq 1500.400225 1500.400225 9687.480625 0.0 0.0 0.0 -14535098.11
0.0 0.0 174.31 $ inside tank top ellipsoid
4 sq 1549.9969 1549.9969 9812.8836 0.0 0.0 0.0 -15209939.16
0.0 0.0 174.31 $ outside tank top ellipsoid
5 cz 98.425 $ tank inside radius (38.75 in.)
6 cz 99.060 $ tank outside radius (39.00 in.)
7 px -250.00 $ -x of system
8 px -144.78 $ -x outside of concrete wall (-57.00 in.)
9 px -114.30 $ -x inside of concrete wall (-45.00 in.)
10 px 114.30 $ +x inside of concrete wall (45.00 in.)
11 px 144.78 $ +x outside of concrete wall (57.00 in.)
12 px 250.00 $ +x of system
13 py -250.00 $ -y of system
14 py -144.78 $ -y outside of concrete wall (-57.00 in.)
15 py -114.30 $ -y inside of concrete wall (-45.00 in.)
16 py 114.30 $ +y inside of concrete wall (45.00 in.)
17 py 144.78 $ +y outside of concrete wall (57.00 in.)
18 py 250.00 $ +y of system
19 pz -100.00 $ -z of system
20 pz -45.72 $ -z bottom of concrete floor (-18.00 in.)
21 pz -15.24 $ -z bottom of concrete slab (-6.00 in.)
22 pz 0.00 $ +z top of concrete slab (0.00 in.)
c pz 12.70 $ bottom tip of sandfilter (5.00 in.)
23 pz 52.07 $ 1 in. below 54 in section (20.50 in.)
24 pz 67.31 $ +z concrete level (26.50 in.)
25 pz 86.36 $ +z coarse sand level
c 25 pz 86.36 $ +z coarse sand level (34.00 in.)
26 pz 161.925 $ +z fine sand level (63.75 in.)
27 pz 194.31 $ 1 in. above 54 in section (76.50 in.)
c pz 213.68 $ top tip of sandfilter (92.00 in.)
28 pz 243.84 $ +z inside of concrete cover (96.00 in.)
29 pz 259.08 $ +z outside of concrete cover (102.00 in.)
30 pz 300.00 $ model top

```

```

kcode 1000 1.0 5 100
ksrc 0.00 0.00 76.00 $ source centered
0.00 0.00 86.00
0.00 0.00 96.00
0.00 0.00 106.00
0.00 0.00 116.00
0.00 0.00 126.00
0.00 0.00 136.00
0.00 0.00 146.00
0.00 0.00 156.00
0.00 0.00 166.00
50.00 0.00 76.00 $ source +x centered

```

50.00	0.00	86.00	
50.00	0.00	96.00	
50.00	0.00	106.00	
50.00	0.00	116.00	
50.00	0.00	126.00	
50.00	0.00	136.00	
50.00	0.00	146.00	
50.00	0.00	156.00	
50.00	0.00	166.00	
0.00	50.00	76.00	\$ source +Y centered
0.00	50.00	86.00	
0.00	50.00	96.00	
0.00	50.00	106.00	
0.00	50.00	116.00	
0.00	50.00	126.00	
0.00	50.00	136.00	
0.00	50.00	146.00	
0.00	50.00	156.00	
0.00	50.00	166.00	
-50.00	0.00	76.00	\$ source -X centered
-50.00	0.00	86.00	
-50.00	0.00	96.00	
-50.00	0.00	106.00	
-50.00	0.00	116.00	
-50.00	0.00	126.00	
-50.00	0.00	136.00	
-50.00	0.00	146.00	
-50.00	0.00	156.00	
-50.00	0.00	166.00	
0.00	-50.00	76.00	\$ source -Y centered
0.00	-50.00	86.00	
0.00	-50.00	96.00	
0.00	-50.00	106.00	
0.00	-50.00	116.00	
0.00	-50.00	126.00	
0.00	-50.00	136.00	
0.00	-50.00	146.00	
