RAI Responses 13-17

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RESPONSE TO RAI COMMENT 13
ROADMAP TO REFERENCES

REFERENCED DOCUMENT	*EXCERPT LOCATION	REMARK
Cozzi 2004	Enclosed following response: Whole document	
Dean 2004 (Reference in RAI and 3 places in RAI Attachment)	Enclosed following response: Whole document; Pages 26 - 30	Document is referenced in the RAI attachment in three places.
Fowler 2004	Other	See full document.
Fowler 2005 (Reference in RAI Attachment)	Excerpt enclosed following response: Table 1 and Case 1 including Table 3.	
Lambert and Fink 2003	Other	See full document.
Lambert and Stallings 2003	Other	See full document.
Lambert et al. 2003	Other	See full document.
Maxwell 2004 (Reference in RAI and 3 places in RAI Attachment)	Enclosed following response: Whole document for each of 4 references	
Peters et al. 2003	Other	See full document.
Peters and Barnes et al. 2004	Enclosed following response: Whole document	
Peters and Lambert et al. 2004 (Reference in RAI and 1 place in RAI Attachment)	Other	See full document.
Tran 2005	Enclosed following response: Tables 4, 5, and 6	The curies in Table 13-2 are the sums of the individual radioisotopes for the tanks.
WSRC 2002 (Reference in RAI and 2 places in RAI Attachment)	Other: Whole document; Pages 43 and 86; Pages 43 and 64.	See document in file. Referenced in RAI attachment in two places.
WSRC 2003a (Reference in RAI and 4 places in RAI Attachment)	Excerpt enclosed following response	Section 3.2.1, 3.2.2, 3.2.3, 3.2.4
WSRC 2003b (Reference in RAI Attachment)	Excerpt enclosed following response	Purchasing specification (Pages 9-35)
Zapp and Mickalonis 2003	Other	See full document.

*Excerpt Locations:

1. Excerpt included within response: The excerpt is included within the text of the response or is appended to the response.
2. Excerpt enclosed following response: The excerpt is enclosed on a separate sheet or sheets following the response.
3. Representative excerpt(s) enclosed following response: Representative excerpts from a document that is wholly or largely applicable are enclosed following the response.
4. Other

FORMULATION DEVELOPMENT FOR PROCESSING TANK 48H IN SALTSTONE

A.D. Cozzi

October 2004

SAVANNAH RIVER NATIONAL LABORATORY

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SRNL
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FORMULATION DEVELOPMENT FOR PROCESSING TANK 48H IN SALTSTONE

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EXECUTIVE SUMMARY

Salt Program Engineering (SPE) requested research to help evaluate the Saltstone process as a disposition path for the contents of Tank 48H. The main objective of the task was to evaluate the processing and cured properties of Saltstone prepared with Tank 48H material aggregated with other Tank 50H inflows to determine the suitability of Saltstone as a disposition path for the contents of Tank 48H.

The Tank 48H waste was aggregated with inhibited water (IW) and a simulant of the recycle stream from the Defense Waste Processing Facility (DWPF). The aggregates targeted three tetraphenyl borate (TPB) concentrations: 1) 5500 mg/L, the aggregate determined from assumptions at the maximum reasonable limits, 2) 1500 mg/L, the aggregate containing the minimum proportion of Tank 48H material that is programmatically acceptable, and 3) 3500 mg/L, the average of the two endpoints. Saltstone prepared with Tank 48H waste aggregated with IW and a simulant of the recycle stream from the DWPF was produced in the Savannah River National Laboratory (SRNL) shielded cells. Processable Saltstone slurry formulations can be prepared with Tank 48H material and both DWPF recycle simulant and inhibited water with concentrations of 1500, 3500, and 5500 mg/L TPB. Toxic Characterization Leaching Procedure (TCLP) extractions were performed on the six aggregates. The extracts were analyzed for benzene, nitrobenzene and mercury. All of the samples passed TCLP.

Saltstone was also prepared with a Tank 48H simulant and DWPF recycle simulant. Testing of the fresh Saltstone slurry and cured Saltstone prepared with simulants indicate that neither the fresh nor cured Saltstone is hazardous for ignitability.

After transferring Tank 48H material to Tank 50H and prior to processing through the Saltstone Production Facility (SPF), Tank 50H should be sampled to verify processability.

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LIST OF ACRONYMS

ADS	Analytical Development Section
CVAA	Cold Vapor - Atomic Absorption
DWPF	Defense Waste Processing Facility
EPA	United States Environmental Protection Agency
FA	Fly Ash
GC	Gas Chromatography
GGBFS	Ground Granulated Blast Furnace Slag
ITP	In Tank Precipitation
IW	Inhibited Water
KTBP	Potassium Tetraphenylborate
MS	Mass Spectrometry
MST	Monosodium Titanate
SCS	Statistical Consulting Section
SPE	Salt Program Engineering
SPF	Saltstone Production Facility
SRNL	Savannah River National Laboratory
SVOA	Semi-Volatile Organic Analysis
SRS	Savannah River Site
TBP	Tri-n-butyl Phosphate
TCLP	Toxic Characteristic Leaching Procedure
TPB	Tetraphenyl borate
VOA	Volatile Organic Analysis
VOC	Volatile Organic Compound
ZHE	Zero-Headspace Extraction

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1.0 INTRODUCTION AND BACKGROUND

Tank 48H contains approximately 250,000 gallons of salt waste. The waste contains approximately 19,000 kg of organic material, primarily as potassium tetraphenyl borate (KTPB). The tetraphenyl borate, along with approximately 1450 kg monosodium titanate (MST), was added to Tank 48H during the demonstration and startup of the In-Tank Precipitation Facility (ITP). After the shutdown of the ITP process, no process existed for the destruction of the organic material in Tank 48H. Tank 48H is slated to serve as the feed tank for the Savannah River Site (SRS) Actinide Removal Process. Prior to this use, the current Tank 48H waste must be treated or removed.

Two options being considered for disposition of the contents of Tank 48H include[1]:

1. Aggregation of the material with DWPF recycle stream and disposal in the Saltstone Processing Facility.

2. In-Situ Thermal Decomposition using heat in combination with pH reduction and catalyst addition.

Salt Program Engineering (SPE) requested research to help evaluate the Saltstone process (option #1 above) as a disposition path for the contents of Tank 48H. The main objective of the research was to evaluate the processing (gel time, set time and bleed water) and cured (leach) properties of Saltstone prepared with Tank 48H material aggregated with recycle from the DWPF or other tank contents to determine the suitability of Saltstone as a disposition path for the contents of Tank 48H. Table 1-1 is the designation of the processing terminology used is this study.

Table 1-1. Process Terminology used in Study.

Term	Designation
Gel Time	The time at which the Saltstone slurry does not flow due to gravity, i.e. readily pour from the casting cup. For this study, acceptable gel time is 30 min < gel time < 120 min.
Set Time*	The elapsed time from casting the Saltstone slurry until the mixture reaches rigidity as indicated by the Set Time Determination† (penetrometer penetration < 2.5 mm). Preferred set time is less than three days. However, set times up to six days are acceptable†.
Bleed Water*	The autogenous emergence of water from Saltstone slurry caused by the settlement of solid materials. For this study, acceptable bleed water is 1% after 72 h†.

The Savannah River National Laboratory (SRNL) was requested to 1) confirm that Saltstone prepared with actual Tank 48H material can be processed into Saltstone and pass the Toxic Characteristic Leaching Procedure (TCLP) to be considered non-hazardous and 2) confirm that Saltstone mixes prepared with a Tank 48H simulant are not considered ignitable‡.

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* ASTM C 125-03 "Standard Terminology Relating to Concrete and Concrete Aggregates".
† Manual 704-Z Procedure 4400, "Saltstone Grout Lab Analysis (U), Rev. 11 (2002).
‡ Curing Saltstone passes the EPA manual SW-846 Methods 1010a "Pensky-Martens Closed-Cup Method for Determining Ignitability," Revision 1 (2002) and 1030 "Ignitability of Solids" Revision 0 (1996).

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2.0 APPROACH

The Tank 48H waste was aggregated with inhibited water (IW) and a simulant of the recycle stream from the DWPF. The DWPF recycle simulant targeted the average of the Tank 23 and Tank 24 samples taken 100 inches from the tank bottom as reported by Swingle[2]. Table 2-1 is the composition of the DWPF Recycle simulant. The concentration of TPB in Tank 48H is 18,800 mg/L[3]. Table 2-2 is the components and properties of interest for the materials prior to aggregation. For the tests to determine ignitability, a simulant of the Tank 48H material was prepared to represent the material in Reference 3[4].

Table 2-1. Composition of DWPF Recycle Simulant.

Component	g/L
$NaNO_2$	21.734
$NaNO_3$	5.219
NaOH	17.399
Na_2CO_3	7.419
$Hg(NO_3)_2$	14.5 ppm
Total	51.771
Solids	5.2 wt %

Table 2-2. Concentration and Properties of Materials Used for Aggregation.

Material	TPB (mg/L)	Mercury (mg/L)	Cs activity[3] (dpm/mL) (Ci/gal)	Alpha[3] (dpm/mL)	wt % Solids		Density (g/mL)
					Undissolved	Total †	
Tank 48H[3]	18,800	10.3	1E+09 (1.72)	2.8E+05	2.18	18.42	1.144
DWPF Recycle simulant	0	14.5[2‡]	0	0	<1	5.2	1
Inhibited Water	0	0	0	0	0	0.1	1

†Total solids is used to determine the water:premix ratio used for Saltstone processing.
‡Value from Tank 24.

The aggregates targeted three TPB concentrations: 5500 mg/L, the aggregate determined from assumptions at the maximum reasonable limits, 1500 mg/L, the aggregate containing the minimum proportion of Tank 48H material that is programmatically acceptable, and 3500 mg/L, the average of the two endpoints. This resulted in six aggregates for testing (i.e., three TPB levels with two simulants). These aggregates span the range of potential Saltstone compositions. Table 2-3 is the calculated make up of each of the aggregates.

Table 2-3. Calculated Compositions and Properties of Aggregates.

Material	TPB (mg/L)	Solids (wt %)	Density (g/ml)	Mercury (mg/L)	Cs activity (dpm/mL) (Ci/gal)	Alpha (dpm/mL)
Tank 48H/DWPF Recycle (s)	5500	8.0	1.04	13.3	3E+08 (0.50)	8.2E+04
	3500	6.2	1.03	13.7	2E+08 (0.32)	5.2E+04
	1500	4.4	1.01	14.2	8E+07 (0.14)	2.2E+04
Tank 48H/IW	5500	6.0	1.04	3.0	3E+08 (0.50)	8.2E+04
	3500	4.1	1.03	1.9	2E+08 (0.32)	5.2E+04
	1500	1.8	1.01	0.8	8E+07 (0.14)	2.2E+04

Together, the dry materials used to make the Saltstone slurry are called premix. The ratio of the premix materials was fixed for this study. Table 2-4 is the premix composition used throughout this study.

Table 2-4. Premix Composition used in this Study.

Premix by Weight
45% Class F Fly Ash (FA)
45% GGBFS[a] (Slag)
10% Cement

[a]Ground granulated blast furnace slag.

2.1 Sample Preparation

To prepare the aggregate, a portion of the Tank 48H material was transferred from a well-mixed bottle of the material from Reference 3 into a bottle and weighed. Using the measured mass of the Tank 48H material transferred and the data in Table 2-2, the amount of IW or DWPF recycle simulant required to achieve the desired TPB concentration in the aggregate was calculated. The data in Table 2-3 then was used to calculate the amount of premix to achieve the desired water to premix ratio.

To prepare the Saltstone slurry, the aggregated liquids were added to a one liter blender carafe. At this point, set retarder or antifoam was added to the aggregate, if appropriate. The calculated amount of premix was then added to the carafe. The materials were then agitated for one minute. The contents were inspected to ensure that the premix had dispersed. Any remaining premix that had not been dispersed was reintroduced to the slurry with a spatula. The slurry was then agitated for an additional two minutes.

For each mix, five 120-mL cups were marked at 50 milliliters. Two cups were designated for gel time, one cup was designated for set time, and the remaining two cups were reserved for bleed water determination. The Saltstone slurry was then cast into the five cups and capped. For each of the six unique aggregates, Saltstone slurry was cast into two Teflon® vessels suitable for elevated temperature and pressure engraved with permanent identifications. The vessels were filled to minimize head space. One sample of each aggregate cast in Teflon® (six vessels total) was set aside to cure at ambient temperature and the remaining samples were cured for 28 days at 90 °C for TCLP extractions. After curing was complete, the heated samples were cooled to ambient and placed with the unheated samples until sampling. The TCLP samples were collected randomly being handled one sample at a time to minimize exposure to atmosphere.

2.2 Gel Time Determination

There is not a formally documented range of gel times to designate Saltstone slurry as "acceptable". However, the range 30 min < gel time < 120 min is regarded as a conservative time frame where the formation of a gel structure in the slurry would be unlikely to cause difficulties pumping slurry to Saltstone Vaults and would not substantially increase the probability of the slurry settling. This range of gel times was applicable to the SPF prior to FY04 facility modifications and may not adequately meet the current needs of the SPF. The two samples designated for gel time determination were maintained undisturbed until a flowability test was performed. After an appropriate waiting period, the contents of one of the cups was poured into an empty cup and the flowability of the slurry was observed. Following a second waiting period, the contents of the second cup were poured into an empty cup and the flowability of the slurry was observed. This process was repeated until the slurry did not readily flow and was deemed gelled. The gel time was then recorded as the elapsed time between the casting of the sample and the unsuccessful pour that signified the conclusion of the test. For several of the aggregates it was necessary to add set retarder and antifoam to achieve an acceptable gel time. The set retarder used in these

experiments was Daratard 17*. Two antifoams were used in these tests. The primary antifoam used in these tests was B52†. Previous testing indicates that B52 is effective in breaking down foam in aggregates containing TPB. An additional antifoam, tri-n-butyl phosphate (TBP), was also evaluated for effectiveness in mitigating foam formation.

2.3 Bleed Water Determination

The desired maximum bleed water is 1 vol %. The two cups designated for bleed water were inspected after 72 h. The mass of bleed water, if any, in the two cups is measured. By using 100 mL of Saltstone (two 50-mL samples), the volume percent bleed water is the mass of the water recovered from the two samples.

2.4 Set Time Determination

The desired maximum set time is three days. The time of set was determined using a Vicat needle modified for performance in shielded cells. The method of determination used instructions based on the Z-Area procedure‡. One day after casting into the cup in Section 2.1 designated for set time determination, the cup is placed under the Vicat needle and the zero distance mark is set with the needle at the surface of the sample. The needle is raised 50 mm and released. The penetration of the penetrometer into the sample is recorded from the gauge. This process is repeated daily until the penetration is < 2.5 mm.

2.5 Toxic Characteristic Leaching Procedure

A solid waste exhibits the characteristic of toxicity if the concentration of the contaminants in the TCLP extract is greater than the regulatory levels§. The analysis of pure, unaggregated Tank 48H contents performed in Reference 3 reported the presence of hazardous concentrations of benzene as defined by the United States Environmental Protection Agency (EPA). The nitrobenzene content was below the detection limits, but greater than the EPA regulatory limit for toxicity. The mercury content of The Tank 48H was below the limits defined by the EPA as characteristic for toxicity. However, since mercury was part of the aggregates prepared with DWPF recycle simulant, and there was a potential for the formation of benzene and nitrobenzene during curing, a modified TCLP extraction based on the EPA method was used to determine the presence of these species in the TCLP extract[5]. Table 2-5 is the regulatory limit for the contaminants of concern in this study.

Table 2-5. EPA Regulatory Limits for Contaminants in TCLP Extracts.

Contaminant	Regulatory Level (mg/L)
Benzene	0.5
Nitrobenzene	2.0
Mercury	0.2

The EPA extraction method was adhered to as closely as possible as dictated by the test conditions (i.e. radioactive materials handled with manipulators in shielded cells). For example, in Section 7.2.5 of the method, a mass of at least 100 grams is specified. This was neither practical nor possible for the samples prepared in Section 2.1, as there was not sufficient Tank 48H material available to prepare sufficient Saltstone for all of the testing and perform TCLP extractions. Table 2-6 summarizes the deviations from

* W.R. Grace Daratard 17
† Illinois Institute of Technology (IIT) B-52
‡ Manual 704-Z Procedure 4400, "Saltstone Grout Lab Analysis (U), Rev. 11 (2002).
§ 40CFR261.24 Toxicity characteristic

the EPA method and provides explanations for the variance. To compensate for the deviation in extraction fluid to sample ratio in 7.2.11 of the EPA method, the analyses results are normalized to an extraction fluid to sample ratio of 15.

Table 2-6. Variance from EPA Method for TCLP Extraction.

Section	Action	Variance	Explanation
	Non-Volatiles		
7.2.5	Sample size Recommended > 100 g.	Used ~1 g samples.	Limited material available. Reference 6 precedence.
7.2.11	• Extraction fluid volume 20x mass of sample. • Rotate 30±2 rpm for 18±2 h @ 23±2 °C.	• Used fixed volume ~15x sample mass. • T_{cell} not controlled, exceeded 25 °C.	• Used pre-measured extract for efficiency in shielded cell. Reduced ratio introduced conservatism. • Test performed in summer. Air temperature of shielded cells not regulated.
7.2.12	Filter extract.	Settled solids and decanted extract.	During shakeout tests filters plugged, exposed extract to environment. Decant provides more conservative result.
7.2.14	Store extracts at 4 °C.	Extracts stored at ambient temperature in cells, refrigerated in ADS sample receiving.	To maintain 4 °C in shielded cells is costly. Samplers refrigerated in ADS sample receiving.
	Volatiles		
4.3.1	Use approved Zero-Headspace Extractor (ZHE) vessel.	Used glass vials with Teflon® lids filled to top.	Approved ZHE vessels for 25 g samples.
7.3.3	Sample size Recommended ~ 25 g.	Used ~1 g.	Limited material available. Reference 6 precedence.
7.3.15	Store extracts with minimal headspace at 4 °C.	Extracts stored with minimal headspace at ambient temperature. Samples refrigerated in ADS sample receiving.	To maintain 4 °C in shielded cells is costly. Samplers refrigerated in ADS sample receiving. Although samples are sealed with minimal head space, variance is non-conservative as benzene is a volatile compound.

2.5.1 Volatile Organic Compound (VOC) Extraction

After the samples prepared in Section 2.1 had cured for 28 days, samples were collected for extraction. Duplicate samples of approximately one gram each were retrieved from each vessel. The use of one gram of sample for extraction was explored previously[6]. Samples collected ranged from 0.773 to 1.015 grams. The samples were placed in 15 mL glass vials with Teflon® gaskets. To minimize exposure of the Saltstone to the environment, minimal effort was made to precisely collect one gram of material. A minimum of 0.75 grams was necessary to ensure that the extraction fluid to sample ratio was no more than 20. Extraction fluid 1* was used to fill the vial to form a meniscus, and capped. The vials were

* Extraction Fluid 1 is a pH 4.93 buffer made from acetic acid and sodium hydroxide.

placed in a rotator preset to 30 rpm and rotated for 18 h. After the vials were removed from the rotator, the samples were set aside to settle the solids. The extract was decanted into a sample vial and overfilled to minimize head space and limit volatility of volatile compounds. The vials then were removed from the shielded cells and submitted to the SRNL-Analytical Development Section (ADS) for volatile organic analysis (VOA) of benzene. The samples were analyzed by purge and trap Gas Chromatography / Mass Spectrometry (GC/MS). The method detection limit for this study was 0.005 mg/L for VOA. To determine the recovery of benzene during the analysis a matrix spiking experiment was performed. A 25 ppb spike of benzene was added to one of the samples and analyzed. It was determined that 83% of the benzene was recovered. This recovery rate is used to correct results for benzene losses during analysis.

2.5.2 Semi-Volatile Organic Compound (SVOC) and Metals Extraction

After the samples prepared in Section 2.1 had cured for 28 days, samples were collected for extraction. Approximately five additional grams of sample was collected to determine the appropriate extraction fluid for the TCLP*. Results determine that Extraction Fluid 2† be used for the SVOC and metals TCLP. Duplicate samples of approximately one gram each were retrieved from each vessel. The use of one gram of sample for extraction was explored previously[6]. Samples collected ranged from 0.967 to 1.025 grams. The samples were placed in 25 mL glass vials with Teflon® gaskets. A minimum of 0.75 grams was necessary to ensure that the extraction fluid to sample ratio was no more than 20. The vials were placed in a rotator preset to 30 rpm and rotated for 18 h. After the vials were removed from the rotator, the samples were set aside to settle the solids. The extract was decanted into two sample vials. The vials then were removed from the shielded cells and submitted to the SRNL-ADS for semi-volatile organic analysis (SVOA) of nitrobenzene and cold vapor atomic absorption (CV-AA) of mercury. The SVOC samples were extracted with methylene chloride, and the extract was analyzed by GC/MS. Gas Chromatography / Mass Spectrometry analysis was employed to identify organic compounds in the samples. The method detection limit for this study was 0.5 mg/L for nitrobenzene. The mercury is reduced to the elemental state and aerated from solution in a closed system. The mercury vapor passes through a cell positioned in the light path of an atomic absorption spectrophotometer. Absorbance (peak height) is measured as a function of mercury concentration. The method detection limit for this study was 0.11 mg/L for mercury.

2.6 Ignitability Determination of Fresh Saltstone Slurry

The presence of TPB in the Tank 48H material and the potential to form benzene in the Saltstone slurry is the basis for testing the Saltstone slurry for the characteristic of ignitability. A solid waste exhibits the characteristic of ignitability if the waste is a liquid and has a flash point of less than 60 °C (140 °F) as determined using a Pensky-Martens closed cup tester‡. Using a Tank 48H simulant[7], an aggregate was made with DWPF recycle simulant to target a TPB concentration of 5500 mg/L. A water to premix ratio of 0.63 was used to prepare the Saltstone slurry. Four replicate samples were submitted to SRNL-ADS for flash point testing. Samples were tested using a flash point tester similar to the Pensky-Martens tester. Dodecane (flash point 71°C/160°F) was used as the standard material.

2.7 Ignitability Determination of Cured Saltstone

The potential for the TPB present in the Tank 48H material to create benzene during curing of the Saltstone dictates testing the cured Saltstone for the characteristic of ignitability. A solid waste exhibits the characteristic of ignitability if the waste is not a liquid and is capable of causing fire and, when ignited, burns so vigorously and persistently that is becomes a hazard‡. Using a Tank 48H simulant[7], an

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* ADS Manual L16.1, Procedure 2512, "Modified Toxicity Characteristic Leaching Process"
† Extraction Fluid 2 is a pH 2.88 solution made from acetic acid.
‡ 40CFR261.21 Characteristic of Ignitability

aggregate was made with DWPF recycle simulant to target a TPB concentration of 5500 mg/L. The Saltstone sample was prepared using a water to premix ratio of 0.63. Two replicate samples were cast and tested for ignitability using the EPA method 1030 "Ignitability of Solids." A propane torch was used to produce an open flame of ~1050 °C. The flame was directed at one end of the sample for two minutes to determine if the sample was ignitable.

3.0 RESULTS

Saltstone prepared with Tank 48H waste aggregated with IW and a simulant of the recycle stream from the DWPF was produced in the SRNL shielded cells. Saltstone was also prepared with a Tank 48H simulant[7] and DWPF recycle simulant. The processing (gel time, set time and bleed water) and cured (leach) properties of the Saltstone were determined for the samples prepared with Tank 48H material. The determination of whether the Saltstone slurry or cured Saltstone were characteristic for ignitability was determined with samples prepared with the Tank 48H simulant from Reference 7 and DWPF recycle simulant.

