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1. ECN 187821

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2. ECN Category (mark one) Supplemental ☐ Direct Revision ☒ Change ECN ☐ Temporary ☐ Standby ☐ Supersedure ☐ Cancel/Void ☐	3. Originator's Name, Organization, MSIN, and Telephone No. David G. Erickson, Nuclear Analysis and Characterization, HO-38, 376-4146 <i>W8D 520</i>		4. Date 12/01/94									
	5. Project Title/No./Work Order No. K Basins <i>E35511</i>	6. Bldg./Sys./Fac. No. Sandfilters	7. Approval Designator <i>KN</i> <i>N/A QS</i>									
	8. Document Numbers Changed by this ECN (includes sheet no. and rev.) <i>814</i> WHC-SD-NR-CSER Rev. 0	9. Related ECN No(s). N/A	10. Related PO No. N/A									
11a. Modification Work ☐ Yes (fill out Blk. 11b) ☒ No (NA Blks. 11b, 11c, 11d)	11b. Work Package No.	11c. Modification Work Complete <i>David G. Erickson</i> 12-2-94 Cog. Engineer Signature & Date	11d. Restored to Original Condition (Temp. or Standby ECN only) Cog. Engineer Signature & Date									
12. Description of Change Appendix C was added to address additional information available. Minor additions/changes to the main document were added to point out Appendix C.												
13a. Justification (mark one) <table border="0"> <tr> <td>Criteria Change ☐</td> <td>Design Improvement ☐</td> <td>Environmental ☐</td> </tr> <tr> <td>As-Found ☐</td> <td>Facilitate Const. ☐</td> <td>Const. Error/Omission ☐</td> </tr> <tr> <td></td> <td></td> <td>Design Error/Omission ☐</td> </tr> </table>				Criteria Change ☐	Design Improvement ☐	Environmental ☐	As-Found ☐	Facilitate Const. ☐	Const. Error/Omission ☐			Design Error/Omission ☐
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13b. Justification Details												
14. Distribution (include name, MSIN, and no. of copies) See Distribution list		RELEASE STAMP OFFICIAL RELEASE <i>(21)</i> BY WHC DATE DEC 6 1994 <i>St. 21</i>										

A-7900-013-2 (06/94) GEF095

A-7900-013-1 (11/88)

A-7900-013-3 (06/94) GEF096

RELEASE AUTHORIZATION

**Document
Number:**

WHC-SD-NR-CSER-014, Revision 1

Document Title:

Criticality Safety Evaluation Report for the
100 KE Basin Sandfilter Backwash Pit

Release Date:

December 6, 1994

**This document was reviewed following the
procedures described in WHC-CM-3-4 and is:**

APPROVED FOR PUBLIC RELEASE

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SUPPORTING DOCUMENT		1. Total Pages 29
2. Title Criticality Safety Evaluation Report for the 100 KE Basin Sandfilter Backwash Pit	3. Number WHC-SD-NR-CSER-014	4. Rev No. 1
5. Key Words criticality, KE Basin, criticality safety evaluation, sandfilter backwash pit	6. Author Name: David G. Erickson <i>David G. Erickson</i> Signature Organization/Charge Code W8D520 / E35511	
7. Abstract This analysis presents the technical basis for establishing a safe mass limit for continued operations of the KE Basin sandfilter backwash pit. The main analysis is based on a very conservative UO_2 - PuO_2 - H_2O system using the measured isotopic concentrations of uranium and plutonium in the sludge. Appendix C contains analyses of the sandfilter backwash pit utilizing all verified materials presently in the pit, and gives new limits based on assumptions made.		

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8.	RELEASE STAMP
<div style="border: 1px solid black; padding: 10px; width: fit-content; margin: auto;"> OFFICIAL RELEASE 21 BY WHC DATE DEC 6 1994 <i>Sta. 21</i> </div>	

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1.0 INTRODUCTION

The purpose of this evaluation is to provide the technical basis for establishing a safe mass limit for continued operations in the KE Basin sandfilter backwash pit. The analysis in this report is based on a uranium-plutonium-water system using the measured isotopic concentrations for the uranium and plutonium. The actual sandfilter backwash pit sludge contains many other constituents including fission products, activation products, and corrosion products from the stored spent fuel and other materials in the basin. Appendix C lists these other constituents in the sludge and shows the additional significant safety margin provided by them. The main body of this document ignores the presence of these other materials for conservatism. The other conservative assumptions made were: geometry of the sludge, hydrogen to uranium ratio (H:U), and full water reflection during off-normal conditions. Appendix C contains criticality calculations for the actual sludge makeup.

2.0 DESCRIPTION OF SYSTEM AND FACILITY

2.1 KE BASIN SANDFILTER BACKWASH PIT

The KE Basin sandfilter backwash pit is used to hold the backwash from the sandfilter. Basin water is skimmed from the surface of the basin and pumped through the sandfilter. The sandfilter is regularly backwashed to remove the material that has built up in it. The backwash water is pumped into the backwash pit. The particulates in the backwash pit water will tend to settle to the bottom of the pit and form sludge.

The backwash pit (Figure 1) is approximately 281-cm-long, 212-cm-wide and more than 700-cm-deep (9.2 ft, by 7 ft, by 23 ft). The backwash pit is surrounded by more than 41 cm (16 in.) of concrete on five sides. There is also has a transfer channel connected at one end that is 175-cm-long, 96-cm-wide and 550-cm-deep (5.7 ft, by 3.1 ft, by 18 ft) (Drawing H-1-21072). The sandfilter backwash pit and transfer channel are isolated from the rest of the basin.