0.00	-50.00	156.00	
0.00	-50.00	166.00	
m1	7014.50e	-0.80000	\$ air (1.29e-3 g/cc)
	8016.50e	-0.20000	
m2	26000.55e	-0.00312	\$ normal concrete (2.37 g/cm3)
	1001.50e	-0.00206	
	8016.50e	-0.49333	
	12000.50e	-0.00209	
	20000.50e	-0.24959	
	14000.50e	-0.18816	
	13027.50e	-0.00510	
	16032.50e	-0.00082	
	6000.50e	-0.05571	
mt2	poTy.01t		\$ hydrogen in solid
m3	6000.50e	-0.00040	\$ Stainless steel (7.80 g/cm3)
	25055.50e	-0.00100	
	14000.50e	-0.00500	
	12000.50e	-0.17000	
	24000.50e	-0.12000	
	42000.50e	-0.02500	
	15031.50e	-0.00023	
	16032.50e	-0.00015	
	26000.55e	-0.67822	
m4	1001.50e	0.66667	\$ water (1.000 g/cm3)
	8016.50e	0.33333	
mt4	lutr.01t		\$ hydrogen in liquid
m5	1001.50e	-4.827e-03	\$ wet sand (2.706 g/cm3)
	8016.50e	-4.971e-01	\$ K/U=10
	92234.50e	-8.528e-06	\$ 234U .0074565 wt% U
	92235.50e	-7.935e-04	\$ 235U .6938084 wt% U
	92236.50e	-9.020e-05	\$ 236U .0788619 wt% U
	92238.50e	-1.135e-01	\$ 238U 99.2198732 wt% U
	94238.50e	-3.806e-07	\$ 238Pu .0745458 wt% Pu
	94239.55e	-4.388e-04	\$ 239Pu 86.0096250 wt% Pu
	94240.50e	-6.427e-05	\$ 240Pu 12.5987204 wt% Pu
	94241.50e	-5.616e-06	\$ 241Pu 1.1008806 wt% Pu
	94242.50e	-1.103e-06	\$ 242Pu .2162082 wt% Pu
	13027.50e	-5.163e-02	
	20000.50e	-2.064e-03	
	29000.50e	-7.962e-04	

	26000.50c	-8.831e-02	
	12000.50c	-6.416e-04	
	25055.50c	-6.628e-04	
	42000.50c	-4.580e-05	
	11023.50c	-4.636e-04	
	28000.50c	-1.325e-04	
	82000.50c	-4.012e-04	
	14000.50c	-2.370e-01	
	40000.50c	-6.029e-05	
	31000.50c	-9.121e-04	
mt5	lwtr.01t		\$ hydrogen in liquid
mb	13027.50c	-1.254e-02	\$ U/Pu=0.
	20000.50c	-1.118e-03	\$ H/(U+Pu)=0.
	17000.50c	-4.942e-05	\$ dry sand (5.035 g/cm3)
	9019.50c	-2.746e-05	\$ Pu density= 3.7333 g/cm3
	26000.55c	-1.172e-03	
	12000.50c	-2.980e-04	
	19000.50c	-7.222e-03	
	14000.50c	-1.044e-01	
	11023.50c	-3.320e-03	
	16032.50c	-1.090e-04	
	22000.50c	-1.373e-05	
	8016.50c	-2.298e-01	
	94238.50c	-4.775e-04	
	94239.50c	-5.499e-01	
	94240.50c	-8.089e-02	
	94241.50c	-7.150e-03	
	94242.50c	-1.398e-03	
mt7	13027.50c	-2.147e-02	\$ U/Pu=0.
	20000.50c	-1.913e-03	\$ H/(U+Pu)=5.
	17000.50c	-6.459e-05	\$ wet sand (3.409 g/cm3)
	9019.50c	-4.699e-05	\$ Pu density= 1.3789 g/cm3
	26000.55c	-2.007e-03	
	12000.50c	-5.101e-04	
	19000.50c	-1.236e-02	
	14000.50c	-1.788e-01	
	11023.50c	-5.683e-03	
	16032.50c	-1.880e-04	
	22000.50c	-2.350e-05	
	8016.50c	-3.645e-01	
	1001.50c	-7.939e-03	
	94238.50c	-3.019e-04	
	94239.50c	-3.476e-01	
	94240.50c	-5.114e-02	
	94241.50c	-4.320e-03	
	94242.50c	-8.840e-04	
mt7	lwtr.01t		\$ hydrogen in liquid
mb	13027.50c	-3.060e-02	\$ U/Pu=0.
	20000.50c	-2.727e-03	\$ H/(U+Pu)=25.