3.1 Sample Preparation

The Saltstone samples were prepared as described in Section 2.1. After the blender had mixed the Tank 48H aggregate with the premix materials it was noted during casting that air was entrained in slurry. The quantity of air entrained increased with increasing TPB concentration. Entrained air can enhance the gelation of the slurry by producing a structure in the slurry and necessitate the use of set retarders or antifoams. Additions of antifoam reduced the quantity of entrained air and the bubbles appeared to have coalesced into larger bubbles. The coalescing of the bubbles during antifoam addition may have helped reduce the quantity of air entrained in the sample.

3.2 1500 mg/L TPB with DWPF Recycle Simulant

3.2.1 Gel Time

The Saltstone slurry was prepared as described in Section 2.1 with a water to premix ratio of 0.6. When the slurry was inspected after the first minute of mixing, it appeared thicker than desired. Additional aggregate was added to reduce the consistency of the slurry and raise the water to premix ratio to 0.68. There did not appear to be any air entrainment in the form of frothing of the slurry. The first gel time pour was after 10 minutes and it was determined that the slurry had gelled.

3.2.2 Bleed Water

After 24 hours the two bleed water cups were inspected and no bleed water was detected.

3.2.3 Set Time

Set Time was determined to be one day.

3.3 1500 mg/L TPB with Inhibited Water

3.3.1 Gel Time

Based on the results of the previous test, the Saltstone slurry was prepared with a water to premix ratio of 0.66. In addition, a set retarder (Daratard 17) was added to the aggregate prior to mixing. The amount of set retarder added was equal to 0.12 wt % of the aggregate. The slurry appeared satisfactory as it did not exhibit frothing and was thin enough to pour. The first gel time pour was after 5 minutes and it was pourable. Gel time was declared on the fourth gel time pour after 35 minutes.

3.3.2 Bleed Water

After 48 hours the two bleed water cups were inspected the bleed water was determined to be 7.2 vol %.

3.3.3 Set Time

Set Time was not measured for this aggregate.

3.4 3500 mg/L TPB with Inhibited Water

Based on the results of the previous test, the water to premix ratio was reduced and the set retarder was increased. The Saltstone slurry was prepared with a water to premix ratio of 0.60. A 0.19 wt % addition of set retarder was made to the aggregate prior to mixing. The slurry exhibited noticeable frothing but was thin enough to pour. During casting, it was noted that significant quantities of fine bubbles were entrained in the slurry. The first gel time pour was after 11 minutes. The slurry was thick but pourable. Gel time was declared on the second gel time pour after 16 minutes.

3.4.1 Bleed Water

After 24 hours the two bleed water cups were inspected and no bleed water was detected.

3.4.2 Set Time

Set Time was not measured for this aggregate.

3.5 3500 mg/L TPB with Recycle Simulant

Based on the results of the previous test, the water to premix ratio was increased and the set retarder was increased. The Saltstone slurry was prepared with a water to premix ratio of 0.63. A 0.27 wt % addition of set retarder was made to the aggregate prior to mixing. Again, the slurry exhibited noticeable frothing but was thin enough to pour. The first gel time pour was after 12 minutes. The slurry was thick but pourable. Gel time was declared on the second gel time pour after 21 minutes.

3.5.1 Bleed Water

After 24 hours the two bleed water cups were inspected and no bleed water was detected.

3.5.2 Set Time

Set Time was not measured for this aggregate.

3.6 3500 mg/L TPB with Inhibited Water (Second Iteration)

Based on the results of the two previous tests, the need for antifoam was clear. Antifoam prepared for WSRC, IIT B52 was shown to act as both a defoamer and antifoam in material similar to the contents of Tank 48H[8]. The IIT B52 was too viscous to add precisely using manipulators. A predetermined blend of Daratard 17 and B52 of 2:1 was used. The water to premix ratio was increased, the set retarder was decreased and antifoam was introduced. The Saltstone slurry was prepared with a water to premix ratio of 0.66. The admixture addition consisted of 0.20 wt % of set retarder and 0.10 wt % of B52. The slurry exhibited minor frothing. During casting, it was noted that the fine bubbles present in previous tests had coalesced into larger, less numerous bubbles. The bubbles were still entrained in the slurry. The first gel time pour was after 5 minutes. The slurry was fluid and poured easily. The second gel time pour was after 15 minutes. The slurry was thick but pourable. Gel time was declared on the fourth gel time pour after 30 minutes.

3.6.1 Bleed Water

After 24 hours the two bleed water cups were inspected and no bleed water was detected.

3.6.2 Set Time

Set Time was determined to be two days.

3.7 5500 mg/L TPB with Inhibited Water

Based on the results of the previous test, the water to premix ratio and the admixtures (set retarder + antifoam) were left unchanged. The Saltstone slurry was prepared with a water to premix ratio of 0.65. The admixture addition consisted of 0.21 wt % of set retarder and 0.10 wt % of B52. The slurry exhibited greater frothing than the 3500 mg/L TPB aggregates, but was thin enough to pour. Again, it was noted during casting that significant quantities of large bubbles were entrained in the slurry. The first gel time pour was after 7 minutes. The slurry was thick but pourable. Gel time was declared on the second gel time pour after 15 minutes.

3.7.1 Bleed Water

After 24 hours the two bleed water cups were inspected and no bleed water was detected.

3.7.2 Set Time

Set Time was not measured for this aggregate.

3.8 5500 mg/L TPB with Recycle Simulant

Based on the results of the previous test, the water to premix ratio was maintained and the admixtures were increased. The Saltstone slurry was prepared with a water to premix ratio of 0.64. The admixture addition consisted of 0.31 wt % of set retarder and 0.15 wt % of B52. The quantity of the foam noted during casting was reduced from the previous test. The first gel time pour was after 10 minutes. The slurry poured easily. The second gel time pour was after 20 minutes. During the second pour, the potential for bleed water was detected. The test was halted after the fourth gel time pour after 40 minutes when it was determined that bleed water would be present.

3.8.1 Bleed Water

After 48 hours the two bleed water cups were inspected and 9 vol % bleed water was measured.

3.8.2 Set Time

Set Time was not measured for this aggregate.

3.9 5500 mg/L TPB with Inhibited Water (Second Iteration)

Based on the results of the two previous tests, the water to premix ratio was maintained and the admixtures were decreased. The Saltstone slurry was prepared with a water to premix ratio of 0.65. The admixture addition consisted of 0.26 wt % of set retarder and 0.13 wt % of B52. The slurry exhibited minor frothing. It was noted that the amount of bubbles was similar to the previous test. Bubbles were still entrained in the slurry during casting. The first gel time pour was after 10 minutes. The slurry was fluid and poured easily. The second gel time pour was after 20 minutes. The slurry was thick but pourable. Gel time was declared on the third gel time pour after 30 minutes.

3.9.1 Bleed Water

After 24 hours the two bleed water cups were inspected and no bleed water was detected.

3.9.2 Set Time

Set Time was not measured for this aggregate.

Table 3-1 is a summary of the processing properties of the aggregates tested. The "with adjustments" term was necessary as there was not sufficient Tank 48 material available to perform the necessary test iterations to definitively determine a formulation for each of the six aggregates. Therefore, by bounding the processing requirements, it was determined that there exists an acceptable formulation that could be achieved "with adjustments".

Table 3-1. Summary of Processing Properties of Saltstone Slurries.

Aggregate	Water/ Premix	Daratard 17 Admixture (Wt %)	IIT B52 Antifoam (Wt %)	Gel Time (min)	Set Time (d)	Bleed Water (Vol %)	Processable
1500 Recycle	0.68	0.00	None	10	1	0	with adjustments
1500 IW	0.66	0.12	None	35	--	7.2	with adjustments
3500 IW	0.60	0.19	None	16	--	0	with adjustments
3500 Recycle	0.63	0.27	None	21	--	0	with adjustments
3500 IW-2	0.66	0.2	0.1	30	2	0	YES
5500 IW	0.65	0.21	0.1	15	--	0	with adjustments
5500 Recycle	0.64	0.31	0.15	> 40	--	9	with adjustments
5500 IW-2	0.65	0.26	0.125	30	--	0	Probable*

*Set time was not measured but based on gel time and bleed water results, set is expected to be acceptable.

3.10 Additional Antifoam Tests with 3500 mg/L TPB with Inhibited Water

After the initial test results were analyzed, two additional tests were performed. Aggregate made with 3500 mg/L TBP and IW was selected to represent the most likely TBP concentration. Based on previous tests the water to premix ratio was targeted as 0.65. The admixture addition consisted of 0.2 wt % set retarder and 0.15 wt % antifoam. The only variable between the two tests was the antifoam. In the first test, B52 was used and in the second test, TBP was the antifoam. In both tests, the slurries exhibited minor frothing. During casting, the larger, less numerous bubbles noted in the earlier 3500 mg/L TPB were present. The bubbles were still entrained in the slurry. The slurries were fluid and poured easily. Gel time was declared after 25 minutes.

3.10.1 Bleed Water

After 24 hours the bleed water cups were inspected and no bleed water was detected in either test.

3.10.2 Set Time

The set time was tested after one day. Neither of the mixes were set. The set time was tested again after 3 days. Again, neither of the mixes were set, although the mix made with B52 had firmed considerably. The final test was performed at six days. The mix prepared with B52 was declared set. The mix prepared with TBP as the antifoam had not yet set.

3.11 Toxic Characteristic Leaching Procedure

TCLP extractions were performed in duplicate on samples cured at ambient temperature and at 90 °C for each unique aggregate.

3.11.1 Volatile Organic Compound (VOC) Extraction

TCLP extractions were performed and extracts were analyzed as described in Sections 2.5 and 2.5.1. One of the replicated of the 1500 mg/L TPB aggregate made with IW and cured at 90 °C was compromised during handling and was not removed from the shielded cells for analysis. A statistical analysis of the benzene results performed by SRNL-Statistical Consulting Section (SRNL-SCS) determined that the TPB concentration was the only statistically significant variable affecting the benzene concentration in the TCLP extracts. The curing temperature (90 °C vs. ambient) and aggregation material (DWPF recycle vs. IW) were statistically equivalent. Table 3-2 is the results of the benzene analysis. The measured benzene is corrected for the 83% recovery described in Section 2.5.1. The corrected value is then normalized for the variations in the sample mass to a mass of one gram. Figure 3-1 is the plot of the benzene concentration in the TCLP extracts as a function of the TPB concentration in the aggregate. The benzene limit for RCRA hazardous designation from Table 2-5 is 0.5 mg/L is also displayed for reference. All of the samples passed TCLP for benzene.

Table 3-2. Benzene Concentrations in TCLP Extracts.

TPB (mg/L)	Aggregate*	Cure Temperature (°C)	replicate	Sample Mass (g)	Measured Benzene (mg/L)	Corrected Benzene (mg/L)	Normalized Benzene (mg/L)
1500	IW	27	1	0.954	0.06	0.07	0.08
1500	IW	27	2	0.949	0.06	0.07	0.07
1500	IW	95	2	0.988	0.06	0.07	0.07
1500	RC	27	1	1.000	0.02	0.02	0.02
1500	RC	27	2	1.006	0.10	0.12	0.11
1500	RC	95	1	1.051	0.06	0.07	0.07
1500	RC	95	2	1.011	0.06	0.07	0.07
3500	IW	27	1	0.821	0.12	0.14	0.18
3500	IW	27	2	0.991	0.15	0.18	0.18
3500	IW	95	1	0.911	0.09	0.11	0.12
3500	IW	95	2	1.007	0.10	0.12	0.12
3500	RC	27	1	0.895	0.10	0.12	0.13
3500	RC	27	2	0.931	0.12	0.14	0.16
3500	RC	95	1	0.934	0.14	0.17	0.18
3500	RC	95	2	0.910	0.12	0.14	0.16
5500	IW	27	1	0.804	0.14	0.17	0.21
5500	IW	27	2	1.020	0.11	0.13	0.13
5500	IW	95	1	1.000	0.08	0.10	0.10
5500	IW	95	2	0.934	0.17	0.20	0.22
5500	RC	27	1	0.980	0.10	0.12	0.12
5500	RC	27	2	0.773	0.12	0.14	0.19
5500	RC	95	1	0.856	0.13	0.16	0.18
5500	RC	95	2	0.791	0.12	0.14	0.18

*RC– DWPF Recycle Simulant; IW – Inhibited Water

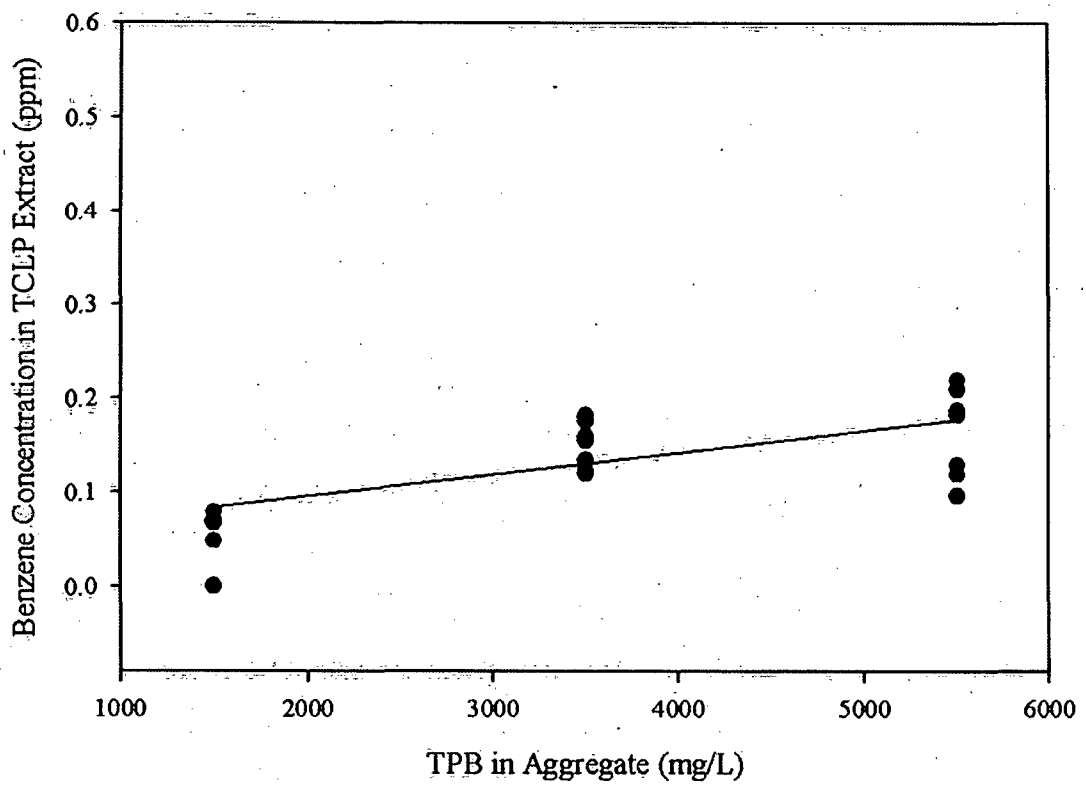

Figure 3-1. Benzene measured in the TCLP extracts for the TPB aggregates.

3.11.2 Semi-Volatile Organic Compound (SVOC) Analysis

TCLP extractions were performed and extracts were analyzed as described in Sections 2.5 and 2.5.2. The analysis for nitrobenzene for all of the samples was below the detection limits of the analytical method, 0.5 mg/L. The RCRA limit for nitrobenzene in TCLP extracts from Table 2-5 is 2.0 mg/L. Therefore all of the samples passed the TCLP for nitrobenzene.

3.11.3 Metals Analysis

TCLP extractions were performed and extracts were analyzed as described in Sections 2.5 and 2.5.2. The analysis for mercury (CV-AA) was performed only on samples that had the potential to be hazardous for mercury (i.e., Aggregates that were prepared with DWPF recycle simulant.). Results for all of the samples analyzed were below the detection limits of the analytical method, 0.11 mg/L. The RCRA limit for mercury in TCLP extracts from Table 2-5 is 0.2 mg/L. Therefore all of the samples passed the TCLP for mercury.

3.12 Ignitability Determination of Fresh Saltstone Slurry

Four replicate samples submitted to SRNL-ADS for flash point testing were analyzed using a closed cup flash point tester. The Saltstone slurry made with the 5500 mg/L aggregate of Tank 48H simulant and DWPF recycle simulant was prepared and tested as described in Section 2.6 and sampled to make the four replicates. A dodecane standard (flash point 71 °C/160 °F) was analyzed prior to the first replicate and after the final replicate. Each replicate was tested a single time. The analysis of the Saltstone slurry began

approximately 20 minutes after the slurry was prepared and analysis continued for an additional 75 minutes. None of the four replicates exhibited a flash point below 100 °C, where the testing was terminated. Table 3-3 is the results of the flash point tests for the four replicates and two standards.

Table 3-3. Flash Point Results using a Closed Cup Tester.

Sample	Elapsed Time from Casting (min)	Flash Point (°C/°F)
Dodecane	10	79/174
5500 mg/L with DWPF Recycle-1	21	No Flash
5500 mg/L with DWPF Recycle-2	39	No Flash
5500 mg/L with DWPF Recycle-3	55	No Flash
5500 mg/L with DWPF Recycle-4	71	No Flash
Dodecane	86	81/178

3.13 Ignitability Determination of Cured Saltstone

The Saltstone slurry made with the 5500 mg/L aggregate of Tank 48H simulant and DWPF recycle simulant was prepared and tested as described in Section 2.7. The two replicate samples were exposed to an open flame for two minutes and it was determined that the samples were not ignitable, Figure 3-2.

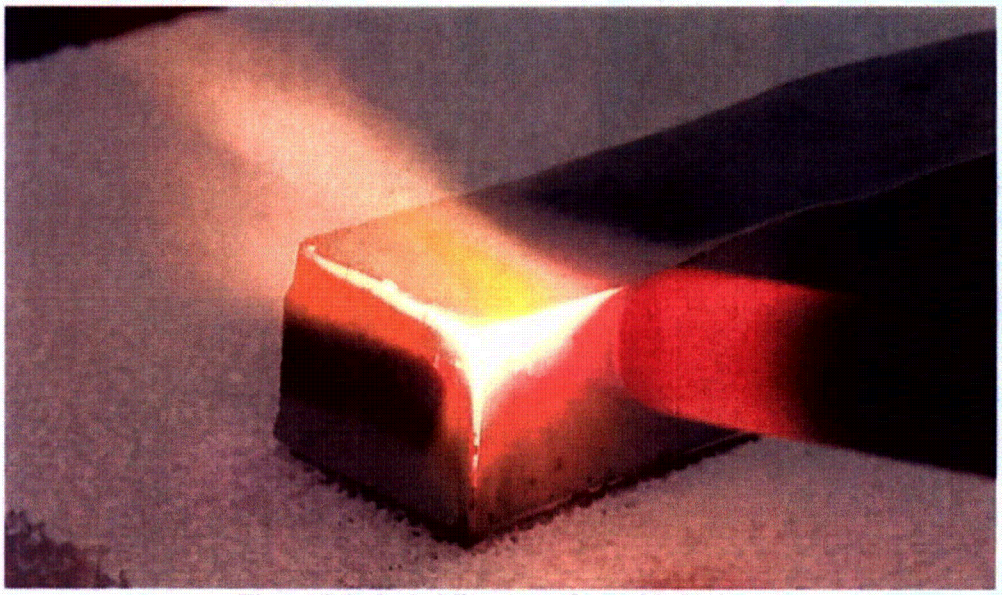

Figure 3-2. Ignitability test of cured Saltstone.

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4.0 CONCLUSIONS AND RECOMMENDATIONS

- Aggregates were prepared with Tank 48H material and either DWPF recycle simulant or inhibited water with concentrations of 1500, 3500, and 5500 mg/L TPB.
- Air entrainment caused by the mixing of the aggregate in the slurry preparation method used produced a stable structure the led to premature gelation of the slurries that required admixtures for remediation.
- Processable Saltstone slurry formulations were demonstrated with Tank 48H material and both DWPF recycle simulant and inhibited water with concentrations of 3500, and 5500 mg/L TPB. It is expected that acceptable formulation can be prepared with aggregates of 1500 mg/L TPB. Table 4-1 is the recommended initial processing parameters for the six aggregates tested.

Table 4-1. Recommended Initial Processing Parameters for Tank 48H Aggregates.

TPB (mg/L)	Water/Premix	Set Retarder (Wt %)	Antifoam (Wt %)
1500	0.60-0.63	0.1-0.2	0.1
3500	0.65	0.2	0.15
5500	0.65	0.30	0.15-0.2

- Analysis of the TCLP extracts of the Saltstone prepared from the six aggregates indicates that the resulting Saltstone is not hazardous for benzene, nitrobenzene, or mercury.
- Testing of the fresh Saltstone slurry and cured Saltstone prepared with simulants indicate that the neither the fresh nor cured Saltstone is hazardous for ignitability.
- After transferring Tank 48H material to Tank 50 and prior to processing through the SPF, Tank 50 should be sampled to verify processability with the recommended processing parameters in Table 4-1.

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G-ADS-H-00007
Revision 0

CLOSURE BUSINESS UNIT
LIQUID WASTE DISPOSITION PROJECTS

SALT PROCESSING PROJECTS

Tank 48 Disposition Project
WSRC In-House Treatment Option Evaluation (U)

APPROVED for Release for
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Savannah River Site
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APPROVAL PAGE

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Summary of Revision

Revision Number	Date	Description of Change
0	2/4/04	Initial Issue

EXECUTIVE SUMMARY

Tank 48 return to service is critical to the processing of high level waste (HLW) at SRS. Tank 48 currently holds legacy material containing organic tetraphenylborate (TPB) compounds from the operation of the In-Tank Precipitation (ITP) process. This material is not compatible with the waste treatment facilities at SRS and must be removed or undergo treatment to destroy the organic compounds before the tank can be returned to Tank Farm service. The scope of Tank 48 Disposition Project is to initiate and complete a project that will include any required design, modifications, testing, material processing, heel removal and return to service procedures.

The Tank 48 Disposition Project strategy is to develop WSRC in-house options and, in a parallel effort, to solicit and evaluate vendor bids on the design and installation of a waste treatment unit (WTU) for Tank 48.

This report documents the results of the WSRC in-house option evaluation performed by the Tank 48 Disposition Project Team.

The Tank 48 Disposition Project Evaluation Team built upon the previous work performed on Tank 48 disposition and documented in the HLW Tank 48 Disposition Alternatives Identification Phase I and II Summary Report (Reference 5.1), and research data developed by Savannah River Technology Center (SRTC) (References 5.2 through 5.7). The options were developed to sufficient maturity to allow major risks to be identified; rough order of magnitude (ROM) cost estimates to be developed and preliminary schedule durations to be estimated.

The Team developed weighted evaluation criteria including: Cost, Schedule, Safety Basis, Research and Development, Operations, Regulatory, and Downstream Process impacts. The Team scored the options for each of the criteria. The results from this evaluation showed that in order of preference the WSRC in-house options ranked as follows:

1. Blending
2. In-Tank Thermal Hydrolysis
3. In-Tank Catalytic Hydrolysis
4. In-Tank Fenton's Hydrolysis
5. DWPF Salt Cell Fenton's Hydrolysis

Blending was ranked as the most favorable WSRC in-house option followed closely by the second-placed option of In-Tank Thermal Hydrolysis. A summary of the two options are listed below.