2.2 KE BASIN SANDFILTER BACKWASH PIT SLUDGE

The sludge in the KE Basin and sandfilter backwash pit comes from the corrosion of damaged spent N Reactor fuel, stored in open canisters, in the basin and from structural materials in the basin. The corroding spent fuel is mostly high exposure N Reactor fuel with a plutonium composition containing approximately 12 wt% ^{240}Pu . The irradiated fuel being stored in the basin is less reactive than unirradiated (green) fuel.

The KE Basin sandfilter backwash pit sludge is a mixture of water, sand, uranium, and plutonium along with fission, activation, and corrosion products. An elemental composition of the sludge is found in Appendix C. The sludge should have plutonium and uranium isotopics and uranium to plutonium (U:Pu) ratios typical of the spent fuel.

Both infinite system computations and finite geometry calculations of the backwash pit were completed. Calculations were performed evaluating parametric changes in the H:U ratio and the U:Pu ratio.

3.0 REQUIREMENTS DOCUMENTATION

There are no unique requirements applicable to this evaluation

4.0 METHODOLOGY

The codes used for the analyses were WIMS-E (Askew 1986), GOLF (Schwinkendorf, 1993) and MCNP-4.2 (Breisemeister 1990, Carter 1994, LANL 1986). All codes are under configuration control and have been tested extensively with experimental data of homogeneous low-enriched uranium oxide-water systems. The codes 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).

WIMS-E is a transport theory code using an 89-group British cross section library. Golf is a multi-group one-dimensional diffusion theory code.

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

Both WIMS-E and MCNP, were used for k_{inf} calculations of the sludge. WIMS-E was used to perform a quick, extensive, parametric study of the system by varying the U:Pu ratio and the H:U ratio. MCNP was used to calculate k_{eff} for an explicit representation of the backwash pit and the transfer channel using different sludge compositions, see Figure 1.

The GOLF code with two-group cross sections generated by WIMS-E was used to calculate minimum critical radii for both fully water reflected spherical and hemispherical geometries. MCNP was used for the checking of several minimum critical geometry dimensions.

The WIMS-E calculations were performed on a WHC HP workstation using the HP Fortran compiler, MCNP calculations were performed on a WHC SGI workstation using the SGI fortran compiler. GOLF was run on a 486 PC using DOS 6.0 and compiled using Microsoft Fortran Version 5.1.

5.0 DISCUSSION OF CONTINGENCIES

Contingencies:

Geometry - Control of the geometry is not feasible. The optimum geometry (spherical) along with more realistic geometries (hemisphere, slab) were investigated.

Moderation - The models used by this evaluation used the most reactive configurations with optimum moderation. Any other geometric configurations or non-optimal moderation will be less reactive. The backwash pit would have to lose all of its water for any significant loss of moderation of the sludge to occur. It would then be impossible for the sludge to be configured in the most reactive geometry, and be fully water reflected.

U-Pu Segregation - There is no known mechanism in basin filtering components or the sandfilter backwash pit that could be separating the uranium and plutonium in the sludge. Nevertheless, a wide range of U:Pu ratios were used to calculate the data presented in this analysis

Addition of material - The results presented in the analysis are based on safe masses of material. The safe mass is defined as one-half of the $k_{\text{eff}} = 0.98$ mass. The quantity of material would need to be doubled to reach the $k_{\text{eff}} = 0.98$ limit for this system.

Loss of neutron absorbers - The analyses did not account for any of the neutron absorbers that are present in the sandfilter backwash pit sludge. The loss of the absorbers from the sludge would be one contingency. (Appendix C considers the presence of neutron absorbers.)

6.0 EVALUATION AND RESULTS

This analysis used the measured isotopic concentrations for the uranium and plutonium from samples of sludge from the sandfilter backwash pit to generate UO_2 - PuO_2 - H_2O solutions for a wide range of U:Pu and H:U ratios. The isotopics for the uranium and plutonium in the sludge have been measured by the PNL analytical laboratory and can be found in Table 1. These isotopic concentrations are used in all the analyses. For this analysis of the sandfilter backwash pit several conservative assumptions were made about the materials in the pit.

- Only uranium (UO_2), plutonium (PuO_2), and water are present. Fission products, activation products, sand, iron, aluminum, and other materials (neutron absorbing) are not included in the analysis.
- The material is in a spherical (most reactive) or hemispherical (more realistic) geometry with an infinite water reflector rather than a less reactive slab geometry.
- The theoretical density for the mixtures used ranged from 2.9 g/cm^3 to $> 5 \text{ g/cm}^3$. In comparison, all measured wet sludge densities are less than 1.6 g/cm^3 (Appendix A). PNL measured the density of a centrifuged and dried sludge sample to be approximately 2.9 g/cm^3 .
- The H:U ratio is changed over a range covering the minimum critical spherical mass at $k_{\text{eff}} = 1.00$ and $k_{\text{eff}} = 0.98$ of H:U between 3 - 15. At an H:U in that range, the sludge would be like a damp sand (i.e. density $> 1.6 \text{ g/cm}^3$.) Density and moisture content measurements of the actual settled sludge in the sandfilter backwash pit (Appendix A) show that the H:U ratio is greater than 23:1. Fully water reflected

hemispherical radii and masses were also calculated for $k_{\text{eff}} = 1.00$ and $k_{\text{eff}} = 0.98$.