	17000.50c	-1.206e-04	\$ wet sand (2.392 g/cm3)
	9019.50c	-6.699e-05	\$ Pu density= 3.9144e-1 g/cm3
	26000.55c	-2.860e-03	
	12000.50c	-7.270e-04	
	19000.50c	-1.762e-02	
	14000.50c	-2.548e-01	
	11023.50c	-8.101e-03	
	16032.50c	-2.679e-04	
	22000.50c	-3.349e-05	
	8016.50c	-5.023e-01	
	1001.50c	-1.606e-02	
	94238.50c	-1.222e-04	
	94239.50c	-1.407e-01	
	94240.50c	-2.069e-02	
	94241.50c	-1.829e-03	
	94242.50c	-3.577e-04	
mt8	lwtr.01t		\$ hydrogen in liquid
mb	13027.50c	-3.581e-02	\$ U/Pu=0.
	20000.50c	-3.111e-03	\$ H/(U+Pu)=200.
	17000.50c	-1.411e-04	\$ wet sand (2.044 g/cm3)
	9019.50c	-7.839e-05	\$ Pu density= 5.3873e-2 g/cm3
	26000.55c	-3.347e-03	
	12000.50c	-8.508e-04	
	19000.50c	-2.062e-02	
	14000.50c	-2.982e-01	
	11023.50c	-9.480e-03	
	16032.50c	-3.135e-04	
	22000.50c	-3.919e-05	

```

      8016.50c -5.809e-01
      1001.50c -2.069e-02
      94238.50c -1.967e-05
      94239.50c -2.266e-02
      94240.50c -3.333e-03
      94241.50c -2.946e-04
      94242.50c -5.761e-05
mt9    lstr.01t
m10    13027.50c -3.661e-02
      20000.50c -3.262e-03
      17000.50c -1.442e-04
      9019.50c -8.012e-05
      26000.50c -3.421e-03
      12000.50c -8.696e-04
      19000.50c -2.108e-02
      14000.50c -3.048e-01
      11023.50c -9.690e-03
      16032.50c -3.205e-04
      22000.50c -4.006e-05
      8016.50c -5.928e-01
      1001.50c -2.140e-02
      94238.50c -4.069e-06
      94239.50c -4.686e-03
      94240.50c -6.892e-04
      94241.50c -6.092e-05
      94242.50c -1.191e-05
mt10   lstr.01t
m11    13027.50c -3.679e-02
      20000.50c -3.279e-03
      17000.50c -1.450e-04
      9019.50c -8.053e-05
      26000.50c -3.439e-03
      12000.50c -8.740e-04
      19000.50c -2.118e-02
      14000.50c -3.064e-01
      11023.50c -9.739e-03
      16032.50c -3.221e-04
      22000.50c -4.026e-05
      8016.50c -5.956e-01
      1001.50c -2.156e-02
      94238.50c -4.100e-07
      94239.50c -4.722e-04
      94240.50c -6.946e-05
      94241.50c -6.139e-06
      94242.50c -1.201e-06
mt11   lstr.01t
totnu
ctme 1000.
print 30 40 60 110 126 140

```

```

$ hydrogen in liquid
$ U/Pu=0.
$ H/(U+Pu)=1000.
$ wet sand (1.999 g/cm3)
$ Pu density= 1.0900e-2 g/cm3

```

```

$ hydrogen in liquid
$ U/Pu=0.
$ H/(U+Pu)=10000.
$ wet sand (1.989 g/cm3)
$ Pu density= 1.0929e-3 g/cm3

```

```

$ hydrogen in liquid

```

MCNP SAMPLE TABLE 14 INPUT FILE.

message:

Sand Filter in KE, 1.25 wt% 235U Uranium Buildup Calculations

c x axis, y axis, vertical z, U/Pu= INFINITE; H/(U+Pu)= 10,000.