Blending - This option consists of blending material from the DWPF recycle tanks with the material in Tank 48. The blending will occur in Tank 48 and Tank 50 (initially Tank 50 then Tank 48). The blended material will be transferred to the Saltstone Processing Facility (SPF). The cost of this option is estimated at $15 million with 23 months schedule duration. The major risks associated with this option are:

- Saltstone (SPF) Class C Permit not received from the state of South Carolina in the timeframe assumed in this evaluation.
- Insoluble TPB concentration not acceptable in SPF for grout formulation.
- Benzene generation rates require equipment modifications to Tank 50, SPF and interconnecting transfer systems (including Low Point Drain Tank, LPDT).

In-Tank Thermal Hydrolysis - Thermal Hydrolysis in Tank 48 decomposes TPB through a hydrolysis reaction to produce benzene. Reaction conditions for this tank treatment option are a pH of 11 and a temperature of 45°C. The cost of this option is estimated at $11 million with 27 months schedule duration. The major risks associated with this option are:

- Organic destruction efficiency (based on extrapolation of data from a limited 2 week test) does not meet end state acceptance criteria (<5% of lower flammability limit [LFL]) within the treatment time assumed in this evaluation.

As noted above, the selected strategies are not without risk, and will require additional evaluations and testing before a completely defined disposition plan can be finalized. Additionally, to bound this study, the estimate of final disposal costs (Saltstone, Canisters, etc.) was considered outside the scope of this evaluation. In addition to the schedule durations noted, the Team also estimated that after achieving the desired end state approximately 3 months should be allowed to enable Tank 48's return to service into the Tank Farm System. This would be applicable to all the options being evaluated; therefore, it was not included in the schedule comparison data for any of the options.

In conclusion, the Team is confident that the Blending option can successfully be completed. As a risk handling strategy to the permitting requirement associated with Blending, the Team also recommends that the In-Tank Thermal Hydrolysis be developed as a backup option.

1.0 Background

The Tank 48 Disposition Project was initiated with the mission of returning Tank 48 to Tank Farm service. Tank 48 return to service is critical to the processing of HLW at SRS as it will provide approximately one million gallons of Type IIIA tank storage space. Tank 48 currently holds legacy material containing organic TPB compounds from the ITP process. This material is not compatible with the waste treatment facilities at SRS and must be removed or undergo treatment to destroy the organic compounds before the tank can be returned to Tank Farm service.

The Tank 48 Disposition Project strategy is to develop WSRC in-house options and, in a parallel effort, to solicit and evaluate vendor bids on the design and installation of a WTU for Tank 48. This strategy is identified in the Tank 48 Disposition Project Risk Analysis Report (Reference 5.8).

This option analysis documents the investigation, evaluation and ranking of the Tank 48 WSRC in-house options.

2.0 Investigation

The Tank 48 Disposition Project Team built upon the previous work performed on Tank 48 disposition and documented in the HLW Tank 48 Disposition Alternatives Identification Phase I and II Summary Report (Reference 5.1). The study selection process concluded the first and second choice were the original Salt Cell Process and Steam Reforming. The Phase II study also concluded that the amount of research needed to complete development of the technical bases for the in-tank process options appears relatively modest versus the costs required to pursue the two leading candidates and the most promising options should be pursued.

From the Phase I & II assessment, potential treatment options for destroying/removing the TPB salts in Tank 48 were downselected for further study as determined in the Technical Program Plan for Tank 48H Processing (Reference 5.9). Some of the downselected option processes could potentially be performed in Tank 48 itself while others would require dedicated facilities. The processes selected are those with the highest potential to successfully disposition Tank 48 contents, either based on process knowledge or limited experimentation. The research effort to recover Tank 48 can be categorized by the process used and by where the process takes place: in-tank and out–of-tank. The processes selected in the Technology Plan were:

- Accelerated Degradation Using Elevated Temperature and Decreased pH
- Catalytic Hydrolysis Using Metals and Decreased pH
- Catalytic Oxidation Using Fenton's Reagent
- Thermal Degradation Using Steam Reforming

The out-of-tank options are considered to be enveloped by the Scope of Work (SOW) (Reference 5.10) used to solicit vendor proposal for the Tank 48 WTU. The SOW allowed the vendors to specify the process and "Best Value" criteria was developed for the selection of the contractor.

The WSRC (i.e., "in-house") options developed in parallel with the vendor solicitation include:

- In-Tank Thermal Hydrolysis
- In-Tank Catalytic Hydrolysis
- In-Tank Fenton's Hydrolysis
- DWPF Salt Cell Fenton's Hydrolysis
- Blending

The combination of the vendor proposed processes and the in-house processes represents the conclusion of the Phase I & II evaluation and the Technical Program Plan (Reference 5.9). In that report, the Low Curie Salt cesium limit of 0.05 Ci/gal was used to feed Saltstone. A project has been initiated to install modifications that would allow an increase in this limit pending approval by the South Carolina regulatory authority. Given this change, the blending option is now included as an option. The preferred option from the Phase I & II report, using the original DWPF Salt Cell Process, was considered to have a cost and schedule that was excessive for a one time process. A substitution was identified (Fenton's) that could possibly present an improved cost and schedule and have potential for other HLW programs, therefore was included in this evaluation.

Investigations focused on In-Tank options, DWPF Salt Processing Cell (SPC) and Blending, as other out-of-tank options were assumed to be enveloped by the solicited scope of work.

Initial conditions for the contents of Tank 48 are defined in Appendix 6.1. (Extracted from Reference 5.10, "Statement of Work, SRS Tank 48H Material Treatment"). The critical initial condition to the investigation was the quantity of TPB, estimated at 23,000 kg in Tank 48.

The final end state of Tank 48 is based on reducing the amount of TPB in Tank 48 to meet the 5% waste tank organic flammability contribution limit (reference 5.11). A conservative calculation (Reference 5.12) was developed that shows that 0.3 kg of TPB meets this requirement. The Team concluded that after achieving the desired end point, additional time (approximately three months) would be required to enable Tank 48's return to service into the Tank Farm System. This additional time primarily accounts for sample analysis, validation of end state achievement by all interested stakeholders (WSRC, DOE, DNFSB, etc.), and equipment and procedure implementation for return to service conditions. This would be applicable to all the options being considered; therefore, it was not included in the schedule comparison data for any of the options.

2.1 Tank 48 WSRC In-House Processing Options

Technical reports, preliminary flow sheets and risk assessments were utilized during the investigation for use by the Team during the evaluation process (References 5.2 through 5.7, and 5.13 through 5.19). To summarize critical information, a data sheet was developed for each option. The salient technical data, schedule, cost and major risks associated with each option was included in the data sheets. These data sheets are contained in Appendix 6.2. The following sections provide a general description of each in-house option as well as a summary of the major risks associated with each option.

2.1.1 In-Tank Thermal Hydrolysis

2.1.1.1 Description

In this option the TPB in Tank 48 is decomposed using elevated temperature and reduced pH. To accomplish thermal decomposition, the alkalinity will be lowered to a pH of 11. The temperature of the tank will be increased to 45°C primarily by using heat generated by slurry pump operation and controlling cooling water flow as required. Initial studies have shown that with a pH of 11 and elevated temperature, there is sufficient decomposition reaction while still maintaining corrosion protection for the tank internal components. The primary products of the reaction are benzene, phenol and borate salts. The benzene is released to the tank vapor space and removed from the tank by the existing Tank 48 nitrogen purge ventilation system. The phenol and borate salts remain with the tank liquid along with the monosodium titanate (MST) solids left over from ITP operations and pose no significant flammability hazard. Once the analysis shows the material is below the established organic limit the resulting liquid can be sent to any tank farm waste tank or concentrated in the HLW evaporator system.

2.1.1.2 Risks

As decomposition efficiency has been extrapolated from limited duration test results (Reference 5.5), this process carries the risk that the decomposition efficiency is not adequate to meet the end state requirement within the 12 month treatment time assumed in this evaluation. A more detail discussion of the risks associated with this option is provided in reference 5.13.

2.1.2 In-Tank Catalytic Hydrolysis

2.1.2.1 Description

In this option the TPB in Tank 48 is decomposed by a hydrolysis reaction using elevated temperature, reduced pH and an added catalyst. To accomplish catalytic decomposition, the alkalinity will be lowered to a pH of 11. The temperature of the tank will be increased to 45°C (primarily by slurry pump operation as discussed in Section 2.1.1.1) and a catalyst (copper nitrate or palladium nitrate) added to promote the decomposition reaction. Initial

studies have shown that with a pH of 11, elevated temperature, and a catalyst addition, there is sufficient decomposition reaction while still maintaining corrosion protection for the tank internal components. The primary products of the reaction are benzene, phenol and borate salts. The benzene is released to the tank vapor space and removed from the tank by the existing Tank 48 nitrogen purge ventilation system. The phenol and borate salts remain within the tank liquid along with the MST solids left over from ITP operations and pose no significant flammability hazard. This resulting liquid can be sent to any tank farm waste tank or concentrated in the HLW evaporator system once the analysis shows the material is below the established organic limit.

2.1.2.2 Risks

As decomposition efficiency has been extrapolated from limited duration test results (Reference 5.5), this process carries the risk that the decomposition efficiency is not adequate to meet the end state requirement within the 12 month treatment time assumed in this evaluation. A more detail discussion of the risks associated with this option is provided in reference 5.14.

2.1.3 In-Tank Fenton's Hydrolysis

2.1.3.1 Description

This option utilizes a catalyst (usually iron [ferric nitrate], copper [cupric nitrate] or a combination of both) in conjunction with hydrogen peroxide (H_2O_2) to destroy organic materials through oxidation. This combination of hydrogen peroxide and catalyst is known as Fenton's Reagent. To accomplish Fenton's decomposition, the alkalinity will be lowered to pH of 11. The temperature of the tank will be increased to 45°C (primarily by slurry pump operation as discussed in Section 2.1.1.1). Catalyst will be added to the tank and hydrogen peroxide will be introduced to the tank sub-surface at a controlled rate. Initial studies have shown that with a pH of 11, elevated temperature, and the presence of Fenton's Reagent there is sufficient decomposition reaction. The primary products of the reaction are carbon dioxide, water and borate salts. The carbon dioxide is released to the tank vapor space and removed from the tank by the existing Tank 48 air-based ventilation system. In addition to carbon dioxide gas, other minor decomposition products are oxygen and benzene due to reaction inefficiencies. The water and borate salts remain within the tank liquid along with the MST solids left over from ITP operations and pose no flammability hazard. Once the analysis shows the material is below the established organic limits the resulting liquid can be sent to any tank farm waste tank or concentrated in the HLW evaporator system.

2.1.3.2 Risks

The presence of peroxide, milder pH conditions, and elevated temperature could result in an increased risk to the tanks internal components due to corrosion unless corrosion chemistry is maintained. This could reduce the service life of the tank based on corrosion

study results that identified potential pitting concerns (Reference 5.7). Second, as decomposition efficiency has been extrapolated from limited duration test results (Reference 5.5), this process carries the risk that the decomposition rate is not adequate to meet the end state requirement within the 12 month treatment time assumed in this evaluation. A more detail discussion of the risks associated with this option is provided in reference 5.15.

2.1.4 Salt Cell Fenton's Hydrolysis

2.1.4.1 Description

This option utilizes the same Fenton's reagent (catalyst and peroxide) as does the in-tank Fenton's option, but performs the reaction in the DWPF Salt Cell. The reaction tanks and piping in the Salt Cell are constructed of corrosion resistant alloys and can withstand higher temperatures and a highly acidic environment. The Salt Cell Fenton's option would operate at boiling (around 100°C) and a pH range of 3-5. These conditions are considered the most efficient for destroying organic compounds using a Fenton's Reagent process.

The primary products of the reaction are carbon dioxide, water and borate salts. The carbon dioxide is released through the salt cell tank ventilation system. In addition to carbon dioxide gas, other minor decomposition products are oxygen and benzene due to reaction inefficiencies. The water and borate salts remain within the tank liquid along with the MST solids left over from ITP operations and pose no flammability hazard. This resulting liquid would be processed through the DWPF system and vitrified with the existing waste stream from the Tank Farm.

2.1.4.2 Risks

The primary risk of this option is that it could negatively impact glass production in DWPF. Coupling this process with DWPF, a series of batch processes, means that any outage of the Fenton Processing Equipment has the potential to shut down DWPF processing. The sharing of process equipment, including condensate collection storage space also has the potential for impacting DWPF production. The Salt Cell would require significant modification in order to process the Tank 48 material. The time to modify the equipment and process the contents may not meet the needed Tank 48 return to service date. No detailed risk analysis was developed and issued for this option. A preliminary risk analysis performed for a small tank precipitation process in the DWPF Salt Cell was reviewed by the Team for guidance in identifying potential risks for the use of Fenton's Hydrolysis in the Salt Cell.

2.1.5 Blending

2.1.5.1 Description

This option consists of blending material from Tank 48 with DWPF recycle. Initially DWPF recycle will be transferred to Tank 50 and then an appropriate quantity of Tank 48 material will be transferred into Tank 50. The solution will be mixed, sampled and compared to SPF waste acceptance criteria (WAC) limits. The blended material will be transferred to SPF for final disposition as grout. The next phase of the blending occurs in Tank 48. DWPF recycle will be sent to Tank 48 in small batches (approximately 55,000 gallons), mixed and the blended solution transferred to Tank 50. This operation will be repeated until the quantity of residual TPB in Tank 48 can meet the end state requirement of less than 5% organic contribution to the LFL. The primary product from this option is grout containing the TPB and MST solids. The blending in Tank 48 will result in two batches of material being sent from Tank 50 and then to SPF. This will result in a total of three batches being used to send material from Tank 48 to final disposition in SPF. Emissions resulting from benzene generation are assumed to be below the permit limit.

2.1.5.2 Risks

The largest risk to this option is a regulatory one. The current radiological permit limits for Saltstone are very low and would require significant amounts of grout to completely disposition Tank 48 material through SPF. SRS is currently pursuing a modification to the permit with South Carolina authorities. Failure to receive relief from current radiological limits is the primary risk for this option. Additionally, the timeliness of permit approval could jeopardize the schedule estimate assumed in this evaluation. Next, at the normal Tank 48 conditions of low temperature (<35°C) and high alkalinity (pH $\geq$ 14) the TPB is very stable and minimal degradation of the TPB is expected. If DWPF recycle contains active catalysts, then mixing this material with DWPF recycle could produce undesirable benzene generation rates in Tank 48 and Tank 50. This could require modifications to Tank 50. The risk of undesirable benzene generation rates also applies to SPF and the interconnecting transfer system (including the LPDT). Another risk for this option is the ability to form acceptable grout with the blended material at SPF. The blended material will contain both TPB and MST solids left over from ITP operations. There is a risk that the concentrations of these solids, particularly the actinides or organic, may not produce an acceptable grout form and in the case of TPB may additionally create problems in leaching organic materials. No testing has been completed with grout containing actinides adsorbed on MST or insoluble TPB at the concentrations planned for Tank 48 processing. Further testing is required to minimize this risk. A detailed discussion of the risk associated with this option is provided in Reference 5.16.

3.0 Evaluation

3.1 Evaluation Team

Team members were selected for their specific expertise, SRS experience and knowledge, research and development knowledge, and familiarity with planning, design and operation of facilities at SRS. In addition to the resources of the Team, subject matter experts were consulted on an as-needed basis. This ensured that the necessary expertise was available for a knowledgeable decision.

The Team was comprised of the following members:

Team Member	Organization
Jim Barber	Salt Engineering
Christopher Cope	WSMS
Gerald Eide	HDP Facility Engineering
Rick Fowler	HLW Program Development and Integration
Anthony Giordano	Tank 48 Project Manager
Dan Lambert	SRTC
Bernice Rogers	Tank 48 Project Owner
Steve Strohmeier	Salt Engineering
Gavin Winship	Salt Engineering
Ben Dean	Salt Engineering

3.2 Evaluation Process

The process used by the Team followed the guidance within the System's Engineering Methodology Guidance Manual (Reference 5.20) and employed a simplified scoring methodology. The major steps of the process were:

- Development of evaluation criteria
- Weighting of evaluation criteria
- Evaluation of options versus criteria
- Performance of sensitivity analysis

These steps are discussed in detail below.

3.2.1 Development of Evaluation Criteria

The Team began the development of evaluation criteria by identifying those criteria that are independent and discriminating between the options. Many criteria were considered for use in evaluating the options. A criterion may be important, but it may not necessarily be useful if it does not discriminate between the options. The criteria below were developed by the Team and agreed to by consensus. Additional details for each option are found in Appendix 6.2.

Cost

The Team, drawing from past experience, issued project estimates and other cost information to develop a Rough Order of Magnitude (ROM) Total Project Cost (TPC) estimate for each of the options. The variation in the estimates are based on the perceived complexity of the modifications, estimated consumables required by the treatment, level of research and development, level of Safety Basis (SB) development and required controls. These estimates are intended for comparison only and may be off by as much as 50%. However, the Team believed that the quality of the estimates and the consistency between the estimates make them acceptable for this evaluation.

Schedule

Again, the Team drew from past experience, existing project schedules and other information to develop critical path logic for each of the options. However, the Team believed that the quality of the schedule and the consistency between the logics make them acceptable for this evaluation.

The base schedule estimates were developed for the options by identifying the critical path (not total time) elements. These elements are:

- Research & Development
- Program Implementation (Stakeholder buy-in for DSA, Modifications, Testing, Procedures)
- SB Development
- Operations

Again, as with the cost data, these schedules are intended for comparison only.

Safety Basis (SB)

The evaluation criterion for the SB focuses on the difficulty in developing an acceptable control strategy for each of the options. Although the development for qualified inputs for the SB is captured as part of the Research and Development Evaluation Criteria, the evaluation applied to the SB criterion must also consider this aspect. Four of the options introduce "new" processes as it relates to control strategies defined within the current DSA (i.e., potential introduction of unanalyzed risk). Another major factor in the evaluation is the ability to satisfactorily address (control) the potential flammability risk associated with each of the options. The ability to produce an acceptable control strategy as it relates to organic production has been very challenging in the past.

Research and Development (R&D)

The evaluation criterion for R&D measures technical maturity between the different processing options. This criterion evaluates whether the process has been used elsewhere, particularly in radioactive service, whether any testing has been completed with simulant

or actual waste, whether the chemistry of the resulting product is well enough understood to estimate its downstream processing impacts, and whether any safety concerns were identified during testing. This criterion also evaluates the availability or R&D needed to obtain qualified data for input to DSA development.

Operations

The evaluation criterion for Operations focuses on the required operations difficulty for each of the options. The level of difficulty was determined based on the level of previous operational experience with the proposed option; the level of complexity of the activity; and the handling and management of new and or hazardous materials.

Regulatory

The evaluation criterion for Regulatory focuses on assessing environmental impacts from secondary waste streams, airborne emissions and liquid effluents. This criterion also assesses the relative difficulty in resolving potential issues with interested stakeholders, including the DOE, Defense Nuclear Facilities Safety Board (DNFSB), and South Carolina Department of Health and Environmental Control (SCDHEC).

Downstream Process Impacts

Chemistry and physical differences in the waste streams produced by each process require that they be handled by downstream facilities in different manners. The final waste form is different between the options. This criterion also assesses the relative difficulty in resolving potential impacts on downstream processes.

3.2.2 Weighting of Evaluation Criteria

After defining the evaluation criteria, the Team determined the weight or importance of each criterion in selecting the option. This was derived through Team consensus with the weights being assigned to represent the relative importance of each criterion. The following weights were assigned by the Team:

Evaluation Criteria Weights

Criteria	Weight
Schedule	25
Cost	20
Safety Basis	10
R&D	15
Operations	5
Regulatory	15
Downstream Process Impacts	10

3.2.3 Evaluation of Options Versus Criteria

To assist in scoring each option against the criteria, a scale of 1 through 5 was developed with appropriate guide words or values to allow a consistent scoring. The higher score represented a less desirable evaluation result while the lower score represented a more desirable evaluation result. The following summarizes the scale established for each criterion.

Cost Scoring Scale:
- 1 - $0-5.9 Million
- 2 - $6-11.9 Million
- 3* - $12-17.9 Million Based on the current budget forecast for Tank 48
- 4 - $18-23.9 Million
- 5 - Above $24 Million

Schedule Scoring Scale:
- 1 - 0-8.9 months
- 2 - 9-17.9 months
- 3* - 18-26.9 months Based on the current milestone for Tank 48
- 4 - 27-35.9 months
- 5 - Greater than 36 months

Safety Basis Scoring Scale:
- 1 - Potential for minimal impacts to existing control strategy
- 3 - Potential for moderate impacts to existing control strategy
- 5 - Potential for significant impacts to existing control strategy

Research and Development Scoring Scale:
- 1 - Proven technology - little or no R&D required
- 3 - Limited application of technology – moderate amount of R&D required
- 5 - Technology application unproven - extensive R&D required

Operations Scoring Scale:
- 1 - Simple and easy to operate and coordinate
- 3 - Moderately difficult to operate and coordinate
- 5 - Complex and difficult to operate and coordinate

Regulatory Scoring Scale:
- 1 - Minimum permitting changes required/Minor stakeholder concerns
- 3 - Some permitting changes required/Moderate stakeholder concerns
- 5 - Major permitting changes or new permits required/Major stakeholder concerns

To allow the score of the evaluated option to represent the aggregate of permitting and stakeholder concerns, both permitting and stakeholder concerns were scored separately, averaged and rounded to give a single score for regulatory.

Downstream Process Scoring Scale:

1 - Minimal impact on downstream facilities
3 - Some impact on downstream facilities
5 - Major impact on downstream facilities

3.2.4 Results

The evaluation of the options against the criteria was performed using a simplified scoring process as described above and outlined in Reference 5.20 (Systems Engineering Methodology Guidance Manual). Each option was evaluated against each of the evaluation criteria using the guide words and values to arrive at a score (between 1 and 5) for a given criterion. The scores were then multiplied by the weighting criteria and a total score for each option obtained. The data and total scores are shown in Appendix 6.3. The scoring technique was applied such that a higher score was indicative of an adverse evaluation result and the lower score indicative of a favorable evaluation result. Thus the lowest scoring option is the preferred option in this evaluation.

After all evaluation criteria were used, the total scores were obtained. The ranking results were as follows:

Ranking Results

Ranking	Option	Score
1	Blending In-tank	280
2	In-tank Thermal Hydrolysis	290
3	In-tank Catalytic Hydrolysis	310
4	In-tank Fenton's Hydrolysis	385
5	Salt Cell Fenton's Hydrolysis	460

3.2.5 Sensitivity Analysis

A sensitivity analysis was performed on the selected options to determine if changes in the weighting of evaluation criteria could alter the final ranking (prioritization).

This was performed by adjusting the weight of a selected criterion upwards and downwards by 50%, proportionally reducing the weights of the other criteria accordingly and calculating the final score for all the options. Adjustments of 20% are normally done but as the cost and schedule estimates have an accuracy of 50%, an adjustment of 50% was used. This was done for all criteria. Of the fourteen cases, ten maintained the same ranking (Blending followed by In-Tank Thermal Hydrolysis). In four cases, In-Tank Thermal Hydrolysis was the top ranked option. The cases were: Cost +50%, Regulatory +50%, Schedule -50%, Down Stream Impacts -50%

Blending was the top ranked option in most of the sensitivity analyses. In half the analyses, the relative score of Blending improved over the other options. As the

importance of Schedule, SB, R&D, and Down Stream Impacts was increased, Blending separated from the other options. Decreasing the importance of Cost, Operation, and Regulatory had the same result.

Sensitivity analysis results are shown in Appendix 6.4.

4.0 Conclusions

In conclusion, Blending was ranked as the most favorable WSRC in-house option. In-Tank Thermal Hydrolysis followed closely as a second option.