- The U:Pu ratio was varied from 100 to over 400. Measured values of the U:Pu ratio are in excess of 300 and the expected U:Pu ratio (from production table data) is approximately 450:1

A review of N Reactor fuel production data (Hedengren 1987) was made for the spent N Reactor fuel stored in the basin. The N Reactor fuel production data consists of calculated data based on the known exposure (burnup) of the fuel when it was discharged (removed) from the reactor. Most of the fuel now stored in the basin is known to consist of high exposure MKIV fuel assemblies with approximately 12 wt% ^{240}Pu . The uranium and plutonium isotopics measured from the analyzed sludge samples (Table 1) agree well with the expected isotopics from the production tables. The U:Pu ratio calculated from the fuel production data for the spent fuel stored in the basin was found to be around 450:1.

Data received from the WHC 222S labs from analysis of thirteen samples of settled sludge from the sandfilter backwash pit (Appendix A) show a maximum density of 1.53g/cm^3 . The average density is 1.26g/cm^3 with a 1σ standard deviation of 0.15g/cm^3 this gives a maximum density of 1.56g/cm^3 at the 2σ level. The data also show a minimum water concentration of 46.5 wt% with an average concentration of 70.4 wt% with a 1σ standard deviation of 13.4 wt% this would give a minimum water concentration of 43.7 wt% at the 2σ level. The maximum density corresponds to a H:U ratio of more than 45:1, and the water concentration data gives a H:U ratio of more than 23:1. With this density and/or this much H_2O present, the calculated k_{inf} is less than 1.0 for all U:Pu ratios greater than or equal to 125, therefore the critical mass would be infinite.

Under normal backwash pit operating conditions, the sludge in the backwash pit will contain more than 43% by weight water (H:U ratio is greater than 23). The only way for the water concentration of the sludge to be reduced (H:U to be lowered) is to lose the water from the backwash pit. As the water is removed from the backwash pit, the sludge would tend to settle into a slab geometry or possibly a hemispherical geometry. The hemispherical geometry is more reactive than the slab geometry, so calculations were made using the fully water reflected hemispherical geometry. Calculations were also made using a fully water reflected spherical geometry if more conservatism is necessary.

K_{inf} calculations made with the $\text{UO}_2\text{-PuO}_2\text{-H}_2\text{O}$ system show that with a U:Pu ratio greater than 400:1, the system cannot go critical under any circumstances ($k_{\text{inf}} < 1.0$ for all H:U ratios). The calculations also show that $k_{\text{inf}} < 1.0$ for all analyzed U:Pu ratios when the H:U ratio is greater than 28. Therefore under normal operating conditions (settled sludge at the bottom of the backwash pit with full water reflection) the sand filter backwash pit is safely subcritical at all times under all normal conditions of moderation (H:U > 30) and material additions.

For the off-normal conditions, it was assumed that all water is lost from the sandfilter backwash pit. At this point the sludge is assumed to be in a hemispherical geometry with optimum moderation and water is then added

back into the pit so there is full water reflection. Figure 2 shows the hemispherical minimum critical mass ($k_{\text{eff}} = 1.00$), the $k_{\text{eff}} = 0.98$ mass and the safe mass of the plutonium in the analyzed system. The safe mass is defined as one-half of the $k_{\text{eff}} = 0.98$ mass. Table 2 contains the hemispherical plutonium and uranium mass information in tabular form. Figure 3 shows how the addition or subtraction of water from the system at optimum moderation (minimum point on curves) affects the safe mass of plutonium for all of the U:Pu ratios. Figures 4 and 5 show the equivalent information for the fully water reflected spherical geometry. Table 3 contains the spherical plutonium and uranium mass information in tabular form. Figure 6 shows the safe mass of plutonium in the system for both the spherical and hemispherical geometries.

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.

8.0 SUMMARY AND CONCLUSIONS

This analysis based on the assumptions discussed above shows that under normal operating conditions a criticality ($k_{\text{inf}} > 1.00$) is not possible even with the backwash pit completely full of sludge. For off-normal conditions the minimum hemispherical and spherical safe mass of plutonium for the sandfilter backwash pit over a wide range of U:Pu ratios are given. These data presented in this analysis can be used to establish a limit for the quantity of plutonium allowed in the sandfilter backwash pit. The data used to generate the plutonium safe mass curves are very conservative. The analysis considers a number of contingencies (geometry, moderation, material addition, and uranium-plutonium segregation). The analysis ignores the presence of neutron absorbers known to be present in the sludge.

Appendix C shows that if the minimum quantity of uranium (mean - 2σ) is in the pit, then approximately 1191 g of plutonium is needed for a $k_{\text{eff}} = 0.98$ giving a safe mass of plutonium of 595 g. If the average quantities of uranium and other materials are present, then 9200 g of plutonium are necessary for a $k_{\text{eff}} = 0.98$ giving a safe mass of 4600 g plutonium. If both uranium and plutonium are added to the pit average contents at a U:Pu ratio of at least 100, then the pit is safely subcritical even with infinite quantities of sludge. The discussion of these results can be found in Appendix C.

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Figure 1. KE Basin Sandfilter Backwash pit MCNP model.

Table 1. Uranium and plutonium isotopics used in analysis.

Uranium		Plutonium	
Isotope	Mass%	Isotope	Mass%
U ²³⁴	0.007	Pu ²³⁸	0.075
U ²³⁵	0.694	Pu ²³⁹	86.010
U ²³⁶	0.080	Pu ²⁴⁰	12.599
U ²³⁸	99.210	Pu ²⁴¹	1.109
		Pu ²⁴²	0.216

Table 2. Plutonium and uranium minimum critical mass, $k_{eff} = 0.98$ mass, and safe mass for a UO_2 - PuO_2 - H_2O system with a fully water reflected hemispherical geometry at optimum moderation.