```

c      xx -xx yy -yy zz -zz rr -rr imp:n= $
1 1 -1.29e-3 7 -12 13 -18 19 -20 imp:n=1 $ air under floor
2 2 -2.370 7 -12 13 -18 20 -21 imp:n=1 $ concrete floor
3 2 -2.370 7 -12 13 -18 21 -22 imp:n=1 $ concrete slab
4 1 -1.29e-3 22 -23 2 -6 imp:n=1 $ air over slab
5 3 -7.800 -23 1 -2 imp:n=1 $ tank SS 316
6 3 -7.800 23 -27 5 -6 imp:n=1 $ tank SS 316
7 3 -7.800 27 3 -4 imp:n=1 $ tank SS 316
8 2 -2.370 -23 -1 imp:n=1 $ concrete
9 2 -2.370 23 -24 -5 imp:n=1 $ concrete
10 6 -1.989 24 -25 -5 imp:n=1 $ coarse sand+UO2
11 6 -1.989 25 -26 -5 imp:n=1 $ working media+UO2
12 4 -1.000 26 -27 -5 imp:n=1 $ water
13 4 -1.000 27 -3 imp:n=1 $ water
14 1 -1.29e-3 27 -28 4 -6 imp:n=1 $ air under roof
15 1 -1.29e-3 22 -28 6 -39 imp:n=1 $ air inside concrete
16 2 -2.370 (39:28) 22 -29 -40 imp:n=1 $ concrete
17 1 -1.29e-3 7 -12 13 -18 22 -30 (40:29) imp:n=1 $ air
18 0 -7: -12: -13: 18: -19: 30 imp:n=0 $ outside world

1 sq 1500.400225 1500.400225 9687.480625 0.0 0.0 0.0 -14535098.11
   0.0 0.0 52.07 $ inside tank bottom ellipsoid
2 sq 1549.9969 1549.9969 9812.8836 0.0 0.0 0.0 -15209939.16
   0.0 0.0 52.07 $ outside tank bottom ellipsoid
3 sq 1500.400225 1500.400225 9687.480625 0.0 0.0 0.0 -14535098.11
   0.0 0.0 174.31 $ inside tank top ellipsoid
4 sq 1549.9969 1549.9969 9812.8836 0.0 0.0 0.0 -15209939.16
   0.0 0.0 174.31 $ outside tank top ellipsoid
5 cz 98.425 $ tank inside radius (38.75 in.)
6 cz 99.060 $ tank outside radius (39.00 in.)
7 px -250.00 $ -x of system
8 px -144.78 $ -x outside of concrete wall (-57.00 in.)
9 px -114.30 $ -x inside of concrete wall (-45.00 in.)
10 px 114.30 $ +x inside of concrete wall (45.00 in.)
11 px 144.78 $ +x outside of concrete wall (57.00 in.)
12 px 250.00 $ +x of system
13 py -250.00 $ -y of system
14 py -144.78 $ -y outside of concrete wall (-57.00 in.)
15 py -114.30 $ -y inside of concrete wall (-45.00 in.)
16 py 114.30 $ +y inside of concrete wall (45.00 in.)
17 py 144.78 $ +y outside of concrete wall (57.00 in.)
18 py 250.00 $ +y of system
19 pz -100.00 $ -z of system
20 pz -45.72 $ -z bottom of concrete floor (-18.00 in.)
21 pz -15.24 $ -z bottom of concrete slab (-6.00 in.)
22 pz 0.00 $ +z top of concrete slab (0.00 in.)
c pz 12.70 $ bottom tip of sandfilter (5.00 in.)
23 pz 52.07 $ 1 in. below 54 in section (20.50 in.)
24 pz 67.31 $ +z concrete level (26.50 in.)
25 pz 86.36 $ +z coarse sand level
c pz 25 pz 86.36 $ +z coarse sand level (34.00 in.)
26 pz 161.925 $ +z fine sand level (63.75 in.)
27 pz 194.31 $ 1 in. above 54 in section (76.50 in.)
c pz 213.68 $ top tip of sandfilter (92.00 in.)
28 pz 243.84 $ +z inside of concrete cover (96.00 in.)
29 pz 259.08 $ +z outside of concrete cover (102.00 in.)