The Team discussed the results of the evaluation and satisfactorily reached consensus with the process used and the results obtained. Blending was the highest ranked option for the analysis and most of the sensitivity analysis. As shown in the sensitivity analysis, adjusting some criterion, In-Tank Thermal becomes more attractive. With respect to the major risk, should an item not be realized, an adjustment could be shown in the ranking. For example, should the permit risk for Blending not be realized, the Regulatory criterion relative importance would decrease, thus causing Blending to separate from the others as a clearer option.

The Team concluded that In-Tank Thermal Hydrolysis should be pursued as a second option, due to the relative ranking, based on variations in the sensitivity analysis, the accuracy of the inputs, and as a mitigation strategy to the risks associated with Blending.

In-Tank Catalytic Hydrolysis is a viable backup should unforeseen problems be encountered in implementing the preferred options.

Several items of note were discussed by the Team during the final closing session:

1. Although a ranking was performed and a preferred option apparent, each of these options have risks associated with them. The Team attempted to address these risks by including them in the evaluation process to achieve a meaningful ranking of options.

   The major risks associated with the top-ranked option (Blending) are as follows:

   - SPF Class C Permit not received from the state of South Carolina in the timeframe assume in this evaluation.
   - Insoluble TPB concentration not acceptable in SPF for grout formulation.
   - Benzene generation rates require equipment modifications to Tank 50, SPF and interconnecting transfer systems (including Low Point Drain Tank (LPDT).

   The major risk associated with the second-ranked option, In-Tank Thermal Hydrolysis, is as follows:

   - Organic decomposition efficiencies are lower than predicted resulting in a longer processing rate.

2. During the closing discussions, the Team recognized the requirement for removal of the residual TPB film deposited on the tank wall and in-tank equipment (cooling coils, pump columns, thermowells, etc.) from the maximum working inventory

levels in 1995. The maximum inventory level was approximately 526,000 gallons or 150 inches. This requirement will be incorporated into the strategy. Residual TPB build up and film removal from Tank 49 was accomplished with filling the tank and normal tank agitation. The Tank 48 flow sheet will incorporate these activities to effectively manage the removal of this film as part of the Tank 48 Return to Service Strategy. The removal of this film is common to all options and therefore, was not considered in this evaluation.

3. The ability to reach a theoretical residual TPB level of 0.3 kg in Tank 48 may be shown as achievable by calculation and extrapolation of data, but for all the options considered, a method of validating the end point will have to be developed. Currently the 0.3 kg of TPB is at or below detection limits depending on the assumed residual heel volume after the end of processing.

4. When Tank 50 is used for the blending option, it is assumed that it will perform future feed missions to the SPF as the residual organics are removed by being blended to decreasing concentrations with future Saltstone feed.

5.0 References

5.1 WSRC-RP-2002-00154, "HLW Tank 48 Disposition Alternatives Identification Phase I and II Summary Report," Revision 1, 7/15/02.

5.2 WSRC-RP-2003-00588, "Downstream Impacts of Tank 48H In-tank and Out-of tank Processing Alternatives," October 22, 2003.

5.3 WMTD (03) P143, "Chemical Oxidation of Tank 48 Simulant," September 2003.

5.4 WSRC-TR-2003-00445, "Electrochemical Tests of Carbon Steel in Simulated Waste Containing Fenton's Reagent," October 2003.

5.5 WSRC-RP-2003-00560, "Tank 48 In-tank Flowsheets," September 11, 2003.

5.6 WSRC-TR-2003-00365, "Process Development for Destruction of Tetraphenylborate in SRS Tank 48H," Revision 0, 10/15/03.

5.7 SRT-LWP-2003-00050, "Tank 48 Corrosion Analysis Sample (THE-03-069, THE-03-070 and HTF-E-03-73)," Revision 1, 9/8/03.

5.8 Y-RAR-H-00042, "Closure Business Unit, Liquid Waste Disposition Projects, Salt Processing Projects, Tank 48 Project, Risk Analysis Report," Revision 0, 9/8/03.

5.9 CBU-PED-2003-00014, "Technical Program Plan for Tank 48 Processing," Revision 0, September 2003.

5.10 G-SOW-H-00032, "Statement of Work, SRS Tank 48H Material Treatment," Revision 1, 9/29/03.

5.11 WSRC-SA-2002-00007, "CSTF Documented Safety Analysis", Revision 2, December 2003.

5.12 X-CLC-H-00445, Maximum Quantity of Residual KTPB Solids Allowed, Revision 0, 7/30/03.

5.13 Y-RAR-H-00045, "CBU, LWDP, Salt Processing Projects, Tank 48 Project, Thermal Decomposition In-Tank Process, Risk Analysis Report," Revision 0, 9/8/03.

5.14 Y-RAR-H-00044, "CBU, LWDP, Salt Processing Projects, Tank 48 Project, Catalytic Decomposition In-Tank Process, Risk Analysis Report," Revision 0, 9/8/03.

5.15 Y-RAR-H-00043, "CBU, LWDP, Salt Processing Projects, Tank 48 Project, Fenton's In-Tank Process, Risk Analysis Report," Revision 0, 9/8/03.

5.16 Y-RAR-H-00049, CBU, LWDP, Salt Processing Projects, Tank 48 Project, Blending, Risk Analysis Report," Revision 0, January 2004.

5.17 CBU-SPT-2003-00139, "Salt Program Flowsheet Development for Treatment of Cs, Sr and Actinides Utilizing Existing Facilities," Revision 0, 8/19/03.

5.18 CBU-SPT-2003-00132, "SRS Closure Business Unit, Salt Decontamination Project Development Team, Small Tank Precipitation Engineering Scope Document," Revision 0, 8/12/03.

5.19 CBU-SPT-2003-00011, Tank 48 TPB Disposition / Return to High Level Waste Service, Engineering Scope Document, Blending Option, January 2004.

5.20 WSRC-IM-98-000033, "Systems Engineering Methodology Guidance Manual, Appendix-A, Alternative Study," Revision 7, September 28, 2001.

6.0 Appendices

6.1 Tank 48 Initial Conditions

The following data for the Tank 48 initial condition was extracted from Appendix 6.3 of Reference 5.10, "Statement of Work, and SRS Tank 48H Material Treatment."

Tank 48H contains approximately 250,000 gal of a radioactive alkaline slurry (pH 14) with roughly 2.3 wt % solids (<10 μm). The solids consist of a mixture of MST, TPB salts, and entrained metal hydroxide sludge. The potassium and cesium tetraphenylborate (KTPB and CsTPB) salts resulted from precipitation after addition of sodium tetraphenylborate (NaTPB).

Non-Radioactive Components

Tables 1 and 2 provide the concentration of non-radioactive components in Tank 48. Table 3 provides the concentration of major isotopes in Tank 48.

Table 1 -- Tank 48H Major Components

Component	M
KTPB	0.0728
NaOH	1.8425
$NaNO_2$	0.4709
$NaNO_3$	0.3481
Na_2CO_3	0.1295
$NaAlO_2$	0.1118
Na_2SO_4	0.0071
Na_3PO_4	0.0077
NaCl	0.0088
NaF	0.0059
KNO_3	0.0051

Table 2 – Metals and Trace Organics

Component	Compound	Concentration in Slurry (mg/L)
Pd	$Pd(NO_3)_2$	13.0
Cu	$Cu(SO_4)\bullet 5H_2O$	3.7
Hg[b]	$Hg(NO_3)_2\bullet H_2O$	2.2
diphenylmercury[b,c]	$(C_6H_5)_2Hg$	150
Mo/Cr/Si/Se/As	$Na_2MoO_4\bullet 2H_2O$	12
	Na_2CrO_4	60
	$Na_2SiO_3\bullet 9H_2O$	16
	Na_2SeO_4	1
	As_2O_3	0.04
Zn/Pb/Fe	$Zn(NO_3)_2\bullet 4H_2O$	8.8
	$Pb(NO_3)_2$	1.2
	$Fe(NO_3)_3\bullet 9H_2O$	2.6
Sn	$SnCl_2$	2.1
Ca/La/Co	$Ca(NO_3)_2\bullet 4H_2O$	12.2
	$La(NO_3)_3\bullet 6H_2O$	0.05
	$Co(NO_3)_2\bullet 6H_2O$	0.04
Cd/Ce	$Cd(NO_3)_2\bullet 4H_2O$	0.4
	$Ce(NO_3)_3\bullet 6H_2O$	0.3
Rh	$Rh(NO_3)_3$	1.4
Ag	$AgNO_3$	6.8
Ru	$RuCl_3\bullet xH_2O$	5.4
sludge	Sludge	500
MST	MST	500

Table 3 - Radionuclide Data from Tank 48H

	Supernate (liquid only)			Slurry (liquid and solids)			Total Mass
Isotope	Conc. (mg/L)	Mass (mg)	Mass (g)	Conc. mg/L	Mass (mg)	Mass (g)	(g)
Sr-90	4.78E-06	4.20E+00	4.20E-03	ND	-	-	4.20E-03
Cs-137	1.72E-01	1.51E+05	1.51E+02	1.15E+01	1.09E+07	1.09E+04	1.16E+04
U-233	5.06E-02	4.44E+04	4.44E+01	3.63E-06	4.05E+04	4.05E+01	8.49E+01
U-234	3.67E-01	3.22E+05	3.22E+02	1.14E-05	1.27E+05	1.27E+02	4.49E+02
U-235	5.88E-01	5.16E+05	5.16E+02	3.20E-05	3.57E+05	3.57E+02	8.73E+02
U-236	1.44E+00	1.26E+06	1.26E+03	6.06E-06	6.76E+04	6.76E+01	1.33E+03
U-238	3.71E+00	3.25E+06	3.25E+03	2.05E-04	2.29E+06	2.29E+03	5.54E+03
total U	6.15E+00	5.40E+06	5.40E+03	2.58E-04	2.88E+06	2.88E+03	8.28E+03
Np-237	5.52E-02	4.85E+04	4.85E+01	1.85E-05	2.06E+05	2.06E+02	2.55E+02
Pu-238	1.81E-02	1.59E+04	1.59E+01	5.70E-06	6.36E+04	6.36E+01	7.94E+01
Pu-239	2.87E-03	2.51E+03	2.51E+00	3.76E-06	4.19E+04	4.19E+01	4.44E+01
Pu-240	ND	-	-	4.58E-07	5.11E+03	5.11E+00	5.11E+00
Pu-241	ND	-	-	7.65E-08	8.53E+02	8.53E-01	8.53E-01

ND=Not Detected

6.2 Option Information

OPTION - In-Tank Thermal Hydrolysis

Description: Thermal Hydrolysis decomposes TPB through a hydrolysis reaction to produce benzene. Reaction conditions for this tank treatment option are a pH of 11 and a temperature of 45 ° C.

Evaluation Comments	Schedule & Experience	Rough Order of Magnitude ROM Cost ($)

Safety Basis
• Moderately difficult to control benzene generation rate with respect to flammability.
• New process (not currently analyzed in the DSA) requiring a Consolidated Hazard Analysis Process (CHAP) evaluation for organic destruction (quantification of degradation products). Past experience with Tank 49 did not show any significant SB concerns although it used a pre-830 SB platform and Justification for Continued Operations (JCO).
Research and Development
• Thermal hydrolysis process has been used in Tank 49H and Tank 50H.
• Testing with simulants has demonstrated TPB decomposition at a pH of 11 and an elevated temperature.
• Corrosion testing with simulants demonstrated minor corrosion concern.
• Gaseous decomposition products have not been quantified.
• Need to confirm complete degradation of TPB
Operations
• Involves routine tank farm operations with increased oversight
• Requires handling and use of 50 wt% Nitric Acid
Regulatory
• Minimum permit modification necessary
• Stakeholder interest expected (familiar with option based on past Tank 49 and 50 experiences)
Downstream Process Impacts
• Product is acceptable for Tank Farm storage
• Product is compatible with DWPF processing
• Biphenyl, terphenyl, or tarry compounds, if produced as by-products, may require an intermediate treatment step
• No solids addition
	Schedule
	Total duration to return tank to service is estimated to be 27 months
	• Estimated time to treat tank contents is 12 months. (Based on extrapolation of a limited duration test)
	• Time to prepare tank– 15 months
	  • This includes R&D, SB, Engineering, Modifications, Testing and Procedures.
	
	Experience
	• Thermal hydrolysis was part of the process used in Tank 49H to treat TPB (along with catalysts).
	• Thermal hydrolysis was used to treat TPB in Tank 50H. Although the pH was not lower as part of this treatment.
		Cost for the In-Tank Thermal Hydrolysis is estimated to be approximately $ 11 Million.
		
		The TPC estimate is based on the following:
		• Operating cost excluding tank returned to service
		• Addition of Nitric Acid Unloading Area
		• Other Equipment needed:
		  • Piping/hose
		  • Process Controls
		  • Separate VFDs for Tank 48 slurry pumps
		
		Major Risks
		• Organic destruction efficiencies are slower than predicted resulting in a longer processing time

OPTION – In-Tank Catalytic Hydrolysis

Description: Catalysis decomposes TPB through an accelerated hydrolysis reaction to produce benzene. Reaction conditions for this tank treatment option are a pH of 11, a temperature of 45 ^{o} C, and addition of a catalyst (copper or palladium).

Evaluation Comments	Schedule & Experience	Rough Order of Magnitude ROM Cost ($)

Safety Basis
• Moderately difficult to control benzene generation rate with respect to flammability.
• New process (not currently analyzed in the DSA) requiring a CHAP evaluation for organic destruction (quantification of degradation products). Past experience with Tank 49 did not show any significant SB concerns although it used a pre-830 SB platform and JCO.
Research and Development
• Catalyzed thermal hydrolysis process has been used successfully in Tank 49H.
• Testing with simulants has demonstrated TPB decomposition at a pH of 11 and an elevated temperature and in the presence of a catalyst.
• Corrosion testing with simulants demonstrated minor corrosion concern.
• Gaseous decomposition products have not been quantified
• Need to confirm complete degradation of TPB
Operations
• Involves routine tank farm operations with increased oversight
• Requires handling and use of 50 wt% Nitric Acid and catalyst
Regulatory
• Minimum permit modification necessary
• Stakeholder interest expected (familiar with option based on past Tank 49 and 50 experiences)
Downstream Process Impacts
• Product is acceptable for Tank Farm storage
• Product is compatible with DWPF processing
• Biphenyl, terphenyl, or tarry compounds, if produced as by-products, may require an intermediate treatment step
• Minor solids addition
	Schedule
	Total duration to return tank to service is estimated to be 27 months
	• Estimated time to treat tank contents is 12 months. (Based on extrapolation of a limited duration test)
	• Time to prepare tank– 15 months
	  • This includes R&D, SB, Engineering, Modifications, Testing and Procedures.
	
	Experience
	• Catalyst (cupric nitrate) and heat utilized to treat Tank 49H.
		Cost for the In-Tank Catalytic option is estimated to be approximately $ 12 Million.
		
		The TPC estimate is based on the following:
		• Operating cost excluding tank returned to service
		• Addition of Nitric Acid Unloading Area
		• Other Equipment needed:
		  • Catalyst Feed tank
		  • Agitator
		  • Piping
		  • Process Controls
		  • Separate VFDs for Tank 48 slurry pumps
		
		Major Risks
		• Organic destruction efficiencies are slower than predicted resulting in a longer processing time.

OPTION – In-Tank Fenton's Hydrolysis

Description: Fenton's Hydrolysis utilizes catalysts (iron, copper or both) in conjunction with peroxide to destroy organic materials through oxidation. Reaction conditions for this tank treatment option are a pH of 11 and a temperature of 45 °C. The use of this oxidant minimizes the production of benzene, and produces carbon dioxide and water as the major byproducts.

Evaluation Comments	Schedule & Experience	Rough Order Magnitude (ROM) Cost ($)

Safety Basis
• Difficulty in controlling flammable vapor generation rate (large-scale in-tank reaction) due to oxygen.
• Difficulty in controlling tank pressure due to large-scale in-tank reaction.
• New process (not currently analyzed in the DSA) requiring a CHAP evaluation for organic destruction (quantification of degradation products).
Research and Development
• In-Tank Fenton processing has only been demonstrated in the laboratory with simulants.
• Testing with simulants has demonstrated TPB decomposition at a pH of 11, an elevated temperature, and in the presence of a catalyst.
• Corrosion testing with simulants identified significant pitting potential.
• Gaseous decomposition products have not been quantified.
• Determination of oxygen generation rate
• Need to confirm complete degradation of TPB
Operations
• Involves non-routine (handling of peroxide) tank farm operations with increased oversight
• Requires handling and use of 50 wt% Nitric Acid and catalyst
• Requires closer control of chemical addition rates due to peroxide reactivity
Regulatory
• Minimum permit modification necessary
• Potential for significant Stakeholder concerns (no HLW In-Tank experience)
• New process for HLW
Downstream Process Impacts
• Product is acceptable for Tank Farm storage
• Product is compatible with DWPF processing
• Creates twice the volume of waste than other In-Tank options
• Minor solids addition
	Schedule
	Total duration to return tank to service is estimated to be 30 months.
	• Estimated time to treat tank contents is 12 months. (Based on extrapolation of a limited duration test)
	• Time to prepare tank– 18 months
	  • This includes R&D, SB, Engineering, Modifications, Testing and Procedures.
	
	Experience
	• No HLW experience at these conditions
		Cost for the In-Tank Fenton's Reagent is estimated to be approximately $ 17 Million.
		
		The TPC estimate is based on the following:
		• Operating cost excluding tank returned to service
		• Addition of Unloading Areas:
		• Peroxide, Nitric Acid, and Catalyst.
		• Other Equipment needed:
		  • 2 - 1000 gal mixing tanks
		  • Agitators
		  • Piping
		  • Process Controls
		  • Separate VFDs for Tank 48 slurry pumps
		
		Major Risks
		• Organic destruction efficiencies are slower than predicted resulting in a longer processing time.
		• Tank service life and operational capacity reduced due to corrosion (defined as performing operations outside of the allowable limits of the corrosion control program).

OPTION - Salt Cell Fenton's Hydrolysis

Description: Proposal utilizes Fenton's Chemistry at ideal conditions (pH of 3-5) at boiling (100°C) to maximize the effectiveness of organic destruction. The use of this oxidant minimizes the production of benzene, and produces carbon dioxide and water as the major byproducts. This occurs in the DWPF Salt Cell.

Evaluation Comments	Schedule & Experience	Rough Order of Magnitude ROM Cost ($)

Safety Basis
• Moderately difficult in controlling flammable vapor generation rate
• Difficulty in addressing interface issues between DSAs (CST and DWPF).
• New process (not currently analyzed in the SB) requiring a CHAP evaluation for organic destruction (quantification of degradation products).
• A potential benefit is a smaller scale reaction vessel. Additionally, the salt cell is located within a robust enclosure (built to SC criteria).
Research and Development
• Fenton processing has been proven at a smaller scale by destroying organics in radioactive ion exchange resins for over a decade.
• A process has been developed and tested at two laboratory scales and has demonstrated that complete destruction of TPB.
• Gaseous decomposition products have not been quantified.
• Determination of oxygen generation rate
• Required glass testing for DWPF
Operations
• Easier to control reaction in smaller batches
• Equipment is designed to accommodate this similar process
• Requires use of Salt Cell which has never operated in radioactive service.
• No experience with this process
• Addition coordination of transfers
• Requires multiple batches to process material
• DCS control for process
Regulatory
• Requires moderate permit modification
• Potential for significant Stakeholder concerns (no HLW experience)
Downstream Process Impacts
• Product should be acceptable in DWPF process
• Negative impact to DWPF canister production due to coupling of this process with DWPF. Any outage could effect production.
• Minor increase in DWPF recycle
	Schedule
	Total duration to return tank to service is estimated to be 42 months
	• Estimated time to treat tank contents is 12 months.
	• Time to prepare tank– 30 months
	  • This includes R&D, SB, Engineering, Modifications, Testing and Procedures.
	
	Experience
	• Similar process is used in nuclear industry. No experience at SRS.
	• DWPF Salt Cell never used.
		Cost for the Fenton's Salt Cell is estimated to be approximately $50 Million.
		
		The TPC estimate is based on the following:
		• Operating cost excluding tank returned to service
		• Major Equipment Impacts:
		  • DWPF
		  • Fenton's Reactor
		  • Cold Feed Tanks
		  • Evaporator
		  • Overheads Collection Tank
		
		Major Risks
		• Impact canister throughput and waste loading.
		• Salt Cell modification and operation does not meet Tank 48H Return To Service Milestone Date

OPTION - Blending

Description: This option consists of blending material from the DWPF recycle tanks with the material in Tank 48. The blending will occur in Tank 48 and Tank 50. The blended material will be transferred from Tank 50 to SPF.

Evaluation Comments	Schedule & Experience	Rough Order of Magnitude ROM Cost ($)

Safety Basis
• Based on known technology/process therefore no CHAP required
• Moderate difficulty in controlling benzene generation rate (flammability control) due to addition of tank farm waste with Tank 48 material in Tank 50 (potential benzene generation due to the addition of active catalysts from DWPF recycle)
• SPF SB will need to be reviewed for impacts due to an increase in insoluble TPB concentration
Research and Development
• SRS's SPF has been making grout since the early 1990's although grout formulation has not been demonstrated at levels that are being considered that will pass TCLP testing (~4000 ppm TPB and 3.5E+4 d/m/mL Gross Alpha) with KTPB and loaded MST present.
• Tanks 49 and 50, both tanks containing TPB, have been successfully processed through the SPF at reduced levels.
• Determination of benzene generation rate due to catalytic elements
• Blending may not be practical if high concentrations of TPB and actinides can not be stabilized in the grout matrix.
Operations
• Involves routine tank farm operations although with increased oversight (mass balance, route coordination, etc.)
• Multiple transfer requires coordination with other activities
Regulatory
• Saltstone permit modification required to proceed
• Potential for moderate Stakeholder concerns
Downstream Process Impacts
• Blended product may not form acceptable grout
• Process will consume significant Saltstone vault space
	Schedule
	Total duration to return tank to service is estimated to be 23 months
	• 9 months to blend and meet end state TPB requirements in Tank 48.
	• Time to prepare tank – 14 months
	  • This includes R&D, Engineering, Modifications, Testing, Procedures and regulatory (permit) activities.
	  • This assumes SFP permit is approved in 14 months.
	