U:Pu Ratio	H:U Ratio @Minimum	Safe Mass (kg)		$k_{eff} = 0.98$ mass (kg)		$k_{eff} = 1.00$ mass (kg)	
		Plutonium	Uranium	Plutonium	Uranium	Plutonium	Uranium
0	H:Pu=760	0.71	0.	1.43	0.	1.58	0.
25	37	1.24	30.8	2.48	61.7	2.86	71.1
50	20	1.67	83.0	3.33	165.9	3.96	197.0
75	14	2.14	160.0	4.26	319.9	5.25	392.1
100	11	2.70	268.5	5.39	537.0	6.85	681.8
125	10	3.35	416.9	6.70	833.8	8.83	1,099.3
150	9	4.14	617.9	8.27	1,235.9	11.45	1,710.7
175	8	5.10	889.6	10.21	1,779.3	14.90	2,596.9
200	7	6.36	1,266.0	12.71	2,532.0	19.67	3,917.8
225	7	7.85	1,759.3	15.70	3,518.5	26.84	6,013.2
250	6	10.03	2,497.4	20.06	4,994.8	37.40	9,310.5
275	6	12.60	3,451.5	25.21	6,902.9	55.01	15,063.6
300	6	16.43	4,907.8	32.86	9,815.5	91.77	27,414.5
325	5	22.54	7,294.2	45.08	14,588.3	175.87	56,917.1
350	5	32.07	11,178.8	64.15	22,357.5	485.27	169,133.5
375	5	47.06	17,573.7	94.12	35,147.3	9,102.40	3,399,120.
400	5	77.88	31,022.2	155.78	62,044.3	INF	INF
425	5	165.14	69,892.1	330.29	139,784.3	INF	INF
450	5	970.90	435,078.1	1,941.81	870,156.1	INF	INF
475	N/A	INF	INF	INF	INF	INF	INF

Table 3. Plutonium and uranium minimum critical mass, $k_{eff} = 0.98$ mass, and safe mass for a UO_2 - PuO_2 - H_2O system with a fully water reflected spherical geometry at optimum moderation.

U:Pu Ratio	H:U Ratio @Minimum	Safe Mass (kg)		$k_{eff} = 0.98$ mass (kg)		$k_{eff} = 1.00$ mass (kg)	
		Plutonium	Uranium	Plutonium	Uranium	Plutonium	Uranium
0	H:Pu=760	0.35	0.	0.70	0.	0.78	0.
25	34	0.65	16.2	1.30	32.3	1.51	37.7
50	19	0.90	45.0	1.81	89.9	2.17	107.8
75	14	1.19	89.0	2.38	178.0	2.95	220.2
100	11	1.53	152.6	3.06	305.2	3.92	390.7
125	10	1.93	240.7	3.87	481.4	5.18	644.2
150	9	2.43	362.6	4.85	725.2	6.83	1,019.9
175	8	3.03	528.7	6.07	1,057.4	9.01	1,569.5
200	7	3.82	760.0	7.63	1,520.0	12.02	2,394.3
225	7	4.78	1,071.3	9.56	2,142.6	16.65	3,731.3
250	6	6.16	1,533.5	12.32	3,067.0	23.41	5,826.8
275	6	7.82	2,140.8	15.64	4,281.7	34.83	9,538.1
300	6	10.27	3,066.8	20.53	6,133.6	58.52	17,481.9
325	5	14.23	4,606.3	28.47	9,212.6	112.66	36,462.7
350	5	20.36	7,094.9	40.71	14,189.7	300.75	104,821.9
375	5	30.02	11,211.3	60.05	22,422.7	6,477.53	2,418,912.
400	5	49.92	19,886.4	99.85	39,772.8	INF	INF
425	5	103.70	43,887.0	207.39	87,774.0	INF	INF
450	5	428.70	192,108.9	857.40	384,217.8	INF	INF
475	N/A	INF	INF	INF	INF	INF	INF

Figure 2. Hemispherical mass of plutonium in a $\text{UO}_2\text{-PuO}_2\text{-H}_2\text{O}$ mixture with varying U:Pu ratios at optimum moderation.

Figure 3. Hemispherical safe mass of plutonium in a $\text{UO}_2\text{-PuO}_2\text{-H}_2\text{O}$ mixture with varying U:PU and H:U ratios.

Figure 4. Spherical masses of plutonium in a $\text{UO}_2\text{-PuO}_2\text{-H}_2\text{O}$ mixture with varying U:Pu ratios at optimum moderation.

Figure 5. Spherical safe mass of plutonium in a UO_2 - PuO_2 - H_2O mixture with varying U:Pu and H:U ratios.

Figure 6. Comparison of the plutonium safe mass for both spherical and hemispherical geometries at optimum moderation.

APPENDIX A.

KE Basin sandfilter backwash pit sludge analysis results

The data in Table A.1 is reproduced from Table 3.1 of WHC-SD-WM-DP-056 REV 0. The data in Table A.2 is reproduced from Table 4.1 of WHC-SD-WM-DP-057 REV 0.