30 pz 300.00 $ model top
31 cz 128.9737388 $ inside radius - equivalent to 4 sided structure
32 cz 159.4537388 $ outside radius - equivalent to 4 sided structure
33 cz 127.1778955 $ inside radius - equivalent to 5 sided structure
34 cz 157.6578955 $ outside radius - equivalent to 5 sided structure
35 cz 137.6582975 $ inside radius - 4/3rds of 4 sided area
36 cz 168.1382975 $ outside radius - 4/3rds of 4 sided area
37 cz 145.8265697 $ inside radius - 5/3rds of 4 sided area
38 cz 176.3065697 $ outside radius - 5/3rds of 4 sided area
39 cz 119.6605354 $ inside radius - 2/3rds of 4 sided area
40 cz 150.1405354 $ outside radius - 2/3rds of 4 sided area
41 cz 109.5584875 $ inside radius - 1/3rds of 4 sided area
42 cz 140.0384875 $ outside radius - 1/3rds of 4 sided area
43 cz 98.4255 $ inside radius - 0/3rds of 4 sided area

```

44 cz 128.9055 \$ outside radius = 0/3rds of 4 sided area

kcode	1000	1.0	5	100	
ksrc	0.00	0.00	0.00	76.00	\$ source centered
	0.00	0.00	0.00	86.00	
	0.00	0.00	0.00	96.00	
	0.00	0.00	0.00	106.00	
	0.00	0.00	0.00	116.00	
	0.00	0.00	0.00	126.00	
	0.00	0.00	0.00	136.00	
	0.00	0.00	0.00	146.00	
	0.00	0.00	0.00	156.00	
	0.00	0.00	0.00	166.00	
	50.00	0.00	0.00	76.00	\$ source +X centered
	50.00	0.00	0.00	86.00	
	50.00	0.00	0.00	96.00	
	50.00	0.00	0.00	106.00	
	50.00	0.00	0.00	116.00	
	50.00	0.00	0.00	126.00	
	50.00	0.00	0.00	136.00	
	50.00	0.00	0.00	146.00	
	50.00	0.00	0.00	156.00	
	50.00	0.00	0.00	166.00	
	0.00	50.00	0.00	76.00	\$ source +Y centered
	0.00	50.00	0.00	86.00	
	0.00	50.00	0.00	96.00	
	0.00	50.00	0.00	106.00	
	0.00	50.00	0.00	116.00	
	0.00	50.00	0.00	126.00	
	0.00	50.00	0.00	136.00	
	0.00	50.00	0.00	146.00	
	0.00	50.00	0.00	156.00	
	0.00	50.00	0.00	166.00	
	-50.00	0.00	0.00	76.00	\$ source -X centered
	-50.00	0.00	0.00	86.00	
	-50.00	0.00	0.00	96.00	
	-50.00	0.00	0.00	106.00	
	-50.00	0.00	0.00	116.00	
	-50.00	0.00	0.00	126.00	
	-50.00	0.00	0.00	136.00	
	-50.00	0.00	0.00	146.00	
	-50.00	0.00	0.00	156.00	
	-50.00	0.00	0.00	166.00	
	0.00	-50.00	0.00	76.00	\$ source -Y centered
	0.00	-50.00	0.00	86.00	
	0.00	-50.00	0.00	96.00	
	0.00	-50.00	0.00	106.00	
	0.00	-50.00	0.00	116.00	
	0.00	-50.00	0.00	126.00	
	0.00	-50.00	0.00	136.00	
	0.00	-50.00	0.00	146.00	
	0.00	-50.00	0.00	156.00	
	0.00	-50.00	0.00	166.00	
m1	7014.50e	-0.80000			\$ air (1.29e-3 g/cc)
	8016.50e	-0.20000			
m2	26000.55e	-0.00312			\$ normal concrete (2.37 g/cm3)
	1001.50e	-0.00206			
	8016.50e	-0.49335			
	12000.50e	-0.00209			
	20000.50e	-0.24959			
	14000.50e	-0.18816			
	13027.50e	-0.00510			
	16032.50e	-0.00082			
	6000.50e	-0.05571			
mt2	poly.01t				\$ hydrogen in solid
m3	6000.50e	-0.00040			\$ stainless steel (7.80 g/cm3)
	25055.50e	-0.00100			
	14000.50e	-0.00500			
	12000.50e	-0.17000			
	24000.50e	-0.12000			
	42000.50e	-0.02500			
	15031.50e	-0.00023			
	16032.50e	-0.00015			
	26000.55e	-0.67822			
m4	1001.50e	0.66667			\$ water (1.000 g/cm3)
	8016.50e	0.33333			
mt4	lwtr.01t				\$ hydrogen in liquid

m5	1001.50c	-4.827e-03	\$ wet sand (2.706 g/cm3)
	8016.50c	-4.971e-01	\$ H/U=10
	92234.50c	-8.528e-04	\$ 234U .0074565 wt% U
	92235.50c	-7.935e-04	\$ 235U .6938084 wt% U
	92236.50c	-9.020e-05	\$ 236U .0788619 wt% U
	92238.50c	-1.135e-01	\$ 238U 99.2198732 wt% U
	94238.50c	-3.806e-07	\$ 238Pu .0745658 wt% Pu
	94239.55c	-4.388e-04	\$ 239Pu 86.0096250 wt% Pu
	94240.50c	-6.427e-05	\$ 240Pu 12.5987204 wt% Pu
	94241.50c	-5.616e-06	\$ 241Pu 1.1008806 wt% Pu
	94242.50c	-1.103e-06	\$ 242Pu .2162082 wt% Pu
	13027.50c	-5.163e-02	
	20000.50c	-2.064e-03	
	29000.50c	-7.962e-04	
	26000.50c	-8.831e-02	
	12000.50c	-6.416e-04	
	25055.50c	-6.628e-04	
	42000.50c	-4.580e-05	
	11023.50c	-4.636e-04	
	28000.50c	-1.325e-04	
	82000.50c	-4.012e-04	
	14000.50c	-2.370e-01	
	40000.50c	-4.029e-05	
	31000.50c	-9.121e-04	
wt5	lwtr.01t		\$ hydrogen in liquid
m6	13027.50c	-3.679e-02	\$ H/U=10,000.