	Experience
	• Extensive experience blending different solutions to meet both regulatory and safety basis issues.
		Cost for Blending is estimated to be approximately $15 Million
		
		The TPC estimate is based on the following:
		• Operating cost excluding tank returned to service
		• Major Equipment Impacts:
		  • Transfer Path Tank 48 to 50
		  • Transfer path Tank 21/24 to 50
		  • Transfer Path Tank 21/24 to 48
		  • New Transfer pump(Pump on a Stick) in Tank 48
		  • Separate VFDs for Tank 48 slurry pumps
		
		Major Risks
		• SPF Class C Permit not received from state within the timeframe assumed herein
		• Benzene generation rates require equipment modifications to Tank 50, SPF and interconnecting transfer system (including LPDT)
		• TPB form (insoluble versus soluble) or concentration not acceptable in Saltstone

6.3 Results

	Schedule (25)	Cost (20)	SB (10)	R&D (15)	Operations (5)	Regulatory (15)	Downstream (10)	Total Score
Blending	3	3	3	2	3	4	1	280
Thermal	4	2	4	3	1	2	3	290
Catalytic	4	3	4	3	1	2	3	310
Fenton's	4	3	5	5	3	3	4	385
Salt Cell	5	5	4	5	5	3	5	460

6.4 Sensitivity Analysis Results

Criteria Number	1	2	3	4	5	6	7
Criteria Name	Schedule	Cost	Safety Basis	R&D	Operation	Regulatory	Down Stream Impacts
Criteria Weight	25	20	10	15	5	15	10
Option							
Blending	3	3	3	2	3	4	1
Thermal	4	2	4	3	1	2	3
Catalytic	4	3	4	3	1	2	3
Fenton's	4	3	5	5	3	3	4
Salt Cell	5	5	4	5	5	3	5

Criteria Weights (Sensitivity Analysis)	50%	50%	50%	50%	50%	50%	50%
1+50%	37.50	16.67	8.33	12.50	4.17	12.50	8.33
2+50%	21.88	30.00	8.75	13.13	4.38	13.13	8.75
3+50%	23.61	18.89	15.00	14.17	4.72	14.17	9.44
4+50%	22.79	18.24	9.12	22.50	4.56	13.68	9.12
5+50%	24.34	19.47	9.74	14.61	7.50	14.61	9.74
6+50%	22.79	18.24	9.12	13.68	4.56	22.50	9.12
7+50%	23.61	18.89	9.44	14.17	4.72	14.17	15.00
1-50%	12.50	23.33	11.67	17.50	5.83	17.50	11.67
2-50%	28.13	10.00	11.25	16.88	5.63	16.88	11.25
3-50%	26.39	21.11	5.00	15.83	5.28	15.83	10.56
4-50%	27.21	21.76	10.88	7.50	5.44	16.32	10.88
5-50%	25.66	20.53	10.26	15.39	2.50	15.39	10.26
6-50%	27.21	21.76	10.88	16.32	5.44	7.50	10.88
7-50%	26.39	21.11	10.56	15.83	5.28	15.83	5.00

	Weighted Scores							
Option	Normal	1+50%	2+50%	3+50%	4+50%	5+50%	6+50%	7+50%
Blending	280	283	283	281	273	281	291	270
Thermal	290	308	279	296	291	285	282	291
Catalytic	310	325	309	315	309	304	300	309
Fenton's	385	388	374	391	395	383	378	386
Salt Cell	460	467	465	457	464	461	446	462
Option	Normal	1-50%	2-50%	3-50%	4-50%	5-50%	6-50%	7-50%
Blending	280	277	278	279	287	279	269	290
Thermal	290	272	301	284	289	295	298	289
Catalytic	310	295	311	305	311	316	320	311
Fenton's	385	383	396	379	375	387	393	384
Salt Cell	460	453	455	463	456	459	474	458

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KEYWORDS:
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RETENTION: PERMANENT
CLASSIFICATION: U

Tank 48 Disposition Project Flowsheet for Aggregation Strategy 0.2 Ci/gal Cesium Max Feed

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APPROVED for Release for
Unlimited (Release to Public)
6/23/2005

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Summary

Tank 48 currently does not comply with the general Tank Farm safety requirements for organic content due to the presence of tetraphenylborate (TPB), and has been isolated from routine Tank Farm service since the shutdown of In-Tank Precipitation (ITP) process in late 1998. To restore Tank 48 to Tank Farm service, the TPB inventory must be removed or reduced to a level that meets the Tank Farm Documented Safety Analysis[2] (DSA) requirements. The Aggregation strategy consists of combining Tank 48 material with Defense Waste Processing Facility (DWPF) recycle material in both Tank 48 and Tank 50, with its final disposal in the Saltstone Facility as low level waste (LLW) in a grout waste form. The aggregated material in Tank 50 will meet the Saltstone Facility Waste Acceptance Criteria (WAC) prior to its transferring to the Saltstone Facility, including the maximum limits of 0.2 Ci/gal for Cesium-137 (Cs-137), 9.60E-04 Ci/gal[6,7] for alpha concentration, and revised TPB concentration limit at the time of the aggregation processing . In addition, the free hydroxide concentration of the aggregated material will be maintained greater than 1.0 molar to minimize decomposition of TPB into benzene. This option also requires modification to the Saltstone Waste Acceptance Criteria to permit higher concentrations of tetraphenylborate (up to 3,000 mg/L from the current 30 mg/L).

Two cases were developed based on the current fill level of Tank 48. During the Tank 48 processing history the liquid reached a level of nearly 150 inches. This processing left residual film potentially containing TPB solids behind on the tank internal walls and components[1]. To ensure that no significant residual TPB remains on the walls or tank internal structures, the tank level will be raised above 150 inches. In Case 1, the level in Tank 48 is raised above 150 inches a single time. In Case 2, the level is raised above 150 inches on two separate occasions (Batch 1 and Batch 4). While Case 2 requires more total batches to complete the TPB removal from Tank 50, it takes only 28 batches to reach the endpoint in Tank 48 versus the 31 batches needed in Case 1. Fluid totals for the two Aggregation cases are presented in Table 1.

→ **Table 1 Material Volumes Used for Aggregation Flowsheet Cases**

Streams (Kgal)	Case 1 (single rinse)	Case 2 (double rinse)
DWPF Recycle	3,405	4,099
NaOH (50 wt%)	162	195
ETP/HEU†	619	796
Total Addition Volumes	4,186	5,090

† The HEU and ETP project will transfer streams to Tank 50 and then Saltstone co-incident with the Aggregation process, but are independent of the Tank 48 Aggregation project.

The primary processing restraints to the batching strategy due to DSA requirements are to maintain the tank level below the 248" and the free hydroxide concentration above 1.0 molar in both Tank 48 and Tank 50. Restricting the level limits the amount of material that can be initially transferred into Tank 50, since only a relatively small volume of fluid can be added to reduce the Cs-137 concentration to 0.20 Ci/gal. After the initial addition of DWPF recycle to Tank 48 (305,000 gallons), three batches are required to process this material through Tank 50 before additional recycle can be added to Tank 48. This is true for both the single wall rinse and double wall rinse cases. Sodium hydroxide will need to be added in both Tank 48 and Tank 50 prior to other transfers to maintain chemistry conditions that reduce the potential of decomposition of the tetraphenylborate to produce into benzene.

→ Case 1 – Single Increase to 155" in Tank 48

The initial batch is prepared by transferring approximately 305,000 gallons of DWPF recycle to Tank 48 that has already received approximately 13,500 gallons of sodium hydroxide to maintain the tank free hydroxide concentration above 1.0 molar. This raises the level in Tank 48 to 159 inches. The material in Tank 48 is mixed and approximately 173,000 gallons from Tank 48 is transferred to Tank 50 (to a level of 110 inches in Tank 48). During the preparation of this batch, material from ETP (Effluent Treatment Project) and the unirradiated HEU (Highly Enriched Uranium) waste program may continue to be added to Tank 50. Before the first batch is transferred to Tank 50, an additional 24,000 gallons of caustic and 480,000 gallons of recycle will be required in Tank 50 to meet the limits for free hydroxide and Cs-137. Tank 50 level at the completion of this first batch is approximately 236 inches. This material will be worked off to Saltstone until Tank 50 has a 38 inch heel of remaining material. The ETP and the unirradiated HEU waste program are assumed to continue during this period.

Batch 2 is prepared by transferring approximately 158,000 gallons of Tank 48 material to Tank 50. Before this transfer, approximately 22,500 gallons of sodium hydroxide and 480,000 gallons of DWPF recycle are added to Tank 50 to maintain the final solution in compliance with hydroxide and Cs-137 concentrations. The Tank 48 level at the completion of Batch 2 is 65 inches. During the preparation of Batch 2, material from ETP and the unirradiated HEU waste program are assumed to be added to Tank 50. The Tank 50 level at the completion of Batch 2 is approximately 231 inches. The resulting material will be worked off to the Saltstone Facility until Tank 50 has a 38 inch heel of remaining material. The ETP and the unirradiated HEU waste program additions may continue during the Tank 50 to Saltstone work off.

For Batch 3, approximately 13,000 gallons of caustic and 265,000 gallons of DWPF recycle are transferred to Tank 50 in anticipation of transferring approximately 95,000 gallons from Tank 48 to Tank 50. This will lower the Tank 48 level to approximately 38 inches. Batches 4, 5, and 6 will be performed in a similar manner. For each of these batches, recycle and caustic will be added to Tank 48 and the mixture then transferred to Tank 50, where additional recycle and caustic are added prior to receiving the material from Tank 48. The combined material in Tank 50 along with incoming unirradiated HEU waste and ETP inflows will be worked off to the Saltstone Facility until the tank level is 38" before additional transfers to Tank 50 resume.

For each of the Batches 7 through 31, approximately 53,000 gallons of recycle and 2,500 gallons of sodium hydroxide are added to Tank 48. This raises the Tank 48 level to about 54 inches. The material is transferred to Tank 50 until Tank 48 reaches a level of 38 inches (approx. 55,000 gal.) with the exception of Batch 31. In this final batch for Tank 48 Aggregation the tank level will be drawn down to 12 inches. This material is processed through Saltstone. Batches 32 through 35 each add 53,000 gallons of recycle and 2,500 gallons of sodium hydroxide to Tank 50 rather than Tank 48. This additional material is required to process the TPB in Tank 50 to the DSA limit for flammable material.

For Batches 1 through 4 the material is worked off in Saltstone until the level reaches 38 inches in Tank 50 before another transfer is made from Tank 48. Starting in Batch 5 and continuing for the remainder of the program material is transferred from Tank 48 while Tank 50 continues to process material to Saltstone.

The total amount of recycle required to remove the TPB from Tank 48 is 1.78 million gallons. In addition, 83,500 gallons of 50 wt.% sodium hydroxide will be needed to maintain the tank at greater than 1.0 molar free hydroxide. The flowsheet shows that Tank 48 will be at the required TPB content after 31 batches. The maximum TPB concentration seen in Tank 50 from this operation is about 2200 mg/L. For Tank 50, the total amount of recycle and caustic added are 1.63 million and 78,500 gallons respectively. An additional 4 batches for a total of 35 are needed to lower the TPB concentration in Tank 50 to the required limit after the cleanout of Tank 48 is completed.

Details of the individual batches are provided in Table 3. Table 1, above, contains the totals of caustic and DWPF recycle required for each case and the total volume expected to be transferred to Saltstone. A curve depicting the TPB work-off rate for Case 1 in Tank 48, assuming ideal mixing is presented in Figure 1.

→ Table 3: Flowsheet for Case 1 (Single Rinse of Tank 48)

Tank 48										Tank 50														
Starting Level	Initial [Cs-137] (Ci/gal)	Initial [TPB] (mg/L)	Recycle Added (gal)	NaOH Addition (gal)	Max Level (in)	Residual [TPB] (Kg)	Final [Cs-137] (Ci/gal)	Post Transfer level (in)	Batch Number	Starting Level (in)	Initial [Cs-137] (Ci/gal)	Initial [TPB] (mg/L)	Tank 48 Transfers (gal)	HEU & ETF Additions (gal)	Recycle Added (gal)	NaOH Addition (gal)	Final [OH] (M)	Final [Na] (M)	Residual [TPB] (Kg)	Final [Alpha] (Ci/gal)	Final [Cs-137] (Ci/gal)	Max Level (in)	Saltstone Transfers (Kgal)
68.5	1.70	20878	305000	13500	159	13125	0.74	110	1	38.0	0.20	34	172835	17692	480000	24000	1.12	1.89	949	6.69E-04	0.20	235.9	694.5
110	0.74	8981	0	0	110	7756	0.74	65	2	38.0	0.20	1880	157950	17692	480000	22500	1.10	2.00	1038	5.85E-04	0.20	231.2	678.1
65	0.74	8981	0	0	65	4534	0.74	38	3	38.0	0.20	2057	94770	17692	265000	13000	1.12	2.02	1085	5.91E-04	0.20	149.2	390.5
38	0.74	8981	52650	2500	54	3208	0.53	38	4	38.0	0.20	2149	55150	17692	105000	5000	1.11	1.98	1778	5.54E-04	0.20	90.1	83.0
38	0.53	6354	52650	2500	54	2269	0.38	38	5	66.4	0.20	2014	55150	17692	55000	2500	1.10	1.95	2096	5.44E-04	0.20	103.6	83.0
38	0.38	4495	52650	2500	54	1606	0.28	38	6	79.9	0.20	1974	55150	17692	30000	1500	1.10	1.93	2165	5.24E-04	0.19	109.7	83.0
38	0.28	3180	52650	2500	54	1136	0.20	38	7	86.0	0.19	1895	55150	17692	0	0	1.10	1.91	2051	5.16E-04	0.20	106.8	83.0
38	0.20	2250	52650	2500	54	804	0.15	38	8	83.1	0.20	1857	55150	17692	0	0	1.09	1.88	1841	4.83E-04	0.19	103.9	83.0
38	0.15	1592	52650	2500	54	569	0.11	38	9	80.2	0.19	1727	55150	17692	0	0	1.09	1.85	1590	4.36E-04	0.18	101.0	83.0
38	0.11	1126	52650	2500	54	402	0.09	38	10	77.3	0.18	1547	55150	17692	0	0	1.09	1.83	1333	3.84E-04	0.16	98.1	83.0
38	0.09	797	52650	2500	54	285	0.07	38	11	74.4	0.16	1348	55150	17692	0	0	1.09	1.80	1090	3.30E-04	0.15	95.2	83.0
38	0.07	564	52650	2500	54	201	0.05	38	12	71.5	0.15	1147	55150	17692	0	0	1.09	1.78	873	2.80E-04	0.14	92.3	83.0
38	0.05	399	52650	2500	54	142	0.04	38	13	68.6	0.14	957	55150	17692	0	0	1.09	1.77	685	2.34E-04	0.12	89.4	83.0
38	0.04	282	52650	2500	54	101	0.04	38	14	65.8	0.12	784	55150	17692	0	0	1.09	1.75	528	1.94E-04	0.11	86.5	83.0
38	0.04	200	52650	2500	54	71	0.03	38	15	62.9	0.11	632	55150	17692	0	0	1.09	1.74	400	1.59E-04	0.10	83.6	83.0
38	0.03	141	52650	2500	54	50	0.03	38	16	60.0	0.10	502	55150	17692	0	0	1.09	1.73	298	1.30E-04	0.09	80.7	83.0
38	0.03	100	52650	2500	54	36	0.03	38	17	57.1	0.09	392	55150	17692	0	0	1.09	1.72	217	1.06E-04	0.09	77.8	83.0
38	0.03	71	52650	2500	54	25	0.02	38	18	54.2	0.09	302	55150	17692	0	0	1.09	1.72	156	8.66E-05	0.08	74.9	83.0
38	0.02	50	52650	2500	54	18	0.02	38	19	51.3	0.08	229	55150	17692	0	0	1.09	1.71	110	7.10E-05	0.08	72.0	83.0
38	0.02	35	52650	2500	54	13	0.02	38	20	48.4	0.08	171	55150	17692	0	0	1.09	1.71	76	5.89E-05	0.07	69.1	83.0
38	0.02	25	52650	2500	54	9	0.02	38	21	45.5	0.07	125	55150	17692	0	0	1.09	1.70	51	4.96E-05	0.07	66.3	83.0
38	0.02	18	52650	2500	54	6	0.02	38	22	42.6	0.07	90	55150	17692	0	0	1.09	1.70	34	4.25E-05	0.07	63.4	83.0
38	0.02	13	52650	2500	54	4	0.02	38	23	39.7	0.07	64	55150	17692	0	0	1.09	1.70	22	3.73E-05	0.07	60.5	78.8
38	0.02	9	52650	2500	54	3	0.02	38	24	38.0	0.07	44	55150	17692	0	0	1.09	1.70	15	3.36E-05	0.07	58.8	72.8
38	0.02	6	52650	2500	54	2	0.02	38	25	38.0	0.07	30	55150	17692	0	0	1.09	1.70	10	3.10E-05	0.07	58.8	72.8
38	0.02	4	52650	2500	54	2	0.02	38	26	38.0	0.07	21	55150	17692	0	0	1.09	1.70	7	2.93E-05	0.07	58.8	72.8
38	0.02	3	52650	2500	54	1.12	0.02	38	27	38.0	0.07	14	55150	17692	0	0	1.09	1.70	5	2.81E-05	0.07	58.8	72.8
38	0.02	2	52650	2500	54	0.79	0.02	38	28	38.0	0.07	10	55150	17692	0	0	1.09	1.70	3	2.73E-05	0.06	58.8	72.8
38	0.02	2	52650	2500	54	0.56	0.02	38	29	38.0	0.06	7	55150	17692	0	0	1.09	1.70	2	2.67E-05	0.06	58.8	72.8
38	0.02	1	52650	2500	54	0.40	0.02	38	30	38.0	0.06	5	55150	17692	0	0	1.09	1.70	2	2.64E-05	0.06	58.8	72.8
38	0.02	1	52650	2500	54	0.09	0.02	12	31	38.0	0.06	3.23	146410	17692	0	0	1.09	1.77	1.40	1.92E-05	0.05	84.8	83.0
									32	61.1	0.05	1.72	0	17692	52650	2500	1.09	1.75	0.99	2.08E-05	0.05	81.9	83.0
									33	58.2	0.05	1.29	0	17692	52650	2500	1.09	1.73	0.70	2.20E-05	0.06	79.0	83.0
									34	55.3	0.06	0.95	0	17692	52650	2500	1.09	1.72	0.48	2.30E-05	0.06	76.1	83.0
									35	52.4	0.06	0.69	0	17692	52650	2500	1.09	1.72	0.33	2.37E-05	0.06	73.2	83.0
	TOTALS		1779200	83500									TOTALS	619225	1625600	78500							

Key Words:
Tank 48H
Tetraphenylborate
Benzene

Retention:
Permanent

TANK 48H DISPOSITION IN-SITU DECISION

CBU-SPT-2004-00244

APPROVED for Release for
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6/27/2005

OCTOBER 21, 2004

Westinghouse Savannah River Company
Savannah River Site
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Prepared for the U.S. Department of Energy Under Contract Number DE-AC09-96SR18500

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1.0 SUMMARY

Tank 48H currently contains ~250,000 gallons of salt solution containing 19,000 Kg[1] of potassium and cesium tetraphenylborate (TPB) salts generated during the In-Tank Precipitation (ITP) Process demonstrations. The organic nature of TPB salts makes the Tank 48H waste incompatible with the existing High Level Waste (HLW) treatment and disposition facilities. Due to the need for additional HLW storage space, successful disposition of the material in Tank 48H and return of the tank to routine service is essential.

The evaluation of alternative methods for disposition of the TPB in Tank 48H[2,3] resulted in the recommendation of two options:

1) Aggregation of material from Tank 48H with Defense Waste Processing Facility (DWPF) recycle and subsequent disposal in the Saltstone Processing Facility (SPF)
2) In-Situ Thermal Decomposition using heat in combination with pH reduction and catalyst addition.

The evaluation further stated that "the selected strategies are not without risk, and will require additional evaluations and testing before a completely defined disposition plan can be finalized."

The Research and Development (R&D) testing necessary to support operating conditions and Safety Basis (SB) input definition was conducted for the In Situ Decomposition option. The testing identified the following conclusions for the Tank 48H material:

- Nitric acid addition for pH adjustment to a pH of 11 resulted in, at most, 6% destruction of insoluble TPB species;
- Elevating the temperature to as high as 75 °C and lowering the pH as low as 11 are not enough to initiate significant, sustained TPB destruction;
- Unacceptably high rates of decomposition – as high as ~220 mg/(L-hr) of KTPB– occurred for experiments at 75 °C, pH of ~11, and 26 mg/L added palladium, however, these reactions essentially ceased after destroying 25-30% of the TPB;
- Most experiments resulted in negligible reaction with rates <0.0554 mg/(L-hr) destruction of KTPB (by gammascan measurement);
- The presence of additional components (mercury, NaTPB, 2PB, etc) did not provide an increase in decomposition; and
- Continued additions of palladium solution beyond the 26 mg/L did not increase the amount of decomposition.

Based on the results of the testing, the use of In-Situ Decomposition is eliminated as a Tank 48H TPB disposition option.

2.0 BACKGROUND

Hydrolysis and catalyzed destruction of the organic material within Tank 48H are among the options under investigation. Testing in 2003 focused on thermal and copper catalyzed destruction of the tetraphenylborate as a potential treatment.[4,5] At this stage, testing employed simulants. While some initial tests in 2003 [6] showed almost complete destruction, later stimulant tests in 2004 were unable to duplicate these results.[7] The lack of sufficient reactivity in these tests resulted in a review of the program.[8] The conclusion of the SRNL peer review resulted in testing with palladium (Pd). Pd catalysis of tetraphenylborate slurry is a known method to produce TPB decomposition in high pH solutions.[9] To develop the palladium-catalyzed process for Tank 48H, experimental studies using actual waste were performed based on the In-Situ Benzene Generation Test Matrix (see figure 1).[10]

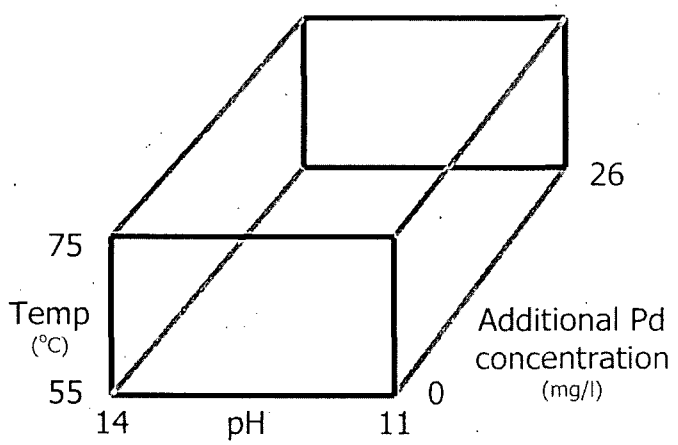

Figure 1. In-Situ Benzene Generation Test Matrix

Prior studies suggest three parameters (i.e., reduction of pH, the addition of palladium, and elevated temperatures) are influential in producing the desired decomposition of TPB. Testing was initiated using Tank 48H actual waste using the parameters of pH (11-14), palladium concentration (0-26 mg/L) and temperature (55°C -75 °C). The goal of the testing was to determine operating parameters and Safety Basis Input information. The initial set of tests was conducted at 75 °C, since previous testing with actual waste did not produce any significant decomposition at temperatures of 55°C and below. The initial set of actual waste tests identified a single reactive condition (75°C, 26 mg/L palladium and pH 11). The initial decomposition rate was as high as ~220 mg/(L-hr), well above the desired reaction rate range of 2-7 mg/(L-hr) of benzene. However, the reaction stopped after destroying 25-30% of the TPB at the 48 hour time mark. All the other tests in the set conducted had no detectable reaction.

The Tank 48 Disposition Project team reviewed the experimental results with the project researchers from the Savannah River National Laboratory (SRNL). Several areas were identified as contributors that would have caused the one reactive test to stop and would be explored further. The conditions that were included in the second set of tests were:

pH	Temp, °C	Added Pd, (mg/L)	Additional components/ comments
11	75	26->78	
11	75	26	No nitrite added (Water added in place of sodium nitrite)
11	75	52	
11	75	26	
14	55	26	Pd added with diphenylmercury
11	55	26	
11	55	26	Added Hg, 2PB, 4PB, C_6H_6
11	65	26	
12	65	13->78	

Using these parameters, additional actual waste tests were conducted to investigate their effect on the process. The only test that showed definitive signs of reactivity was the no nitrite addition tests at pH 11, 75°C, and additional 26 mg/L Pd. In this particular test, water was substituted for the corrosion inhibitor, sodium nitrite, making the test conditions not only lower in total nitrite, but significantly lower in overall ionic strength. A relatively high level of nitrite would be required to process Tank 48H at a temperature of 75°C and still maintain the conditions in the tank within the existing High Level Waste corrosion control program.