TABLE A.1 SAMPLE PROCESSING DATA AND CALCULATED PROPERTIES				
DATUM (units)	SAMPLE S3059-01	SAMPLE S3059-03	SAMPLE S3059-04	SAMPLE S3059-11
SLUDGE DENSITY (g per mL sludge)	1.04	1.08	1.30	1.30
WT % SOLIDS (% by weight)	NA	11.40	37.15	34.64
WT % WATER (% by weight)	NA	88.80	62.85	65.36
SOLIDS CONCENTRATION (g solids per mL sludge)	NA	0.12	0.48	0.45

TABLE A.2 SAMPLE PROCESSING DATA AND CALCULATED PROPERTIES				
DATUM (units)	SAMPLE S3059-05	SAMPLE S3059-06	SAMPLE S3059-07	SAMPLE S3059-08
SLUDGE DENSITY (g per mL sludge)	1.08	1.21	1.41	1.31
WT % SOLIDS (% by weight)	4.52	20.70	34.40	31.06
WT % WATER (% by weight)	95.48	79.30	65.60	68.94
SOLIDS CONCENTRATION (g solids per mL sludge)	0.049	0.251	0.494	0.406

References:

Rice, A. D., 1993, WHC-SD-WM-DP-056 Rev. 0, *KE FILTER BACKWASH PIT*, Westinghouse Hanford Company, Richland, Washington

Rice, A. D., 1994, WHC-SD-WM-DP-057 Rev. 0, *105-KE FILTER BACKWASH PIT (SFBWP) TRANSFER CHANNEL*, Westinghouse Hanford Company, Richland, Washington

Westinghouse
Hanford Company

Internal
Memo

From: Process Chemistry Laboratories 12110-PCL93-120
Phone: 373-2162 T6-09
Date: December 29, 1993
Subject: SLUDGE CALCULATIONS FOR KE BACKWASH PIT SERIES S3062- SAMPLES

To: C. L. Bennett X0-44

RECEIVED

cc: R. P. Bushore *RPB* T6-07
D. A. Dodd T6-50
J. R. Jewett *JR* T6-09
J. P. Sloughter T6-07
Process Aids T6-09
DBB File/LB

C.L. BENNETT

Reference: Bechtold, D. B., 1993, "Laboratory Test Plan for Analysis of KE Basin Backwash Pit Samples," WHC-SD-NR-TP-023, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

The sludge property calculations for the S3062- series of samples from the KE backwash pit have been completed, reviewed, and resolved. The results are presented in the attached table. Some of the values have changed slightly from the informal results you have previously received.

Feel free to call me at 373-2162, if you have any further questions.

D. B. Bechtold
D. B. Bechtold
Principal Scientist

llu

Attachment

Table. KE Backwash Pit Sample Processing Data and
Calculated Sludge Properties -- S3062 Series.

DATUM (units)	SAMPLE S3062-02	SAMPLE S3062-03	SAMPLE S3062-04	SAMPLE S3062-05	SAMPLE S3062-06	SAMPLE S3062-07	SAMPLE S3062-08
SLUDGE NET WEIGHT (g)	159.14	228.44	173.58	227.75	412.18	116.41	198.15
DRY NET WEIGHT (g dry solids)	41.41	88.40	39.87	91.44	220.56	6.20	56.23
DIGEST NET WEIGHT (g)	10.07	9.95	10.05	10.18	10.58	6.20	10.06
RESIDUE NET WEIGHT (g residue)	8.78	9.02	8.09	9.58	9.86	2.42	8.78
SLUDGE VOLUME (mL)	135	185	139	154	270	110	145
VOL. % WET SAND (% by vol. in sludge)	23	28	5	31	57	3	12
VOL. % WET MUD (% by vol. in sludge)	77	72	95	69	43	97	88
WT. % SOLIDS (% by wt. in sludge)	26.02	38.70	22.97	40.15	53.51	5.33	28.38
WT % WATER (% by wt. in sludge)	73.98	61.30	77.03	59.85	46.49	94.67	71.62
WT % RESIDUE OF DIGEST (wt % of dry solids)	87.19	90.65	80.50	94.11	93.19	39.03	87.28
SLUDGE DENSITY (g sludge per mL sludge)	1.18	1.24	1.25	1.48	1.53	1.05	1.36
CALCULATED HEIGHT IN SAMPLER (inches)	10.46	14.35	10.77	11.95	20.96	8.58	11.30
SOLIDS CONCENTRATION (g solids per mL sludge)	0.308	0.479	0.288	0.594	0.818	0.056	0.386
WATER CONCENTRATION (g water per mL sludge)	0.875	0.758	0.965	0.886	0.710	0.998	0.975
AVERAGE PARTICLE DENSITY (g particle per mL particle)	1.79	1.44	3.14	1.94	1.43	16.39 (improbable result)	3.07
DIGEST RATE (mL digest per g solids digested)	99.30	100.50	99.50	98.23	94.52	161.29	99.40
PCL DILUTION FACTOR (no units)	1.000	1.000	1.000	1.000	1.000	1.000	1.000

APPENDIX B.

WIMS-E, GOLF, and MCNP sample input files.