	20000.50c	-3.279e-03	\$ wet sand (1.989 g/cm3)
	17000.50c	-1.450e-04	\$ U density= 1.0217e-3 g/cm3
	9019.50c	-8.053e-05	
	26000.55c	-3.439e-03	
	12000.50c	-8.761e-04	
	19000.50c	-2.118e-02	
	14000.50c	-3.064e-01	
	11023.50c	-9.739e-03	
	16032.50c	-3.221e-04	
	22000.50c	-4.027e-05	
	8016.50c	-5.957e-01	
	1001.50c	-2.157e-02	
	92234.50c	-4.040e-08	
	92235.50c	-6.340e-06	
	92236.50c	-2.547e-07	
	92238.50c	-5.070e-04	
wt6	lwtr.01t		\$ hydrogen in liquid
m7	13027.50c	-3.677e-02	\$ H/U=5,000.
	20000.50c	-3.277e-03	\$ wet sand (1.990 g/cm3)
	17000.50c	-1.449e-04	\$ U density= 2.0428e-3 g/cm3
	9019.50c	-8.049e-05	
	26000.55c	-3.437e-03	
	12000.50c	-8.736e-04	
	19000.50c	-2.117e-02	
	14000.50c	-3.062e-01	
	11023.50c	-9.734e-03	
	16032.50c	-3.220e-04	
	22000.50c	-4.024e-05	
	8016.50c	-5.954e-01	
	1001.50c	-2.155e-02	
	92234.50c	-8.074e-08	
	92235.50c	-1.267e-05	
	92236.50c	-5.089e-07	
	92238.50c	-1.013e-03	
wt7	lwtr.01t		\$ hydrogen in liquid
m8	13027.50c	-3.662e-02	\$ H/U=1,000.
	20000.50c	-3.263e-03	\$ wet sand (1.999 g/cm3)
	17000.50c	-1.443e-04	\$ U density= 1.0191e-2 g/cm3
	9019.50c	-8.015e-05	
	26000.55c	-3.422e-03	
	12000.50c	-8.699e-04	
	19000.50c	-2.108e-02	
	14000.50c	-3.049e-01	
	11023.50c	-9.693e-03	
	16032.50c	-3.206e-04	
	22000.50c	-4.008e-05	
	8016.50c	-5.930e-01	
	1001.50c	-2.141e-02	
	92234.50c	-4.011e-07	
	92235.50c	-4.294e-05	
	92236.50c	-2.529e-06	

mt8	92238.50c	-5.033e-03	\$ hydrogen in liquid
mt9	lwtr.01t		\$ H/U=500.
	13027.50c	-3.643e-02	\$ wet sand (2.009 g/cm3)
	20000.50c	-3.246e-03	\$ U density= 2.0327e-2 g/cm3
	17000.50c	+1.435e-04	
	9019.50c	-7.973e-05	
	26000.55c	-3.405e-03	
	12000.50c	-8.654e-04	
	19000.50c	-2.097e-02	
	14000.50c	-3.033e-01	
	11023.50c	-9.643e-03	
	16032.50c	-3.189e-04	
	22000.50c	-3.987e-05	
	8016.50c	-5.902e-01	
	1001.50c	-2.124e-02	
	92234.50c	-7.959e-07	
	92235.50c	-1.249e-04	
	92236.50c	-5.017e-06	
	92238.50c	-9.987e-03	
mt9	lwtr.01t		\$ hydrogen in liquid
mt10	13027.50c	-3.588e-02	\$ H/U=200.