Conclusions derived from the testing:

- Nitric acid addition for pH adjustment to a pH of 11 resulted in, at most, 6% destruction of insoluble TPB species;
- Elevating the temperature to as high as 75 °C and lowering the pH as low as 11 are not enough to initiate significant, sustained TPB destruction;
- Unacceptably high rates of decomposition – as high as ~220 mg/(L-hr) of KTPB– occurred for experiments at 75 °C, pH of ~11, and 26 mg/L added palladium; however, these reactions essentially ceased after destroying 25-30% of the TPB;
- Most experiments resulted in negligible reaction with rates <0.0554 mg/(L-hr) destruction of KTPB (by gammascan measurement);
- The presence of additional components (mercury, NaTPB, 2PB, etc) did not provide an increase in decomposition; and
- Continued additions of palladium solution beyond the 26 mg/L did not increase the amount of decomposition.

3.0 CONCLUSION

Based on the results of the testing, the use of In-Situ Decomposition is eliminated as a Tank 48H TPB disposition option.

The specific activities to be taken are:

1. Complete the reports documenting the SRNL activities to date, and
2. Continue the activities for the residual TPB disposition.

WSRC-TR-2004-00422, REV. 0

Key Words: Tetraphenylborate
Benzene
Cesium

Retention: Permanent

APPROVED for Release for
Unlimited (Release to Public)

Benzene Generation Testing for Tank 48H Waste Disposition

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November 16, 2004

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LIST OF ACRONYMS

3PB	triphenylborane
2PB	diphenylborinic acid
1PB	phenylboronic acid
ADS	Analytical Development Section
B	boron
Cs	cesium
CsTPB	cesium tetraphenylborate
DWPF	Defense Waste Processing Facility
HLW	High Level Waste
HPLC	High Performance Liquid Chromatography
ICP-ES	Inductively Coupled Plasma – Emissions Spectroscopy
K	potassium
KTPB	potassium tetraphenylborate
SRS	Savannah River Site
SRNL	Savannah River National Laboratory
SPF	Saltstone Production Facility
TPB	tetraphenylborate
WPTS	Waste Processing Technology Section

1.0 EXECUTIVE SUMMARY

In support for the Aggregation option[1], researchers performed a series of tests using actual Tank 48H slurries. The tests were designed to examine potential benzene generation issues if the Tank 48H slurry is disposed to Saltstone. Personnel used the archived Tank 48H sample (HTF-E-03-127, collected September 17, 2003) for the experiments. The tests included a series of three experiments (Tests A, B, and F) performed in duplicate, giving a total of six experiments. Test A used Tank 48H slurry mixed with ~20:1 with Defense Waste Processing Facility (DWPF) Recycle from Tanks 21H and 22H. Test B used Tank 48H slurry mixed with ~ 2.7:1 with DWPF Recycle from Tanks 21H and 22H, while Test F used Tank 48H slurry as-is. Tests A and B occurred at 45 °C, while Test F occurred at 55 °C.

Over a period of 8 weeks, personnel collected samples for analysis, once per week. Each sample was tested with the in-cell gamma counter. The researchers noted a decline in the cesium activity in solution which is attributed to temperature dependence of the complex slurry equilibrium. Selected samples were sent to ADS for potassium, boron, and cesium analysis. The benzene generation rate was inferred from the TPB destruction which is indirectly measured by the in-growth of cesium, potassium or boron. The results of all the analyses reveal no discernible in-growth of radiocesium, potassium or boron, indicating no significant tetraphenylborate (TPB) decomposition in any of the experiments. From boron measurements, the inferred rate of TPB destruction remained less than 0.325 mg/(L-h) implying a maximum benzene generation rate of <0.332 mg/(L-h).

2.0 INTRODUCTION

Tank 48H currently contains approximately 250,000 gallons of alkaline slurry with potassium and cesium tetraphenylborate (KTPB and CsTPB) from the operation of the In-Tank Precipitation process. This material is not compatible with the waste treatment facilities at Savannah River Site (SRS) and must be removed or undergo treatment to destroy the organic compounds before Tank 48H can be returned to Tank Farm service. Return of the tank to routine service is an essential element for operation of the overall system.

Aggregation is one remediation option for the Tank 48H material.[1] However, personnel identified a technology gap, or risk, in the adequacy of understanding the generation rate for benzene during this proposed option.[2] To mitigate this risk, Salt Engineering authorized ("Benzene Generation Testing for Tank 48H Disposition," SP-TTR-2004-00003) this experimental study using actual waste samples to provide measurements of tetraphenylborate (TPB) decomposition rates and the implied benzene generation rates.[3] SRNL researchers wrote a task plan encompassing the scope of work.[4] This report

details the results of the completed experiments to measure benzene generation rates for this processing option.

3.0 EXPERIMENTAL

Personnel used the archived Tank 48H sample (HTF-E-03-127, collected September 17, 2003) for the experiments.[5] Since collection of the sample, Operations added caustic solution to bring the free hydroxide content of the waste above 1 M. Accordingly, the technicians adjusted the waste slurry used for these tests to approximate the current Tank 48H conditions. The adjustment via the addition of 50 wt % caustic caused an effective 2.7% volume increase of the slurry.

After this initial caustic addition, the Tank 48H slurry was prepared according to the needs of each experiment. The added waste used was primarily from DWPF recycle.[a] As the future composition of the recycle is not known, a composite of samples from Tanks 21H and 22H supernate – which consists primarily of DWPF Recycle material – was used. For Tests A-1 and A-2, personnel mixed 7.5 mL of the Tank 48H slurry with 143 mL of DWPF recycle. In Tests B-1 and B-2, technicians added 55 mL of Tank 48H slurry with 95 mL of DWPF recycle. Tests F-1 and F-2 used 150 mL of the Tank 48H slurry with no other additives. For each of the experiments, a filtrate sample (i.e., well mixed slurry was filtered through a 0.45 μm syringe filter) was pulled after preparing the slurry, and before the bottles were placed in their respective water baths. This sample serves as the time = 0 data point. Table 1 lists the experimental conditions for each of the experiments.

Table 1. List of Experiments and Generic Conditions.

Test ID	TPB Concentration#	pH	Temperature
A	1,000 mg/L	~12.5	45 °C
B	7,500 mg/L	~13.5	45 °C
F	20,600 mg/L	~14	55 °C

The three concentrations represent specific ratios of Tank 48H waste with DWPF Recycle Stream waste: 20,600 mg/L TPB - Tank 48H waste as-is, at full (current) TPB concentration, 7500 mg/L TPB – maximum bounding concentration for aggregation strategy, and 1000 mg/L TPB – minimum reasonable bounding concentration for the aggregation strategy.

During the time of the experiments, the water baths were heated to a constant temperature (±3 °C) with the experiments constantly agitated using a magnetic stirrer.

[a] The DWPF recycle was approximately by volume 50% Tank 21H samples (HTF-571, -572, -573, and -574) and 50% Tank 22H samples (HTF-575, -576, -577, and -578). The samples were received July 2, 2003.

The experiments monitored the decomposition of the organic (KTPB/CsTPB) at elevated temperature over an 8 week period. Sample collection occurred weekly (i.e., 9 total samples per vessel, including the time = 0 sample). Personnel collected filtrate samples, using 0.45 micron or smaller pore size media, for chemical analyses. Chemical analyses included determination of ^{137}Cs concentration – as a measure of decomposition of the CsTPB – using the gamma counter available within the Cells. Selected samples also received potassium analysis by the Analytical Development Section outside the Cells using Inductively Coupled Plasma – Emissions Spectroscopy (ICP-ES). The task plan indicated that personnel would analyze a final slurry sample from the vessels using High Performance Liquid Chromatography (HPLC) to determine the net destruction of TPB during the 8 week period. However, the gamma counts and ICP-ES analyses showed no indication of any reaction, so the HPLC analyses were not performed. The results were recorded into the experimental notebook.[6]

4.0 EXPERIMENTAL RESULTS

4.1 Gamma Count Results

For the six experiments, a total of 9 filtrate samples were pulled for gamma counting. The in-cell gamma counter was used to measure gamma activity. The data is presented in Table 2, while Figure 1 is a graphical display of the data.

Table 2. Gamma Count Results

Time (days)	Cesium-137 Activity (dpm/mL)					
	A-1	A-2	B-1	B-2	F-1	F-2
0 (predicted)	3.03E+06	3.03E+06	1.10E+07	1.10E+07	2.69E+07	2.69E+07
0	8.37E+06	1.43E+07	1.94E+07	1.96E+07	5.26E+07	4.73E+07
7	2.70E+06	3.55E+06	1.19E+07	1.24E+07	3.10E+07	3.37E+07
14	3.13E+06	3.00E+06	1.08E+07	1.06E+07	2.80E+07	2.87E+07
21	2.65E+06	2.21E+06	2.99E+06	2.93E+06	2.60E+07	2.53E+07
28	NA	NA	9.67E+06	6.35E+06	1.78E+07	2.26E+07
35	2.52E+06	2.22E+06	9.98E+06	1.07E+07	2.37E+07	2.62E+07
42	1.95E+06	1.88E+06	8.92E+06	8.79E+06	2.39E+07	2.41E+07
49	2.24E+06	2.06E+06	9.10E+06	8.45E+06	2.37E+07	2.34E+07
56	1.87E+06	1.58E+06	8.98E+06	8.66E+06	2.26E+07	2.35E+07

NA = not available as the background was greater than the sample activity

The initial filtrate activities are higher than predicted. This increased filtrate activity occurs in each of the six experiments. The authors eliminated experimental and

procedural error as a potential reason for this difference and consider the temporary increase to be from an actual physical phenomenon.

Any decomposition of CsTPB would increase the quantity of ^{137}Cs in solution and thus increase the filtrate activity. In each of the experiments, the researchers noted a decline in ^{137}Cs activity over time. The decrease in activity does not indicate the formation of TPB. At time = 35 days, the ^{137}Cs activity in each experiment stabilized at approximately the predicted activity (Figure 1). In Figure 1, the short dashed lines indicate the predicted filtrate cesium activity for each experiment. The decline in cesium activity for the experiments is likely caused by the temperature dependence of the complex equilibrium from dissolution of potassium and cesium tetraphenylborate during heating (i.e., the initial data point was taken at ~20 °C). Due to the differing solubility and relative masses of both species, when the slurries warm to reaction temperature, the increase in TPB concentration from KTPB dissolution (i.e., more soluble than CsTPB) in solution promotes precipitation of CsTPB, thus lowering the amount of cesium in solution.[7]

Between the initial high cesium results and the decline in filtrate activity, a concern exists that the decline in activity may mask – or hide – some TPB destruction. However, the boron data corroborates the cesium data in that both measurements indicate no detectable TPB destruction. Although the potassium data has larger uncertainty during periods of the experiment, the measured values also corroborate the cesium data implying negligible TPB destruction. As all three analytical methods give the same conclusion, the composite dataset indicates that there is no TPB destruction that is being masked by the decline in cesium activity.

From the portion of the gammascan data that had stabilized (35 to 56 days), the researchers calculated the minimum detectable rate for the average of each test (A, B, F). At the end of 56 days, the minimum detectable rate for each experiment exceeded the difference between any of the data points, even accounting for the analytical uncertainty. The gamma count results for all experiments indicate negligible decomposition of CsTPB occurred.

From the portion of the gammascan data that had stabilized (35 to 56 days), SRNL calculated the rates of reaction. As a comparison, researchers calculated the minimum detectable decomposition rate for the average of each test. The minimum detectable rate represents the rate below which, decomposition cannot be distinguished from analytical noise. The minimum detectable decomposition rate is determined for each experiment by taking the starting data point, and increasing the % destruction value by the 2σ analytical uncertainty (1.93 %).[b] This new value is then assigned to a new point at the end of the experiment (56 days). For example, for the average of experiment A-1 and A-2, the time

[b] The uncertainty was calculated from the deviation of the standards over time and was calculated to be 1.93%.

= 0 data point is 2.32E+06 dpm/mL. The new data point is assigned an activity of 2.36E+06 dpm/mL (2.32E+06 × 1.0193). Experiments A-1 and A-2 ran for 504 hours (21 days × 24 hours/day), so the new data point is set to time = 504 hours. From the starting time (35 days) data point and the new data point (56 days), a line is drawn. This line represents the minimum detectable rate over the time of the experiment. The minimum detectable rate is determined for the average of each pair of experiments; A, B, and F. The minimum detectable rate is then compared to the data points that determine the rate. In the case of our experiments, all the data points of A, B, and F lie beneath the line representing the minimum detectable rate (Table 3). Therefore, we can determine that if any TPB decomposition is occurring, it is at a level beneath what we can detect.

Table 3. Reaction Rates as a Function of Gamma Scan Data

Experiment	Benzene Generation Rate (mg/(L-hour))	TPB Destruction Rate (mg/(L-hour))
Average A	<7.95E-03	<8.11E-03
Average B	<3.52E-02	<3.59E-02
Average F	<8.55E-02	<8.72E-02

4.2 ICP-ES Results for Potassium and Boron

Researchers analyzed selected samples via ICP-ES. For each experiment, we analyzed the Day 0, 6, and 85 samples. While the gamma scan analyses stopped at 56 days, we pulled samples at day 85 for ICPES analyses. We also examined the Day 28 samples for experiments F-1 and F-2. The task plan specified analysis of final ICP-ES samples, which are the time 85 samples. Table 4 contains the tabular data and Figures 2 and 3 contain the graph of those data points.

The large variances in the potassium data [c] make a detailed conclusion difficult; however, a lack of potassium in-growth is apparent. This indicates a lack of KTPB decomposition during the reactions.

The boron data presents a much clearer perspective (Figure 3). With a low uncertainty in each data point (5%), the lack of any in-growth indicates a lack of any reaction. In the figure, the data points in experiment A-2 are obscured by the A-1 data points.

The Minimum detectable rate was determined from boron data in the same fashion as with the gamma scan data. The starting point is the Day 6 sample, and the end is the Day 85 sample. The time 0 data point is omitted from the plot as the increase in boron across 5 of 6 experiments looks to be a function of increased solubility due to the solution

[c] Most of the potassium data points were either below detection limits or close to it.

temperature increase at that time.[d] The resulting line shows greater slopes than the comparable experimental data. Test F-1 has a final data point that could surpass the minimal detectable rate if adding the uncertainty. However, the average of the two F data points still is less than the minimal detection limit. Therefore, we can determine that if any TPB decomposition is occurring, it is at a level beneath what we can detect.

Table 4. Potassium and Boron Results

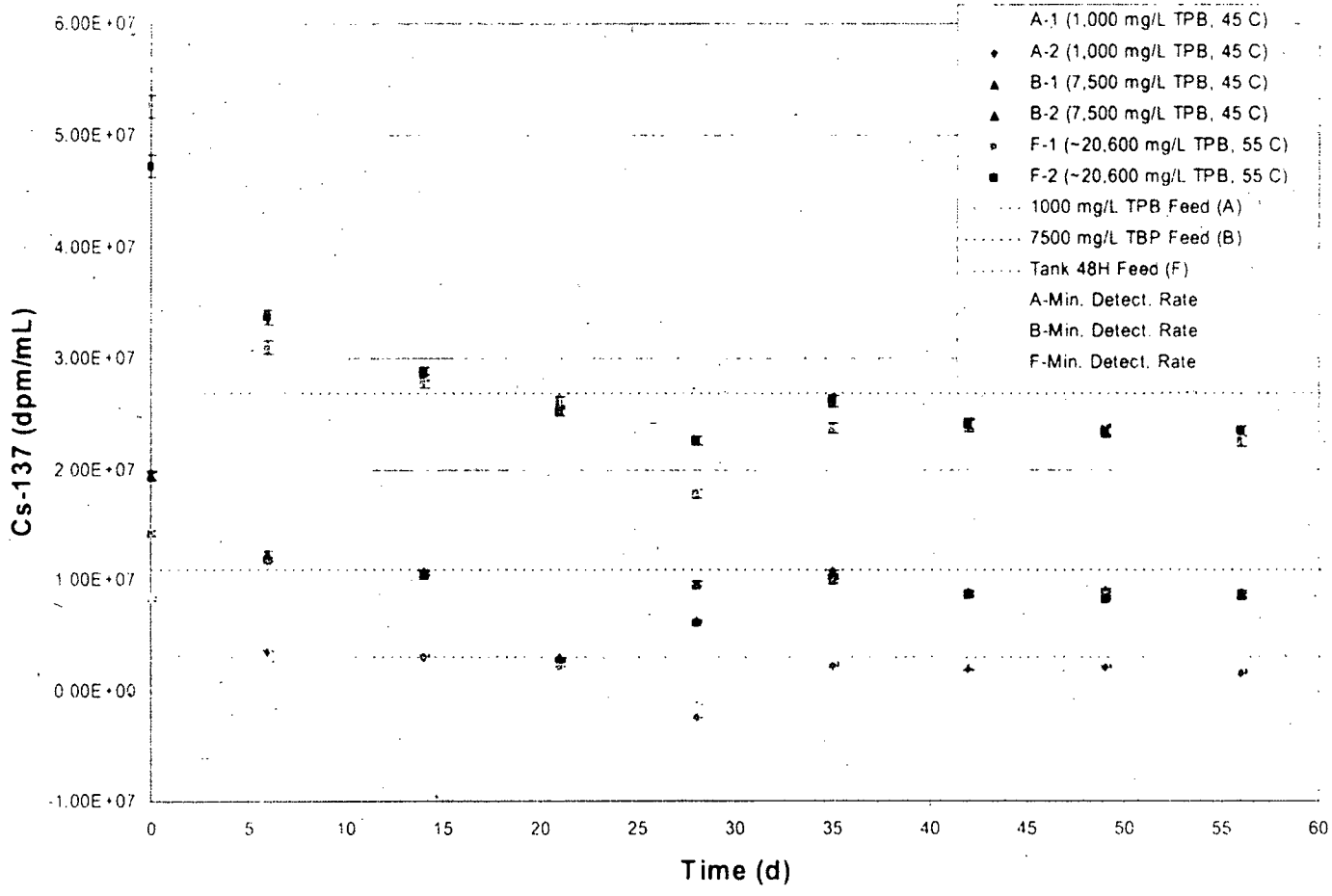
Sample ID	Time (days)	Potassium (mg/L)	Uncertainty (mg/L)	Boron (mg/L)	Uncertainty (mg/L)
A-1	0	52.7	35.3	26.1	1.31
	6	< 167	NA	33.9	1.69
	85	27.8	5.56	29.5	1.48
A-2	0	35.1	37.2	25.7	1.29
	6	< 177	NA	34.6	1.73
	85	30.9	6.18	31.0	1.55
B-1	0	199	43.7	173	8.67
	6	209	328	188	9.39
	85	96.1	19.2	132	6.60
B-2	0	193	44.4	184	9.21
	6	< 168	NA	182	9.10
	85	99.7	19.9	165	8.25
F-1	0	283	289	425	21.2
	6	219	343	432	21.6
	28	296	237	424	21.2
	85	264	52.8	430	21.5
F-2	0	336	138	407	20.4
	6	269	323	420	21.0
	28	251	244	418	20.9
	85	267	53.4	413	20.7

[d] The time=0 sample was taken at room temperature, before the water bath had heated to temperature.

Table 5. Reaction Rates as a Function of Boron Data

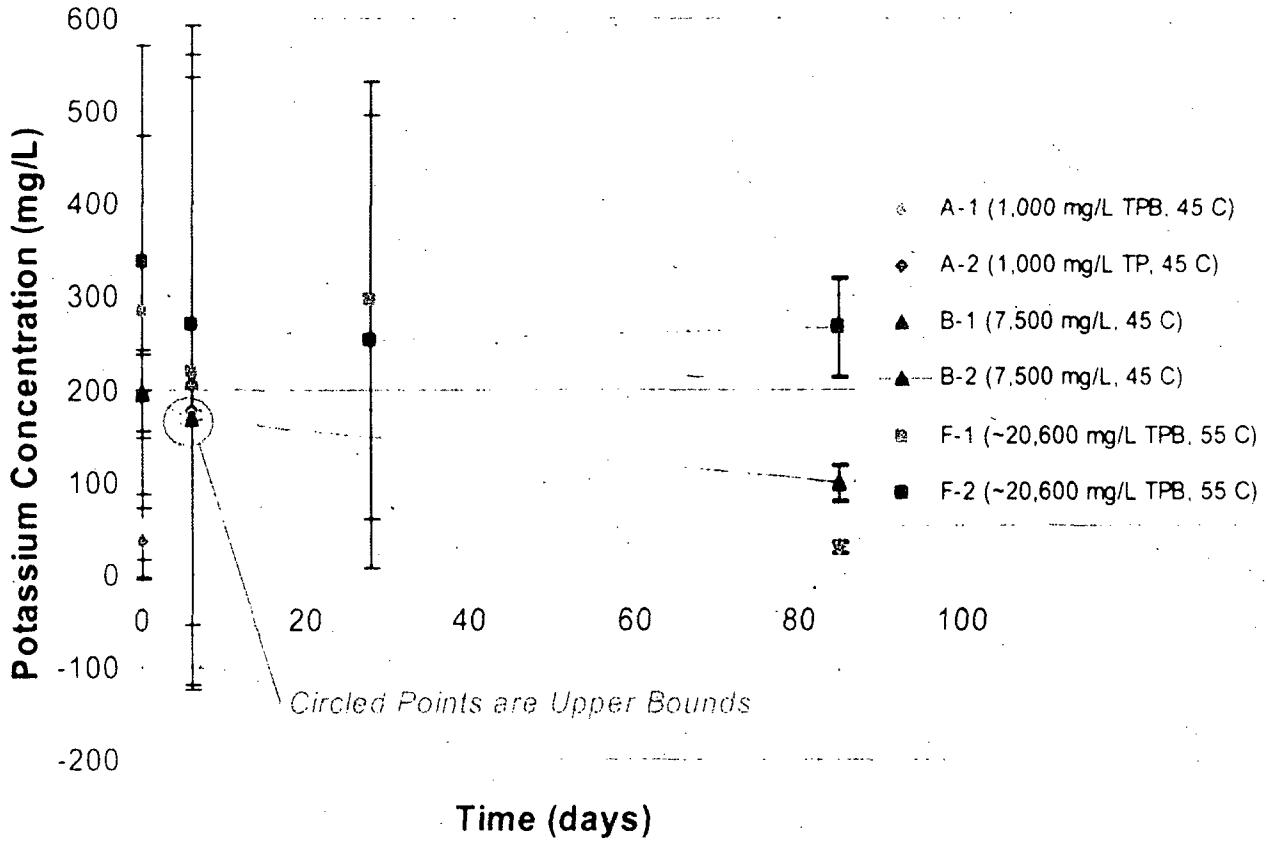
Experiment	Benzene Generation Rate (mg/(L-hour))	TPB Destruction Rate (mg/(L-hour))
Average A	<2.61E-02	<2.66E-02
Average B	<1.41E-01	<1.44E-01
Average F	<3.25E-01	<3.32E-01

Figure 1. Graph of Gamma Scan Data



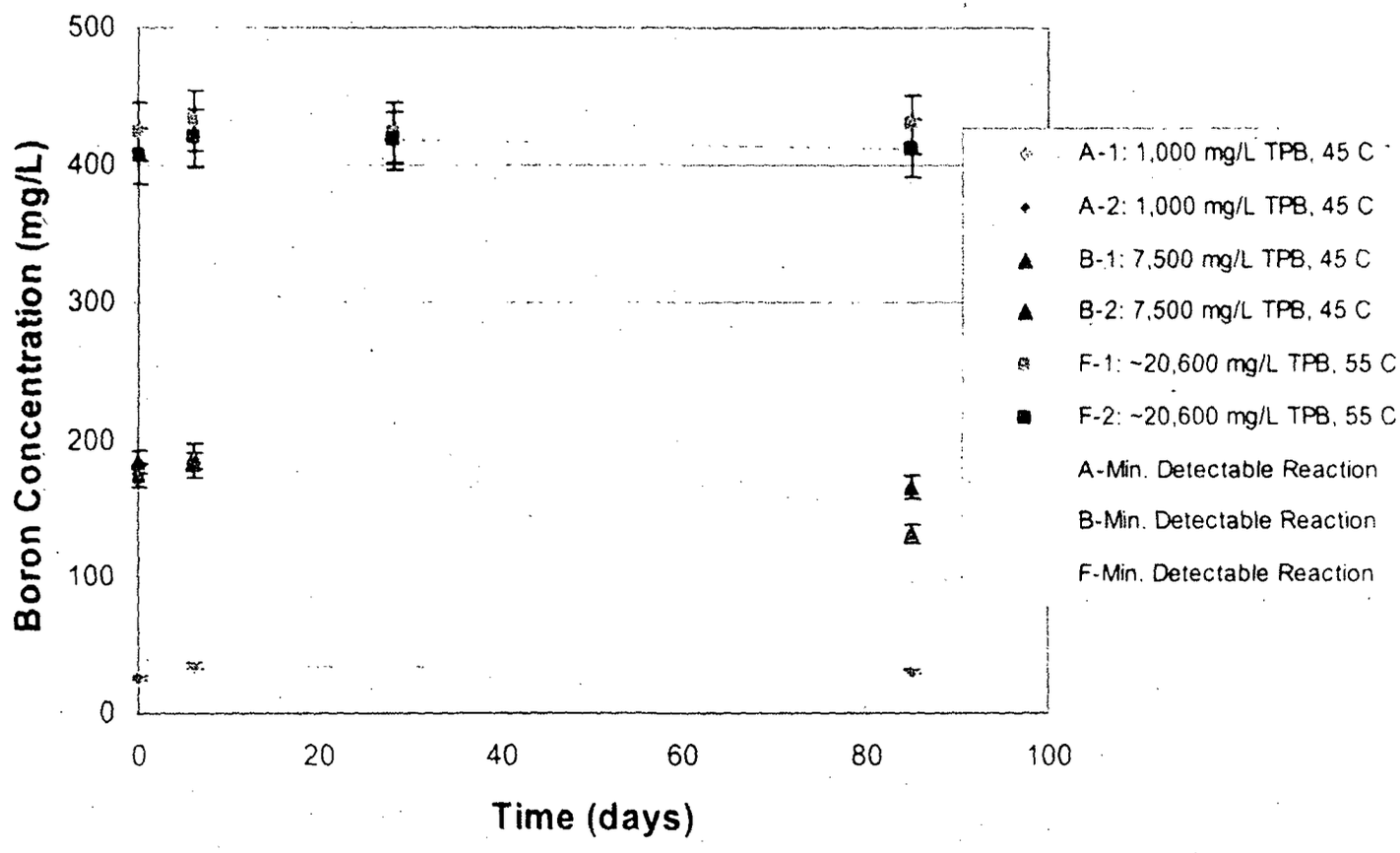
Time=0 data point is at room temperature.