WIMS-E sample input file for infinite solution calculations

```

*****
* infinite solution calculation for KE backwash pit sludge
*****
*
WHEAD      1
NMESH      7
NREGION    1
NMATERIAL  1
ENDP
PRINT      0
CENT
MESH       7
MATERIAL 1 1.551 296.0 1 3001 5.476E+00 6016 6.500E+01
                2235 1.222E-01 8238 1.278E+01
                948 9.627E-05 6239 1.110E-01
                1240 1.626E-02 1241 1.421E-03
                1242 2.790E-04
                91 1.911E-02 27 5.767E+00
                1059 2.595E-03 3063 1.227E-01
                6 4.841E-04 58 7.175E-03
                2056 9.455E+00 52 5.056E-02
                4145 2.669E-02 4149 9.589E-02
                24 6.907E-02 23 7.778E-03
                4095 1.482E-03 207 8.114E-02
                48 8.985E-03 2113 1.053E-02
                55 7.041E-02 121 3.447E-02
                51 7.041E-02 9 3.091E-03
ANNULUS 1 4.0000 1 * INFINITE REGION OF SOLUTION
BEGIN
*
* PERSEUS CALCULATIONS
*
WTHES      1
PRINT      0
BEGIN
*
WPIP       1
PRINT      0
TOLER 1.0E-5
OMEGA 1.25
BEGIN
STOP

```

Golf input for $k_{\text{eff}}=1.00$ sphere.

```
1.000 5.0e-5 1 1 0 0 1 1
2 2 2 1 0.00e-04 1.0e-05 1.0 0.0001 2.0e-03 1.0e-5 1
30.510 46.0
350 150
1.0 0.0
0.0 1
```

Golf input for $k_{\text{eff}}=0.98$ hemisphere.

```
0.980 5.0e-5 1 1 0 1 1 1
2 2 2 1 0.00e-04 1.0e-05 1.0 0.0001 2.0e-03 1.0e-5 1
30.510 46.0
350 150
1.0 0.0
0.0 1
```

MCNP sample input for infinite solution calculations

message:

INF011 Infinite sphere, WHC analysis, U:Pu = 456:1, H:U = 8:1

c	m	dens	geom	\$Comment
1	1	-2.86	-1	imp:n=1 \$ inside sphere
2	0		1	imp:n=0 \$ outside sphere

*1	so	30.	\$edge of sphere (in cm)

mode	n		
m1	1001.50c	-8.032E-03	\$H
	8016.50c	-4.516E-01	\$O
	92234.50c	-1.778E-05	\$U234
	92235.50c	-1.654E-03	\$U235
	92236.50c	-1.880E-04	\$U236
	92238.50c	-2.366E-01	\$U238
	94238.50c	-3.901E-07	\$Pu238
	94239.55c	-4.497E-04	\$Pu239
	94240.50c	-6.587E-05	\$Pu240
	94241.50c	-5.756E-06	\$Pu241
	94242.50c	-1.130E-06	\$Pu242
	40000.50c	-3.493E-04	\$Zr
	13027.50c	-1.054E-01	\$Al
	27059.50c	-4.743E-05	\$Co
	29000.50c	-2.243E-03	\$Cu
	3006.50c	-8.848E-06	\$Li
	28000.50c	-1.311E-04	\$Ni
	26000.55c	-1.728E-01	\$Fe
	20000.50c	-4.424E-03	\$Ca
	24000.50c	-9.240E-04	\$Cr
	62149.50c	-1.752E-03	\$Sm
	56138.50c	-2.292E-04	\$Ba
	15031.50c	-1.336E-03	\$P
	16032.50c	-1.642E-03	\$S
	12000.50c	-1.262E-03	\$Mg
	33075.35c	-7.096E-05	\$As
	11023.50c	-1.422E-04	\$Na
	42000.50c	-2.708E-05	\$Mo
	82000.50c	-1.483E-03	\$Pb
	22000.50c	-1.642E-04	\$Ti
	48000.50c	-1.924E-04	\$Cd
	19000.50c	-2.096E-04	\$K
	25055.50c	-1.287E-03	\$Mn
	23000.50c	-1.287E-03	\$V
	4009.50c	-5.649E-05	\$Be

mt1	lwtr.01t					\$ Hydrogen in water 300
kcode	500	1.0	5	50		

ksrc	0.0	0.0	0.0			
	0.0	0.0	10.0	0.0	0.0	20.0
	0.0	10.0	0.0	0.0	20.0	0.0
	10.0	0.0	0.0	20.0	0.0	0.0
	0.0	0.0	-10.0	0.0	0.0	-20.0
	0.0	-10.0	0.0	0.0	-20.0	0.0
	-10.0	0.0	0.0	-20.0	0.0	0.0

totnu
print
ctme

MCNP sample input for backwash pit k effective calculations

message:

BKWOWB - K Basin backwash pit and chute, WHC analysis, U:Pu = 456:1, H:U = 100

```

c
c  m  dens      geom      $Comment
1  1  -2.3      19 -22    8 -17    1 -2    $ Pit floor
2  1  -2.3      21 -22    8 -17    2 -7    $ Pit end wall
3  1  -2.3      20 -21    8 -9     2 -7    $ Pit - side wall
4  1  -2.3      20 -21    16 -17   2 -7    $ Pit + side wall
5  1  -2.3      19 -20    8 -17    2 -5    $ Pit/chute wall
6  1  -2.3      19 -20    8 -12    5 -7    $ Pit/chute - top wall
7  1  -2.3      19 -20    13 -17   5 -7    $ Pit/chute + top wall
8  1  -2.3      18 -19    10 -15   4 -5    $ Chute floor
9  1  -2.3      18 -19    10 -11   5 -7    $ Chute - wall
10 1  -2.3      18 -19    14 -15   5 -7    $ Chute + wall
11 2  -1.55     20 -21    9 -16    2 -3    $ Pit sludge
12 2  -1.55     19 -20    12 -13   5 -6    $ Gap sludge
13 2  -1.55     18 -19    11 -14   5 -6    $ Chute sludge
14 3  -1.0      20 -21    9 -16    3 -7    $ Pit water
15 3  -1.0      19 -20    12 -13   6 -7    $ Gap water
16 3  -1.0      18 -19    11 -14   6 -7    $ Chute water
17 0          18 -19 8 -17 1 -7 (-10:15:-4) $ around chute
18 0          -23 (-18:22:-8:17:-1:7)    $ outside area