	20000.50c	-3.197e-03	\$ wet sand (2.040 g/cm3)
	17000.50c	-1.413e-04	\$ U density= 5.0407e-2 g/cm3
	9019.50c	-7.852e-05	
	26000.55c	-3.353e-03	
	12000.50c	-8.523e-04	
	19000.50c	-2.065e-02	
	14000.50c	-2.987e-01	
	11023.50c	-9.496e-03	
	16032.50c	-3.141e-04	
	22000.50c	-3.926e-05	
	8016.50c	-5.818e-01	
	1001.50c	-2.075e-02	
	92234.50c	-1.944e-06	
	92235.50c	-3.050e-04	
	92236.50c	-1.225e-05	
	92238.50c	-2.439e-02	
mt10	lwtr.01t		\$ hydrogen in liquid
mt11	13027.50c	-3.501e-02	\$ H/U=100.
	20000.50c	-3.120e-03	\$ wet sand (2.091 g/cm3)
	17000.50c	-1.379e-04	\$ U density= 9.9470e-2 g/cm3
	9019.50c	-7.662e-05	
	26000.55c	-3.272e-03	
	12000.50c	-8.316e-04	
	19000.50c	-2.016e-02	
	14000.50c	-2.915e-01	
	11023.50c	-9.266e-03	
	16032.50c	-3.063e-04	
	22000.50c	-3.831e-05	
	8016.50c	-5.687e-01	
	1001.50c	-1.998e-02	
	92234.50c	-3.743e-06	
	92235.50c	-5.873e-04	
	92236.50c	-2.359e-05	
	92238.50c	-4.676e-02	
mt11	lwtr.01t		\$ hydrogen in liquid
mt12	13027.50c	-3.345e-02	\$ H/U=50.
	20000.50c	-2.981e-03	\$ wet sand (2.188 g/cm3)
	17000.50c	-1.318e-04	\$ U density= 1.9377e-1 g/cm3
	9019.50c	-7.322e-05	
	26000.55c	-3.126e-03	
	12000.50c	-7.947e-04	
	19000.50c	-1.926e-02	
	14000.50c	-2.783e-01	
	11023.50c	-8.855e-03	
	16032.50c	-2.929e-04	
	22000.50c	-3.661e-05	
	8016.50c	-5.453e-01	
	1001.50c	-1.859e-02	
	92234.50c	-6.967e-06	
	92235.50c	-1.093e-03	
	92236.50c	-4.392e-05	
	92238.50c	-8.742e-02	
mt12	lwtr.01t		\$ hydrogen in liquid
mt13	13027.50c	-2.986e-02	\$ H/U=20.
	20000.50c	-2.661e-03	\$ wet sand (2.492 g/cm3)
	17000.50c	-1.176e-04	\$ U density= 4.4942e-1 g/cm3

	9019.50c	+6.535e-05	
	26000.55c	-2.790e-03	
	12000.50c	-7.092e-04	
	19000.50c	-1.719e-02	
	14000.50c	-2.486e-01	
	11023.50c	-7.903e-03	
	16032.50c	-2.614e-04	
	22000.50c	-3.267e-05	
	8016.50c	-4.911e-01	
	1001.50c	-1.540e-02	
	92234.50c	-1.442e-05	
	92235.50c	-2.263e-03	
	92236.50c	-9.091e-05	
	92238.50c	-1.810e-01	
mt13	lwtr.01t		\$ hydrogen in liquid
mt14	13027.50c	-2.600e-02	\$ H/U=10.
	20000.50c	-2.317e-03	\$ wet sand (2.815 g/cm3)
	17000.50c	-1.024e-04	\$ U density= 8.0221e-1 g/cm3
	9019.50c	-5.690e-05	
	26000.55c	-2.430e-03	
	12000.50c	-6.176e-04	
	19000.50c	-1.497e-02	
	14000.50c	-2.165e-01	
	11023.50c	-6.882e-03	
	16032.50c	-2.276e-04	
	22000.50c	-2.845e-05	
	8016.50c	-4.330e-01	
	1001.50c	-1.197e-02	
	92234.50c	-2.242e-05	
	92235.50c	-3.518e-03	
	92236.50c	-1.413e-04	
	92238.50c	-2.813e-01	
mt14	lwtr.01t		\$ hydrogen in liquid
mt15	13027.50c	-2.465e-02	\$ H/U=5.