Figure 2. Graph of Potassium Data



Time=0 data point is at room temperature.

Figure 3. Graph of Boron Data



The analytical uncertainty of the boron measurements is 5% for all data points. Time=0 data point is at room temperature.

5.0 CONCLUSIONS

SRNL performed duplicate experiments at three different ratios of Tank 48H added to DWPF Recycle waste designed to determine if Tank 48H slurries at elevated temperatures would rapidly decompose the CsTPB and KTPB. This reaction, in turn, could generate benzene at too high a rate to handle safely. The added waste, when used, came from DWPF Recycle samples collected from Tanks 21H and 22H. In all three experiments, the TPB decomposition proved negligible, as determined by measurement of changes in concentration of ^{137}Cs, boron or potassium. The researchers noted a decline in the cesium activity in solution which is attributed to the increase in temperature (increase in temperature brings more TPB into solution which causes CsTPB to precipitate). Data from this work indicates that Tank 48H slurries, under these reaction conditions, even when mixed with DWPF recycle, exhibit negligible reaction at elevated temperatures of 45-55 °C for approximately 3 months.

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WSRC-TR-2004-00505, REV. 0

Key Words: Tetraphenylborate
Benzene
Cesium

Retention: Permanent

Operability Window Tests Using Tank 48H Samples

T. B. Peters
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November 17, 2004

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Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

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Prepared for the U.S. Department of Energy Under
Contract Number DE-AC09-96SR18500

CBU-PIT-2005-00138
Rev. 0
June 14, 2005

KEYWORDS:
Waste Characterization Report
Radionuclides

RETENTION: PERMANENT
CLASSIFICATION: NA
Does not Contain UCNI

Tank Radionuclide Inventories

H. Q. Tran

APPROVED for Release for
Unlimited (Release to Public)

Westinghouse Savannah River Company
Closure Business Unit
Planning Integration & Technology Department
Aiken, SC 29808

Prepared for U.S. Department of Energy Under Contract No. DE-AC09-96S

Table 4: Dry Sludge Radioisotope Inventory by Tank

Tank	Sludge Volume, gal	H-3 (Ci)	C-14 (Ci)	Co-60 (Ci)	Ni-59 (Ci)	Ni-63 (Ci)	Se-79 (Ci)	Sr-90 (Ci)	Y-90 (Ci)	Nb-94 (Ci)	Tc-99 (Ci)	Ru-106 (Ci)	Rh-106 (Ci)	Sb-125 (Ci)	Sn-126 (Ci)	I-129 (Ci)	Cs-134 (Ci)	Cs-135 (Ci)	Cs-137 (Ci)
1	7.05E+03	-	1.20E-02	1.87E+02	2.16E+01	1.77E+03	1.50E+01	5.20E+05	5.20E+05	1.13E-02	2.60E+02	4.48E-06	4.48E-06	1.14E+01	2.80E+01	1.24E-03	1.07E-02	1.74E-01	3.68E+04
2	4.07E+03	-	2.86E-03	1.36E+01	3.37E+00	2.68E+02	2.31E+00	7.11E+04	7.11E+04	1.73E-03	3.99E+01	3.09E-09	3.09E-09	3.34E-01	4.29E+00	1.90E-04	1.60E-04	2.67E-02	5.07E+03
3	4.07E+03	-	2.40E-03	1.50E+01	2.82E+00	2.27E+02	1.93E+00	6.24E+04	6.24E+04	1.45E-03	3.34E+01	2.04E-08	2.04E-08	5.01E-01	3.59E+00	1.59E-04	3.03E-04	2.24E-02	4.44E+03
4	1.27E+05	-	3.34E-03	4.21E+03	1.00E+02	8.77E+03	7.16E+01	3.16E+06	3.16E+06	5.37E-02	1.24E+03	2.09E-01	2.09E-01	1.41E+03	1.33E+02	5.90E-03	4.22E+00	8.29E-01	2.21E+05
5	3.06E+04	-	4.43E-02	1.34E+03	9.82E+01	8.23E+03	6.86E+01	2.58E+06	2.58E+06	5.14E-02	1.19E+03	2.10E-04	2.10E-04	1.25E+02	1.28E+02	5.66E-03	1.56E-01	7.95E-01	1.82E+05
6	2.49E+04	-	-	2.00E+03	9.30E+01	8.01E+03	6.66E+01	2.74E+06	2.74E+06	4.99E-02	1.15E+03	1.30E-03	1.30E-03	2.54E+02	1.24E+02	5.49E-03	3.88E-01	7.71E-01	1.93E+05
7	1.97E+04	-	5.39E-02	1.13E+02	9.73E+00	8.22E+02	4.96E+00	1.84E+05	1.84E+05	3.66E-03	8.58E+01	6.44E-04	6.44E-04	1.81E+01	9.23E+00	4.09E-04	3.62E-02	5.74E-02	1.30E+04
8	4.10E+03	-	1.96E-03	2.80E+01	1.03E+00	8.98E+01	6.62E-01	2.84E+04	2.84E+04	4.94E-04	1.14E+01	2.18E-04	2.18E-04	5.56E+00	1.23E+00	5.45E-05	1.17E-02	7.66E-03	1.99E+03
9	2.71E+03	-	3.09E-03	1.46E+01	3.64E+00	2.89E+02	2.49E+00	7.66E+04	7.66E+04	1.86E-03	4.31E+01	3.27E-09	3.27E-09	3.58E-01	4.63E+00	2.05E-04	1.71E-04	2.88E-02	5.47E+03
10	2.71E+03	-	3.16E-04	1.65E+00	3.72E-01	2.97E+01	2.55E-01	7.98E+03	7.98E+03	1.91E-04	4.41E+00	6.20E-10	6.20E-10	4.46E-02	4.74E-01	2.10E-05	2.28E-05	2.95E-03	5.69E+02
11	1.98E+04	-	2.00E-02	1.30E+03	2.24E+01	1.98E+03	1.24E+01	7.00E+05	7.00E+05	3.14E-03	2.10E+02	3.28E-03	3.28E-03	5.62E+01	1.14E+01	7.28E-04	2.60E+00	1.41E-01	3.86E+04
12	1.43E+05	-	2.51E-01	9.26E+03	2.78E+02	2.39E+04	1.56E+02	7.77E+06	7.77E+06	4.89E-02	2.66E+03	1.05E-03	1.05E-03	2.32E+02	1.61E+02	9.61E-03	7.06E+00	1.78E+00	4.40E+05
13	2.52E+05	-	1.74E-01	5.07E+03	2.60E+02	2.17E+04	1.65E+02	6.92E+06	6.92E+06	7.56E-02	2.82E+03	5.26E-04	5.26E-04	1.24E+02	2.19E+02	1.14E-02	3.27E+00	1.89E+00	4.19E+05
14	2.80E+04	-	1.17E-03	5.56E+01	7.35E+00	5.96E+02	5.05E+00	1.76E+05	1.76E+05	3.38E-03	8.72E+01	7.17E-08	7.17E-08	1.45E+00	8.64E+00	3.97E-04	3.93E-03	5.83E-02	1.19E+04
15	3.12E+05	-	2.25E-01	6.96E+03	2.50E+02	2.13E+04	1.38E+02	6.79E+06	6.79E+06	3.51E-02	2.35E+03	1.67E-03	1.67E-03	1.50E+02	1.27E+02	8.12E-03	4.45E+00	1.57E+00	3.77E+05
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	6.09E+03	-	3.01E-03	1.35E+02	1.03E+00	9.45E+01	7.79E-01	5.43E+04	5.43E+04	1.44E-04	1.34E+01	2.17E-01	2.17E-01	1.28E+01	7.13E-01	4.81E-05	1.28E+00	8.81E-03	3.07E+03
22	9.98E+03	-	-	2.61E+02	2.13E+00	1.96E+02	1.66E+00	1.06E+05	1.06E+05	2.97E-04	2.80E+01	2.47E-03	2.47E-03	2.21E+01	1.51E+00	9.70E-05	1.29E+00	1.87E-02	5.80E+03
23	5.61E+04	-	-	3.72E-01	-	-	-	-	-	-	-	-	-	-	-	-	1.12E-02	-	4.23E+02
24	3.54E+03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	2.59E+05	-	5.46E-01	9.31E+02	3.21E+01	3.14E+03	2.66E+00	1.72E+05	1.72E+05	1.41E-03	4.61E+01	6.59E+01	6.59E+01	1.24E+03	4.93E+00	2.19E-04	9.94E+00	3.08E-02	1.18E+04
27	3.86E+03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	6.32E+02	-	7.80E-04	3.20E+02	8.56E-01	8.41E+01	4.71E-01	3.81E+04	3.81E+04	1.20E-04	7.98E+00	1.93E-01	1.93E-01	6.23E+01	4.31E-01	2.76E-05	7.26E+00	5.33E-03	2.06E+03
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	9.85E+04	-	2.45E-01	3.51E+04	2.70E+02	2.48E+04	1.49E+02	9.56E+06	9.56E+06	3.79E-02	2.53E+03	1.22E+01	1.22E+01	4.19E+03	1.36E+02	8.74E-03	4.30E+02	1.69E+00	5.23E+05
33	8.42E+04	-	1.25E-01	5.00E+04	1.65E+02	1.63E+04	1.13E+02	7.62E+06	7.62E+06	8.47E-02	1.96E+03	3.94E+03	3.94E+03	8.24E+04	2.10E+02	9.32E-03	7.22E+02	1.31E+00	5.20E+05
34	2.02E+04	-	-	3.26E+04	1.66E+02	1.61E+04	1.19E+02	7.37E+06	7.37E+06	8.92E-02	2.06E+03	2.22E+02	2.22E+02	3.23E+04	2.21E+02	9.80E-03	1.97E+02	1.38E+00	5.06E+05
35	6.32E+04	-	2.03E-01	3.99E+04	2.23E+02	2.10E+04	1.23E+02	8.55E+06	8.55E+06	3.12E-02	2.08E+03	1.41E+01	1.41E+01	4.82E+03	1.12E+02	7.18E-03	4.67E+02	1.39E+00	4.65E+05
36	1.86E+02	-	2.34E-04	3.42E+01	2.57E-01	2.39E+01	1.41E-01	9.45E+03	9.45E+03	3.60E-05	2.39E+00	2.82E-04	2.82E-04	2.56E+00	1.29E-01	8.28E-06	1.57E-01	1.60E-03	5.16E+02
37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39	1.04E+05	-	2.40E-01	1.24E+05	2.64E+02	2.60E+04	1.46E+02	1.20E+07	1.20E+07	3.70E-02	2.47E+03	2.48E+03	2.48E+03	4.10E+04	1.33E+02	8.54E-03	7.75E+03	1.65E+00	6.46E+05
40	4.39E+05	-	5.26E-01	2.39E+03	1.46E+02	1.23E+04	8.35E+01	3.28E+06	3.23E+06	5.77E-02	1.44E+03	2.15E+00	1.31E-02	3.11E+02	1.47E+02	6.68E-03	2.50E+00	9.64E-01	2.25E+05
41	2.67E+03	-	-	4.78E+01	2.07E-01	1.97E+01	1.61E-01	1.17E+04	1.17E+04	2.89E-05	2.72E+00	3.10E-03	3.10E-03	6.80E+00	1.47E-01	9.43E-06	5.49E-01	1.82E-03	6.33E+02
42	1.76E+04	-	1.96E-02	3.33E+02	1.07E+01	9.20E+02	5.74E+00	2.87E+05	2.87E+05	1.44E-03	9.72E+01	1.05E-03	1.05E-03	1.24E+01	5.30E+00	3.38E-04	5.51E-01	6.50E-02	1.59E+04
43	2.42E+05	-	1.95E-02	1.85E+04	3.43E+01	3.41E+03	2.18E+01	1.84E+06	1.84E+06	4.80E-03	3.69E+02	9.73E+01	9.73E+01	5.63E+03	1.99E+01	1.28E-03	8.81E+02	2.47E-01	9.90E+04
44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
47	2.48E+05	-	4.32E-01	5.43E+02	2.54E+01	2.45E+03	2.10E+00	1.30E+05	1.30E+05	1.11E-03	3.65E+01	1.18E+00	1.18E+00	4.63E+02	3.90E+00	1.73E-04	2.44E+00	2.43E-02	8.91E+03
48	1.81E+04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	1.39E+05	-	1.54E-01	8.68E+03	1.48E+02	5.69E+03	8.22E+01	4.60E+06	4.60E+06	1.03E-02	1.39E+03	1.52E-01	2.67E-02	3.91E+02	7.78E+01	4.88E-03	1.86E+01	9.32E-01	2.55E+05
Phase Totals	2.80E+06	-	3.31E+00	3.44E+05	2.64E+03	2.30E+05	1.56E+03	8.74E+07	8.74E+07	6.99E-01	2.67E+04	6.83E+03	6.83E+03	1.75E+05	2.04E+03	1.07E-01	1.05E+04	1.79E+01	5.24E+06

Table 4: Dry Sludge Radioisotope Inventory by Tank, continued

Tank	Sludge Volume, gal	Ba-137m (Ci)	Ce-144 (Ci)	Pr-144 (Ci)	Pm-147 (Ci)	Eu-154 (Ci)	Th-232 (Ci)	U-232 (Ci)	U-233 (Ci)	U-234 (Ci)	U-235 (Ci)	U-236 (Ci)	U-238 (Ci)	Np-237 (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Pu-241 (Ci)	Pu-242 (Ci)
1	7.05E+03	3.48E+04	4.72E-09	4.72E-09	1.58E+02	8.69E+02	-	1.14E-02	-	-	1.76E-02	-	4.39E-01	6.41E-01	4.97E+02	1.33E+02	2.97E+01	1.63E+02	6.12E-03
2	4.07E+03	4.80E+03	4.35E-13	4.35E-13	4.27E+00	8.82E+01	-	1.69E-03	-	-	8.12E-04	-	2.02E-02	2.12E-01	1.38E+02	1.98E+01	4.42E+00	1.85E+01	9.08E-04
3	4.07E+03	4.20E+03	7.13E-12	7.13E-12	6.59E+00	8.64E+01	-	1.44E-03	-	-	2.03E-03	-	5.06E-02	3.78E-01	1.66E+02	2.38E+01	5.31E+00	2.69E+01	1.09E-03
4	1.27E+05	2.09E+05	3.76E-03	3.76E-03	2.27E+04	9.86E+03	-	5.92E-02	-	-	7.77E-02	-	3.34E+00	2.98E+00	6.05E+02	5.98E+02	1.34E+02	1.13E+03	2.75E-02
5	3.06E+04	1.72E+05	4.13E-07	4.13E-07	1.79E+03	5.20E+03	-	5.38E-02	-	-	1.05E-01	-	2.48E+00	4.19E+00	2.89E+03	4.82E+02	1.15E+02	7.71E+02	3.40E-02
6	2.49E+04	1.82E+05	4.73E-06	4.73E-06	3.75E+03	6.64E+03	-	5.38E-02	-	-	6.65E-02	-	2.49E+00	8.63E-01	-	2.55E+02	8.84E+01	9.93E+02	1.74E-01
7	1.97E+04	1.23E+04	1.03E-05	1.03E-05	2.75E+02	3.85E+02	-	4.36E-03	-	-	2.04E-02	-	7.06E-01	3.51E-01	1.72E+03	3.10E+02	7.61E+01	7.28E+02	7.05E-02
8	4.10E+03	1.88E+03	3.62E-06	3.62E-06	8.53E+01	7.86E+01	-	5.63E-04	-	-	1.49E-03	-	6.84E-02	3.11E-02	8.90E+01	1.95E+01	4.60E+00	4.38E+01	5.80E-03
9	2.71E+03	5.17E+03	4.56E-13	4.56E-13	4.58E+00	9.49E+01	-	1.82E-03	-	-	1.18E-03	-	2.94E-02	2.01E-01	4.37E+01	6.24E+00	1.39E+00	5.79E+00	2.87E-04
10	2.71E+03	5.38E+02	1.13E-13	1.13E-13	5.75E-01	1.03E+01	-	1.87E-04	-	-	2.28E-04	-	5.69E-03	4.35E-02	2.21E+01	3.16E+00	7.06E-01	3.14E+00	1.45E-04
11	1.98E+04	3.65E+04	2.93E-04	2.93E-04	1.43E+03	6.73E+03	2.00E-03	-	2.85E-01	2.34E-01	4.41E-03	3.61E-02	8.17E-03	1.54E-01	2.09E+04	2.07E+02	1.30E+02	7.46E+03	2.77E-01
12	1.43E+05	4.16E+05	1.87E-05	1.87E-05	5.57E+03	5.78E+04	1.36E+00	1.37E-02	3.83E+01	3.58E+00	6.74E-02	2.84E-01	6.79E-01	7.94E+00	1.38E+05	2.32E+03	1.28E+03	3.25E+04	1.85E+00
13	2.52E+05	3.97E+05	1.06E-05	1.06E-05	2.82E+03	3.66E+04	1.98E-01	5.27E-02	4.06E+01	5.73E+00	1.57E-01	5.91E-01	1.83E+00	1.47E+01	5.39E+04	1.46E+03	6.03E+02	1.06E+04	4.00E-01
14	2.80E+04	1.13E+04	1.33E-10	1.33E-10	2.09E+01	3.92E+02	1.06E-02	3.14E-03	3.74E-01	5.13E-02	4.15E-03	4.41E-03	7.91E-02	5.48E-01	2.45E+02	6.04E+01	1.95E+01	9.88E+01	3.57E-03
15	3.12E+05	3.57E+05	1.29E-04	1.29E-04	3.60E+03	4.79E+04	1.13E+00	-	1.39E+01	3.79E+00	6.12E-02	3.59E-01	1.40E-03	3.55E+00	5.70E+04	1.22E+03	5.90E+02	1.22E+04	4.45E-01
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	6.09E+03	2.90E+03	3.09E-01	1.89E-04	3.60E+03	6.61E+02	5.67E-06	-	1.79E-01	1.91E-01	3.03E-03	3.50E-02	1.79E-02	1.58E-01	9.51E+02	1.40E+01	4.76E+00	8.35E+01	5.33E-04
22	9.98E+03	5.49E+03	1.99E-04	1.99E-04	5.78E+02	1.34E+03	-	-	1.07E+00	3.86E-01	5.91E-03	6.36E-02	1.31E-01	2.35E-01	1.59E+03	-	-	-	-
23	5.61E+04	4.00E+02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	3.54E+03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	2.59E+05	1.11E+04	3.11E+01	3.11E+01	2.25E+04	1.14E+03	-	8.82E-03	2.69E-08	8.57E-08	2.54E-02	3.27E-03	3.04E+00	7.85E-03	1.62E+04	2.54E+03	5.68E+02	1.34E+04	1.13E-01
27	3.86E+03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	6.32E+02	1.95E+03	6.72E-02	6.72E-02	1.78E+03	7.98E+02	-	-	-	1.83E-02	3.25E-04	3.37E-03	1.20E-05	8.25E-03	3.52E+03	3.06E+01	2.20E+01	2.26E+03	5.26E-02
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	9.85E+04	4.94E+05	4.96E+00	4.96E+00	1.17E+05	1.26E+05	-	-	-	2.77E+00	3.97E-02	6.22E-01	1.86E-02	1.15E+00	4.02E+05	3.53E+03	2.62E+03	1.80E+05	5.53E+00
33	8.42E+04	4.92E+05	1.32E+03	1.32E+03	1.51E+06	5.59E+04	-	1.12E-01	5.39E-07	1.11E-02	2.09E-01	1.16E-01	3.02E+01	9.48E+00	1.55E+04	8.44E+03	1.48E+03	4.40E+04	8.57E-02
34	2.02E+04	4.78E+05	2.95E+01	2.95E+01	5.68E+05	4.46E+04	-	1.13E-01	-	-	1.14E-01	-	8.05E+00	6.22E+00	-	1.30E+03	2.91E+02	6.01E+03	6.03E-02
35	6.32E+04	4.40E+05	7.21E+00	7.21E+00	1.34E+05	1.31E+05	-	-	-	2.72E+00	4.72E-02	8.02E-01	2.79E-02	9.83E-01	4.07E+05	3.29E+03	2.52E+03	1.96E+05	5.66E+00
36	1.86E+02	4.88E+02	1.91E-05	1.91E-05	6.76E+01	1.29E+02	-	-	-	7.26E-03	1.41E-04	2.56E-03	4.60E-05	2.03E-03	6.29E+02	4.90E+00	3.90E+00	2.55E+02	8.42E-03
37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39	1.04E+05	6.11E+05	4.44E+03	4.44E+03	1.24E+06	2.71E+05	-	-	-	1.12E+01	1.62E-01	1.93E+00	3.42E-02	7.05E+00	6.25E+05	7.78E+03	4.83E+03	5.55E+05	1.03E+01
40	4.39E+05	2.10E+05	9.04E-01	4.22E-04	5.05E+03	1.29E+04	5.67E-02	6.30E-02	1.61E+00	1.55E+00	2.93E-01	3.87E-01	9.17E+00	3.20E+01	2.93E+04	9.45E+03	3.58E+03	5.03E+04	1.81E+00
41	2.67E+03	5.99E+02	4.25E-04	4.25E-04	1.86E+02	1.92E+02	-	-	-	1.23E-02	1.43E-04	3.54E-03	9.78E-06	3.69E-02	2.02E+02	-	-	-	-
42	1.76E+04	1.51E+04	9.41E-05	9.41E-05	3.06E+02	2.15E+03	4.36E-02	1.54E-04	6.14E-01	2.26E-01	5.33E-03	3.02E-02	9.35E-02	1.86E-01	2.94E+03	1.05E+02	3.76E+01	6.43E+02	3.44E-02
43	2.42E+05	9.37E+04	8.95E+01	8.95E+01	1.67E+05	4.32E+04	-	-	-	3.41E+00	4.70E-02	6.49E-01	3.82E-03	3.63E+00	8.26E+04	3.26E+02	2.75E+02	7.07E+04	4.06E+00
44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
47	2.48E+05	8.43E+03	8.35E-02	8.35E-02	8.00E+03	7.67E+02	-	6.86E-03	-	-	1.86E-02	-	1.48E+00	-	1.58E+04	2.26E+03	5.06E+02	9.84E+03	1.04E-01
48	1.81E+04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	1.39E+05	2.41E+05	5.57E-02	2.60E-03	9.94E+03	4.44E+04	1.52E-02	2.22E-03	1.84E+00	1.53E+00	3.99E-02	2.48E-01	3.64E-01	1.24E+00	1.34E+05	1.79E+03	1.01E+03	5.07E+04	1.83E+00
Phase Totals	2.80E+06	4.95E+06	5.92E+03	5.92E+03	3.83E+06	9.09E+05	2.82E+00	5.64E-01	9.87E+01	3.75E+01	1.60E+00	6.17E+00	6.49E+01	9.92E+01	2.01E+06	4.80E+04	2.08E+04	1.25E+06	3.29E+01