```

```

1  pz  -53.34    $ Bottom of concrete
2  pz   0.000    $ Backwash pit floor
3  pz  43.18     $ Top of sludge in pit
4  pz  91.44     $ Bottom of chute concrete
5  pz 152.40     $ Chute floor
6  pz 180.34     $ Top of chute sludge
7  pz 271.78     $ Top of model
8  py -147.32    $ - Outside of pit concrete
9  py -106.68    $ - Side of pit
10 py -88.90     $ - Outside of chute
11 py -48.26     $ - Side of chute
12 py -33.02     $ - Side of pit end wall
13 py 33.02      $ + Side of pit end wall
14 py 48.26      $ + Side of chute
15 py 88.90      $ + Outside of chute
16 py 106.68     $ + Side of pit
17 py 147.32     $ + Outside of pit concrete
18 px 0.000      $ End of chute
19 px 175.26     $ Inside of chute
20 px 215.90     $ Inside of pit
21 px 496.25     $ Inside of pit end
22 px 541.335    $ Outside of pit end
23 so 1000.0     $ Outside world

```

```

mode  n
imp:n 1 15r 0 0
m1    13027.50c -0.034    $ Al      Concrete
      20000.50c -0.044    $ Ca      (Common
      26000.55c -0.014    $ Fe      Portland)
      1001.50c  -0.010    $ H
      8016.50c  -0.532    $ O
      14000.50c -0.337    $ Si
      11023.50c -0.029    $ Na
m2    1001.50c  -5.482E-02 $H
      8016.50c  -6.501E-01 $O
      92234.50c -9.708E-06 $U234
      92235.50c -9.033E-04 $U235
      92236.50c -1.027E-04 $U236
      92238.50c -1.292E-01 $U238
      94238.50c -2.130E-07 $Pu238
      94239.55c -2.456E-04 $Pu239
      94240.50c -3.597E-05 $Pu240
      94241.50c -3.143E-06 $Pu241
      94242.50c -6.173E-07 $Pu242
      40000.50c -1.907E-04 $Zr

```

13027.50c	-5.755E-02	\$Al
27059.50c	-2.590E-05	\$Co
29000.50c	-1.225E-03	\$Cu
3006.50c	-4.832E-06	\$Li
28000.50c	-7.160E-05	\$Ni
26000.55c	-9.436E-02	\$Fe
20000.50c	-2.416E-03	\$Ca
24000.50c	-5.046E-04	\$Cr
62149.50c	-9.569E-04	\$Sm
56138.50c	-1.251E-04	\$Ba
15031.50c	-7.294E-04	\$P
16032.50c	-8.967E-04	\$S
12000.50c	-6.893E-04	\$Mg
33075.35c	-3.875E-05	\$As
11023.50c	-7.763E-05	\$Na
42000.50c	-1.479E-05	\$Mo
82000.50c	-8.097E-04	\$Pb
22000.50c	-8.967E-05	\$Ti
48000.50c	-1.051E-04	\$Cd
19000.50c	-1.144E-04	\$K
25055.50c	-7.027E-04	\$Mn
23000.50c	-7.027E-04	\$V
4009.50c	-3.085E-05	\$Be
mt2	lwtr.01t	\$ Hydrogen in water 300
m3	1001.50c 2	\$ H H2O
	8016.50c 1	\$ O
mt3	lwtr.01t	\$ Hydrogen in water 300
kcode	1000 0.5 5 50	
ksrc	250.0 48.0 20.0	250.0 -48.0 20.0
	450.0 48.0 20.0	450.0 -48.0 20.0
	50.0 0.0 175.0	100.0 0.0 175.0
totnu		
print		
ctme		

APPENDIX C.

Analysis of actual backwash pit sludge constituents.

1.0 Introduction

In September and November of 1993, two sandfilter backwash pit sludge sampling campaigns were conducted. As a result of these sampling campaigns, 13 samples of sludge were obtained. These samples were analyzed by both PNL and WHC laboratories for all materials present. The results of these analyses were extensively studied and statistically analyzed in Welch 1994, to yield the data presented in Table 1. Table 1 shows the total quantity of each element extrapolated out to the volume of sludge in the pit.

Table 1. K East Basin Sandfilter Backwash Pit Contents

Analyte	Total Amount (mean)	Uncertainty (1 RSD)*
Plutonium	97.5 g	19.1%
Uranium	39,000.0 g	20.4%
Aluminum	30,000.0 g	25.1%
Barium	401.0 g	24.8%
Beryllium	29.2 g	30.5%
Calcium	22,700.0 g	24.2%
Cadmium	206.0 g	20.4%
Chromium	494.0 g	35.1%
Copper	1,040.0 g	23.0%
Iron	89,800.0 g	34.4%
Magnesium	2,860.0 g	25.1%
Manganese	1,240.0 g	18.6%
Lead	347.0 g	17.8%
Zinc	888.0 g	20.2%
Sodium	1,630.0 g	26.4%
Silicon	3,440.0 g	19.8%

* RSD - relative standard deviation

The data collected from the 13 sludge samples also included the settled density of the sludge and the weight percent (wt%) of water present in the sludge. These data extracted from Rice 1993 and Rice 1994 are presented in Table 2. Table 2 also includes the mean and standard deviation for the sludge density and the wt% water. The worst case data for density and wt% was calculated by taking the average and adding two times the standard deviation for the density and subtracting two times the standard deviation for the wt% water.