	20000.50c	-2.197e-03	\$ wet sand (2.969 g/cm3)
	17000.50c	-9.711e-05	\$ U density= 9.5162e-1 g/cm3
	9019.50c	-5.395e-05	
	26000.55c	-2.304e-03	
	12000.50c	-5.856e-04	
	19000.50c	-1.419e-02	
	14000.50c	-2.052e-01	
	11023.50c	-6.325e-03	
	16032.50c	-2.158e-04	
	22000.50c	-2.698e-05	
	8016.50c	-4.127e-01	
	1001.50c	-1.077e-02	
	92234.50c	-2.521e-05	
	92235.50c	-3.956e-03	
	92236.50c	-1.589e-04	
	92238.50c	-3.163e-01	
mt15	lwtr.01t		\$ hydrogen in liquid
mt16	13027.50c	-2.185e-02	\$ H/U=5.
	20000.50c	-1.947e-03	\$ wet sand (3.350 g/cm3)
	17000.50c	-8.609e-05	\$ U density= 1.3205e+0 g/cm3
	9019.50c	-4.783e-05	
	26000.55c	-2.042e-03	
	12000.50c	-5.191e-04	
	19000.50c	-1.258e-02	
	14000.50c	-1.819e-01	
	11023.50c	-5.784e-03	
	16032.50c	-1.913e-04	
	22000.50c	-2.391e-05	
	8016.50c	-3.705e-01	
	1001.50c	-8.277e-03	
	92234.50c	-3.101e-05	
	92235.50c	-4.867e-03	
	92236.50c	-1.955e-04	
	92238.50c	-3.891e-01	
mt16	lwtr.01t		\$ hydrogen in liquid
mt17	13027.50c	-1.738e-02	\$ H/U=2.
	20000.50c	-1.549e-03	\$ wet sand (4.211 g/cm3)
	17000.50c	-6.847e-05	\$ U density= 2.1565e+0 g/cm3
	9019.50c	-3.804e-05	
	26000.55c	-1.624e-03	
	12000.50c	-4.129e-04	
	19000.50c	-1.001e-02	
	14000.50c	-1.447e-01	

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11023.50c -4.600e-03
16032.50c -1.522e-04
22000.50c -1.902e-05
8016.50c -3.031e-01
1001.50c -4.300e-03
92234.50c -4.028e-05
92235.50c -6.321e-03
92236.50c -2.539e-04
92238.50c -5.054e-01
mt17  (wtr.01t
m18  13027.50c -1.523e-02
      20000.50c -1.357e-03
      17000.50c -6.000e-05
      9019.50c -3.333e-05
      26000.55c -1.423e-03
      12000.50c -3.618e-04
      19000.50c -8.768e-03
      14000.50c -1.268e-01
      11023.50c -4.031e-03
      16032.50c -1.333e-04
      22000.50c -1.667e-05
      8016.50c -2.707e-01
      1001.50c -2.388e-03
      92234.50c -4.474e-05
      92235.50c -7.020e-03
      92236.50c -2.820e-04
      92238.50c -5.614e-01
mt18  (wtr.01t
m19  13027.50c -1.254e-02
      20000.50c -1.118e-03
      17000.50c -4.942e-05
      9019.50c -2.746e-05
      26000.55c -1.172e-03
      12000.50c -2.980e-04
      19000.50c -7.222e-03
      14000.50c -1.044e-01
      11023.50c -3.320e-03
      16032.50c -1.098e-04
      22000.50c -1.373e-05
      8016.50c -2.302e-01
      92234.50c -5.030e-05
      92235.50c -7.894e-03
      92236.50c -3.171e-04
      92238.50c -6.312e-01
totnu
ctme  1000.
print  30 40 60 110 126 140

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\$ hydrogen in liquid

\$ H/U=1.

\$ wet sand (4.806 g/cm3)

\$ U density= 2.7332e+0 g/cm3

\$ hydrogen in liquid

\$ H/U=0.

\$ dry sand (3.833 g/cm3)

\$ U density= 3.7311e+0 g/cm3