Table 2. Analysis of K East Basin Backwash Pit Sludge Density and WT% Water.

Sample #	Density (g/cm ³)	Water (wt%)
1	1.05	N/A
2	1.08	88.80
3	1.30	62.85
4	1.31	65.36
5	1.08	95.48
6	1.21	79.30
7	1.41	65.60
8	1.31	68.94
9	1.18	73.98
10	1.24	61.50
11	1.25	77.03
12	1.48	59.85
13	1.53	46.49
Mean	1.26	70.43
Std. Dev.	0.15	13.39
Worst case	1.56	43.64

2.0 Evaluation and Results

The information from Tables 1 and 2 were used to calculate the reactivity of the sandfilter backwash pit with actual quantities of materials. The results of these calculations can be found in Table 3. Table 3 shows that even with infinite quantities of sludge the sandfilter backwash pit is very subcritical.

Table 3. Results from analysis of actual pit contents.

Backwash pit actual contents	
Case	$K_{eff} \pm 1\sigma$
Normal H ₂ O (70%)	0.0768 ± 0.0002
Worst H ₂ O (44%)	0.1187 ± 0.0004
K-infinity (worst H ₂ O)	0.1286 ± 0.0004

Remembering that the sandfilter should continue to remove all materials from the basin water, just as it has in the past, three studies were performed

to investigate the consequences of adding additional plutonium only or uranium and plutonium at various ratios to the present inventory.

The first study evaluated only plutonium (not accounting for any of the other sludge constituents) addition to 23.1 kg of uranium (minimum quantity presently in the pit) as a function of water concentration. The calculated k_{eff} values for this study are shown in Figure 1. Figure 1 shows that with about 60 wt% water, 1191 g of plutonium gives a $k_{\text{eff}} = 0.98$. Therefore the safe mass of plutonium under these conditions is 595 g.

The second study considered the measured inventory of the pit, and then adding plutonium only. The results of this study can be found in Figure 2. This study shows that accounting for all materials presently in the backwash pit, with 55 wt% water, 9200 g of plutonium yields a calculated $k_{\text{eff}} = 0.98$. The safe mass of plutonium for this system would be approximately 4600 g.

The final study took the same quantities of materials as used above, but added uranium and plutonium at several different ratios. The results of this study are shown in Figure 3. This study shows that with a U:Pu ratio of 100 or greater, infinite quantities of uranium and plutonium can be added and still remain very subcritical. With a U:Pu of 75, more than 140 kg of plutonium and 10,500 kg of uranium need to be added to get a k_{eff} around 0.98 for a safe mass of about 70 kg of plutonium and 5,250 kg of uranium. It may be seen in figure 3 that the curve for U:Pu = 75 is approaching an asymptote, and may be less than $k_{\text{eff}} = 1.00$ even for nearly infinite quantities.

The data in Table 1 indicate a U:Pu ratio of 400, and there is no reason to believe that any basin operations would cause this ratio to change significantly. Using the minus 2 relative standard deviation (RSD) quantity of uranium and the plus 2 RSD quantity of plutonium yields a U:Pu ratio of 170. Even this U:Pu ratio is approximately double the U:Pu ratio of 75 where there may be a concern of a criticality in the sandfilter backwash pit under these circumstances.

The first study is the most conservative utilizing only the current minimum quantity of uranium in the pit and adding only plutonium. The second study is less conservative, utilizing the average quantities of all materials, and adding only plutonium. The final study is the least conservative, adding uranium and plutonium to the materials present in the pit. But, it can be seen by comparison to the data from Table 3 that even the final study is still conservative when compared to actual operations where all materials should continue to accumulate in approximately equivalent proportions in the future.

3.0 Conclusions

The results of these studies show that the most conservative safe mass limit for plutonium in the backwash pit is 595 g. This is assuming that 1) no additional uranium enters the pit beyond the minimum experimentally verified quantity of 29.1 kgs, and 2) there are no non-fuel materials in the pit.

If it is assumed that 1) the current, experimentally verified mean quantities of non-fuel materials always remain intimately mixed with the

current mean verified quantities of uranium and plutonium, and 2) only additional plutonium enters the backwash pit, then the plutonium safe mass is 4600 g.

If it is further assumed that uranium enters the backwash pit along with the plutonium at a U:Pu ratio of 100 or greater, then the backwash pit is safely subcritical even when completely filled.

The results in Table 3 show that if the backwash pit is completely homogeneously filled with the same ratios of materials that have been shown to be present, then the backwash pit is very subcritical under all conditions.

4.0 References

Rice, A. D., 1993, WHC-SD-WM-DP-056 Rev. 0, *KE FILTER BACKWASH PIT*, Westinghouse Hanford Company, Richland, Washington.

Rice, A. D., 1994, WHC-SD-WM-DP-057 Rev. 0, *105-KE FILTER BACKWASH PIT (SFBWP) TRANSFER CHANNEL*, Westinghouse Hanford Company, Richland, Washington.

Welsh, T. L., 1994, WHC-SD-SNF-TI-004, Rev. 0, *STATISTICAL EVALUATION OF THE DATA OBTAINED FROM THE K EAST BASIN SANDFILTER BACKWASH PIT SAMPLES*, Westinghouse Hanford Company, Richland, Washington.

Figure 1. Constant 23.1 kg Uranium with Additional Plutonium.

Figure 2. Constant 39 kg Uranium plus Absorbers with Additional Plutonium.

Figure 3. Constant Pit Contents with additional Uranium and Plutonium at different ratios.