Table 4: Dry Sludge Radioisotope Inventory by Tank, continued

Tank	Sludge Volume, gal	Am-241 (Ci)	Am-242m (Ci)	Cm-244 (Ci)	Cm-245 (Ci)	Na-22 (Ci)	Al-26 (Ci)	Te-125m (Ci)	Sb-126 (Ci)	Sb-126m (Ci)	Sm-151 (Ci)	Eu-152 (Ci)	Eu-155 (Ci)	Ra-226 (Ci)	Ra-228 (Ci)	Ac-227 (Ci)	Th-229 (Ci)	Th-230 (Ci)	Pa-231 (Ci)
1	7.05E+03	1.98E+03	2.43E+00	3.51E-01	4.27E-07	7.83E-02	4.13E-02	2.78E+00	3.91E+00	2.80E+01	3.02E+04	1.46E+02	1.71E+03	-	-	4.03E-06	-	-	1.12E-05
2	4.07E+03	3.01E+02	3.64E-01	4.47E-02	6.55E-08	1.08E-02	5.69E-03	8.16E-02	6.01E-01	4.29E+00	4.16E+03	2.01E+01	2.35E+02	-	-	1.85E-07	-	-	5.15E-07
3	4.07E+03	2.55E+02	3.08E-01	4.03E-02	5.49E-08	9.43E-03	4.98E-03	1.22E-01	5.03E-01	3.59E+00	3.64E+03	1.76E+01	2.06E+02	-	-	4.63E-07	-	-	1.29E-06
4	1.27E+05	1.00E+04	1.21E+01	1.59E+04	6.90E-01	4.69E-01	2.48E-01	3.45E+02	1.86E+01	1.33E+02	1.81E+05	8.75E+02	1.02E+04	-	-	1.77E-05	-	-	4.92E-05
5	3.06E+04	9.10E+03	1.13E+01	1.83E+00	1.95E-06	3.87E-01	2.04E-01	3.04E+01	1.79E+01	1.28E+02	1.49E+05	7.22E+02	8.44E+03	-	-	2.39E-05	-	-	6.64E-05
6	2.49E+04	8.96E+03	1.12E+01	1.38E+03	1.89E-06	4.09E-01	2.16E-01	6.21E+01	1.73E+01	1.24E+02	1.58E+05	7.64E+02	8.93E+03	-	-	1.52E-05	-	-	4.21E-05
7	1.97E+04	7.38E+02	7.70E-01	1.01E+03	8.89E-03	2.76E-02	1.46E-02	4.41E+00	1.29E+00	9.23E+00	1.06E+04	5.15E+01	6.01E+02	-	-	4.65E-06	-	-	1.29E-05
8	4.10E+03	1.02E+02	1.10E-01	1.83E+02	3.35E-03	4.22E-03	2.23E-03	1.36E+00	1.72E-01	1.23E+00	1.63E+03	7.89E+00	9.21E+01	-	-	3.39E-07	-	-	9.42E-07
9	2.71E+03	3.20E+02	3.93E-01	4.82E-02	7.07E-08	1.16E-02	6.14E-03	8.75E-02	6.48E-01	4.63E+00	4.48E+03	2.17E+01	2.53E+02	-	-	2.69E-07	-	-	7.47E-07
10	2.71E+03	3.36E+01	4.04E-02	5.07E-03	7.24E-09	1.21E-03	6.39E-04	1.09E-02	6.63E-02	4.74E-01	4.67E+02	2.26E+00	2.64E+01	-	-	5.21E-08	-	-	1.45E-07
11	1.98E+04	1.84E+03	1.15E+00	1.17E+02	7.47E-04	8.20E-02	4.33E-02	1.37E+01	1.59E+00	1.14E+01	3.16E+04	1.53E+02	1.79E+03	5.26E-07	2.00E-03	1.01E-06	8.09E-04	6.44E-05	2.79E-06
12	1.43E+05	1.78E+04	1.56E+01	2.16E+03	8.29E-03	9.34E-01	4.93E-01	5.67E+01	2.25E+01	1.61E+02	3.60E+05	1.74E+03	2.04E+04	8.08E-06	1.36E+00	1.54E-05	1.09E-01	9.89E-04	4.27E-05
13	2.52E+05	1.83E+04	1.93E+01	2.56E+03	5.61E-03	8.91E-01	4.71E-01	3.03E+01	3.06E+01	2.19E+02	3.44E+05	1.66E+03	1.94E+04	1.29E-05	1.98E-01	3.57E-05	1.15E-01	1.58E-03	9.93E-05
14	2.80E+04	6.34E+02	7.52E-01	3.57E-01	4.88E-05	2.54E-02	1.34E-02	3.54E-01	1.21E+00	8.64E+00	9.78E+03	4.73E+01	5.53E+02	1.16E-07	1.06E-02	9.47E-07	1.06E-03	1.41E-05	2.63E-06
15	3.12E+05	1.34E+04	1.25E+01	8.80E+02	8.32E-03	8.01E-01	4.23E-01	3.67E+01	1.77E+01	1.27E+02	3.09E+05	1.50E+03	1.75E+04	8.55E-06	1.13E+00	1.40E-05	3.95E-02	1.05E-03	3.88E-05
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	6.09E+03	5.92E+01	3.98E-01	1.38E+02	1.81E-02	6.52E-03	3.44E-03	3.12E+00	9.98E-02	7.13E-01	2.52E+03	1.22E+01	1.42E+02	4.30E-07	5.67E-06	6.91E-07	5.09E-04	5.26E-05	1.92E-06
22	9.98E+03	9.36E+01	1.12E-01	9.91E-01	9.94E-05	1.23E-02	6.52E-03	5.39E+00	2.12E-01	1.51E+00	4.76E+03	2.30E+01	2.69E+02	8.71E-07	-	1.35E-06	3.06E-03	1.07E-04	3.74E-06
23	5.61E+04	-	-	-	-	8.99E-04	4.75E-04	-	-	-	3.47E+02	1.68E+00	1.96E+01	-	-	-	-	-	-
24	3.54E+03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	2.59E+05	5.74E+02	-	1.64E-01	7.62E-08	2.50E-02	1.32E-02	3.04E+02	6.91E-01	4.93E+00	9.64E+03	4.66E+01	5.45E+02	1.93E-13	-	5.79E-06	7.64E-11	2.36E-11	1.61E-05
27	3.86E+03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	6.32E+02	1.48E+02	4.70E-02	4.05E-01	2.83E-05	4.37E-03	2.31E-03	1.52E+01	6.03E-02	4.31E-01	1.69E+03	8.17E+00	9.54E+01	4.12E-08	-	7.41E-08	-	5.04E-06	2.06E-07
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	9.85E+04	2.69E+04	1.42E+01	8.95E+01	8.96E-03	1.11E+00	5.87E-01	1.02E+03	1.91E+01	1.36E+02	4.29E+05	2.07E+03	2.42E+04	6.25E-06	-	9.05E-06	-	7.65E-04	2.51E-05
33	8.42E+04	1.58E+04	2.07E+01	7.53E+00	3.21E-06	1.11E+00	5.84E-01	2.01E+04	2.95E+01	2.10E+02	4.27E+05	2.06E+03	2.41E+04	2.50E-08	-	4.76E-05	1.53E-09	3.06E-06	1.32E-04
34	2.02E+04	1.50E+05	2.15E+01	6.94E+00	3.38E-06	1.07E+00	5.68E-01	7.90E+03	3.10E+01	2.21E+02	4.15E+05	2.01E+03	2.34E+04	-	-	2.60E-05	-	-	7.23E-05
35	6.32E+04	2.44E+04	1.19E+01	8.37E+01	7.36E-03	9.89E-01	5.22E-01	1.18E+03	1.57E+01	1.12E+02	3.82E+05	1.85E+03	2.16E+04	6.13E-06	-	1.08E-05	-	7.50E-04	2.99E-05
36	1.86E+02	3.32E+01	1.36E-02	9.01E-02	8.49E-06	1.10E-03	5.79E-04	6.25E-01	1.81E-02	1.29E-01	4.23E+02	2.05E+00	2.39E+01	1.64E-08	-	3.21E-08	-	2.00E-06	8.91E-08
37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39	1.04E+05	3.29E+04	1.45E+01	1.29E+02	8.75E-03	1.37E+00	7.26E-01	1.00E+04	1.87E+01	1.33E+02	5.30E+05	2.56E+03	3.00E+04	2.53E-05	-	3.70E-05	-	3.10E-03	1.03E-04
40	4.39E+05	1.26E+04	2.65E+01	1.14E+05	1.28E+01	4.78E-01	2.53E-01	7.60E+01	2.06E+01	1.47E+02	1.85E+05	8.93E+02	1.04E+04	3.50E-06	5.67E-02	6.68E-05	4.58E-03	4.28E-04	1.85E-04
41	2.67E+03	9.18E+00	1.12E-02	1.17E-01	9.66E-06	1.35E-03	7.11E-04	1.66E+00	2.06E-02	1.47E-01	5.19E+02	2.51E+00	2.93E+01	2.78E-08	-	3.26E-08	-	3.40E-06	9.05E-08
42	1.76E+04	5.59E+02	5.06E-01	2.41E+02	3.42E-04	3.39E-02	1.79E-02	3.03E+00	7.42E-01	5.30E+00	1.31E+04	6.32E+01	7.39E+02	5.09E-07	4.36E-02	1.22E-06	1.75E-03	6.23E-05	3.38E-06
43	2.42E+05	2.60E+03	1.90E+00	2.01E+01	1.31E-03	2.11E-01	1.11E-01	1.37E+03	2.79E+00	1.99E+01	8.12E+04	3.93E+02	4.59E+03	7.68E-06	-	1.07E-05	-	9.40E-04	2.98E-05
44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
47	2.48E+05	5.67E+02	-	1.21E-01	6.03E-08	1.89E-02	1.00E-02	1.13E+02	5.47E-01	3.90E+00	7.31E+03	3.53E+01	4.13E+02	-	-	4.25E-06	-	-	1.18E-05
48	1.81E+04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	1.39E+05	1.21E+04	8.59E+00	6.83E+03	7.48E-01	5.42E-01	2.86E-01	9.55E+01	1.09E+01	7.78E+01	2.09E+05	1.01E+03	1.18E+04	3.45E-06	1.52E-02	9.11E-06	5.25E-03	4.22E-04	2.53E-05
Phase Totals	2.80E+06	3.63E+05	2.09E+02	1.45E+05	1.43E+01	1.11E+01	5.88E+00	4.28E+04	2.85E+02	2.04E+03	4.30E+06	2.08E+04	2.43E+05	8.44E-05	2.82E+00	3.64E-04	2.81E-01	1.03E-02	1.01E-03

Table 4: Dry Sludge Radioisotope Inventory by Tank, continued

Tank	Sludge Volume, gal	Pu-244 (Ci)	Am-243 (Ci)	Cm-242 (Ci)	Cm-243 (Ci)	Cm-247 (Ci)	Cm-248 (Ci)	Bk-249 (Ci)	Cf-249 (Ci)	Cf-251 (Ci)	Cf-252 (Ci)	DrySludge Transferred Mass (Kg)	Sludge Interstitial Fraction
1	7.05E+03	2.80E-05	4.88E-01	2.02E+00	2.86E-01	5.51E-11	5.74E-11	4.19E-18	3.18E-10	1.09E-11	3.53E-13	1.13E+04	0.70
2	4.07E+03	4.15E-06	6.72E-02	3.02E-01	3.94E-02	7.58E-12	7.90E-12	5.77E-19	4.38E-11	1.50E-12	4.86E-14	1.58E+03	0.70
3	4.07E+03	5.00E-06	5.88E-02	2.55E-01	3.44E-02	6.63E-12	6.91E-12	5.05E-19	3.83E-11	1.31E-12	4.26E-14	3.06E+03	0.70
4	1.27E+05	1.26E-04	2.92E+00	1.01E+01	1.71E+00	3.30E-10	3.44E-10	2.51E-17	1.91E-09	6.52E-11	2.12E-12	6.55E+04	0.70
5	3.06E+04	1.55E-04	2.41E+00	9.36E+00	1.41E+00	2.72E-10	2.84E-10	2.07E-17	1.57E-09	5.38E-11	1.75E-12	5.76E+04	0.56
6	2.49E+04	7.96E-04	2.55E+00	9.26E+00	1.49E+00	2.88E-10	3.00E-10	2.19E-17	1.66E-09	5.69E-11	1.85E-12	3.87E+04	0.70
7	1.97E+04	3.22E-04	1.72E-01	6.39E-01	1.01E-01	1.94E-11	2.02E-11	1.48E-18	1.12E-10	3.84E-12	1.24E-13	4.09E+04	0.70
8	4.10E+03	2.65E-05	2.63E-02	9.13E-02	1.54E-02	2.97E-12	3.10E-12	2.26E-19	1.72E-11	5.88E-13	1.91E-14	1.80E+03	0.70
9	2.71E+03	1.31E-06	7.25E-02	3.26E-01	4.24E-02	8.17E-12	8.52E-12	6.22E-19	4.72E-11	1.62E-12	5.24E-14	1.52E+03	0.70
10	2.71E+03	6.64E-07	7.54E-03	3.35E-02	4.42E-03	8.51E-13	8.87E-13	6.48E-20	4.92E-12	1.68E-13	5.46E-15	3.14E+02	0.70
11	1.98E+04	1.27E-03	5.11E-01	9.53E-01	2.99E-01	5.77E-11	6.01E-11	4.39E-18	3.33E-10	1.14E-11	3.70E-13	1.73E+04	0.70
12	1.43E+05	8.45E-03	5.83E+00	1.30E+01	3.41E+00	6.57E-10	6.85E-10	5.01E-17	3.80E-09	1.30E-10	4.22E-12	1.90E+05	0.53
13	2.52E+05	1.83E-03	5.56E+00	1.60E+01	3.25E+00	6.27E-10	6.53E-10	4.77E-17	3.62E-09	1.24E-10	4.02E-12	4.18E+05	0.70
14	2.80E+04	1.63E-05	1.58E-01	6.24E-01	9.26E-02	1.78E-11	1.86E-11	1.36E-18	1.03E-10	3.53E-12	1.14E-13	4.12E+03	0.70
15	3.12E+05	2.03E-03	5.00E+00	1.04E+01	2.93E+00	5.64E-10	5.87E-10	4.29E-17	3.26E-09	1.11E-10	3.62E-12	1.66E+05	0.48
16	-	-	-	-	-	-	-	-	-	-	-	-	0.70
21	6.09E+03	2.44E-06	4.07E-02	3.30E-01	2.38E-02	4.59E-12	4.78E-12	3.49E-19	2.65E-11	9.07E-13	2.94E-14	6.39E+03	0.70
22	9.98E+03	-	7.69E-02	9.32E-02	4.51E-02	8.68E-12	9.05E-12	6.61E-19	5.02E-11	1.72E-12	5.57E-14	1.70E+04	0.70
23	5.61E+04	-	5.61E-03	-	3.28E-03	6.33E-13	6.59E-13	4.82E-20	3.66E-12	1.25E-13	4.06E-15	4.03E+04	0.70
24	3.54E+03	-	-	-	-	-	-	-	-	-	-	-	0.70
25	-	-	-	-	-	-	-	-	-	-	-	-	0.70
26	2.59E+05	5.17E-04	1.56E-01	-	9.13E-02	1.76E-11	1.83E-11	1.34E-18	1.02E-10	3.48E-12	1.13E-13	1.59E+05	0.70
27	3.86E+03	-	-	-	-	-	-	-	-	-	-	-	0.70
28	-	-	-	-	-	-	-	-	-	-	-	-	0.70
29	-	-	-	-	-	-	-	-	-	-	-	-	0.70
30	6.32E+02	2.41E-04	2.73E-02	3.90E-02	1.60E-02	3.08E-12	3.21E-12	2.34E-19	1.78E-11	6.09E-13	1.97E-14	5.44E+02	0.70
31	-	-	-	-	-	-	-	-	-	-	-	-	0.70
32	9.85E+04	2.53E-02	6.93E+00	1.18E+01	4.06E+00	7.82E-10	8.14E-10	5.95E-17	4.52E-09	1.55E-10	5.01E-12	1.96E+05	0.70
33	8.42E+04	3.92E-04	6.90E+00	1.72E+01	4.04E+00	7.78E-10	8.11E-10	5.93E-17	4.50E-09	1.54E-10	4.99E-12	2.42E+05	0.70
34	2.02E+04	2.76E-04	6.70E+00	1.79E+01	3.93E+00	7.56E-10	7.88E-10	5.76E-17	4.37E-09	1.50E-10	4.85E-12	7.71E+04	0.70
35	6.32E+04	2.59E-02	6.17E+00	9.87E+00	3.61E+00	6.96E-10	7.25E-10	5.30E-17	4.02E-09	1.38E-10	4.46E-12	1.39E+05	0.70
36	1.86E+02	3.85E-05	6.84E-03	1.13E-02	4.00E-03	7.71E-13	8.04E-13	5.87E-20	4.46E-12	1.52E-13	4.95E-15	1.63E+02	0.70
37	-	-	-	-	-	-	-	-	-	-	-	-	0.70
38	-	-	-	-	-	-	-	-	-	-	-	-	0.70
39	1.04E+05	4.71E-02	8.57E+00	1.21E+01	5.02E+00	9.66E-10	1.01E-09	7.36E-17	5.58E-09	1.91E-10	6.20E-12	1.17E+05	0.70
40	4.39E+05	8.26E-03	2.98E+00	2.20E+01	1.75E+00	3.37E-10	3.51E-10	2.56E-17	1.94E-09	6.65E-11	2.16E-12	4.04E+05	0.70
41	2.67E+03	-	8.39E-03	9.28E-03	4.92E-03	9.47E-13	9.87E-13	7.21E-20	5.47E-12	1.87E-13	6.08E-15	2.36E+03	0.70
42	1.76E+04	1.57E-04	2.11E-01	4.20E-01	1.24E-01	2.38E-11	2.48E-11	1.81E-18	1.38E-10	4.71E-12	1.53E-13	1.80E+04	0.80
43	2.42E+05	1.86E-02	1.31E+00	1.58E+00	7.69E-01	1.48E-10	1.54E-10	1.13E-17	8.56E-10	2.93E-11	9.50E-13	9.21E+04	0.70
44	-	-	-	-	-	-	-	-	-	-	-	-	0.70
45	-	-	-	-	-	-	-	-	-	-	-	-	0.70
46	-	-	-	-	-	-	-	-	-	-	-	-	0.70
47	2.48E+05	4.76E-04	1.18E-01	-	6.92E-02	1.33E-11	1.39E-11	1.01E-18	7.70E-11	2.63E-12	8.55E-14	1.38E+05	0.70
48	1.81E+04	-	-	-	-	-	-	-	-	-	-	-	0.70
49	-	-	-	-	-	-	-	-	-	-	-	-	0.70
50	-	-	-	-	-	-	-	-	-	-	-	-	0.70
51	1.39E+05	8.37E-03	3.38E+00	7.13E+00	1.98E+00	3.81E-10	3.97E-10	2.90E-17	2.20E-09	7.54E-11	2.45E-12	1.24E+05	0.80
Phase Totals	2.80E+06	1.51E-01	6.94E+01	1.74E+02	4.07E+01	7.83E-09	8.16E-09	5.96E-16	4.53E-08	1.55E-09	5.02E-11	2.79E+06	-

Table 5: Insoluble Salt Radionuclide Inventory by Tank

Tank	Salt Volume, gal	H-3 (Ci)	C-14 (Ci)	Sr-90 (Ci)	Y-90 (Ci)	Cs-137 (Ci)	Ba-137m (Ci)	U-235 (Ci)	U-238 (Ci)	Pu-238 (Ci)	Pu-239 (Ci)	Na-22 (Ci)	Al-26 (Ci)	Ac-227 (Ci)	Pa-231 (Ci)
1	4.80E+05	-	1.10E+01	1.71E+05	1.71E+05	7.63E+03	7.22E+03	6.72E-03	1.51E-01	2.18E+03	7.27E+01	8.96E+01	3.13E-01	1.53E-06	4.26E-06
2	5.36E+05	-	1.23E+01	1.91E+05	1.91E+05	8.52E+03	8.06E+03	7.51E-03	1.68E-01	2.43E+03	8.12E+01	1.00E+02	3.50E-01	1.71E-06	4.76E-06
3	5.36E+05	-	1.23E+01	1.91E+05	1.91E+05	8.52E+03	8.06E+03	7.51E-03	1.68E-01	2.43E+03	8.12E+01	1.00E+02	3.50E-01	1.71E-06	4.76E-06
4	3.39E+04	-	7.75E-01	1.21E+04	1.21E+04	5.39E+02	5.09E+02	4.74E-04	1.06E-02	1.54E+02	5.13E+00	6.32E+00	2.21E-02	1.08E-07	3.01E-07
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	5.34E+05	-	1.22E+01	1.90E+05	1.90E+05	8.49E+03	8.03E+03	7.48E-03	1.68E-01	2.43E+03	8.08E+01	9.97E+01	3.49E-01	1.71E-06	4.74E-06
10	2.11E+05	-	4.83E+00	7.52E+04	7.52E+04	3.36E+03	3.18E+03	2.96E-03	6.64E-02	9.60E+02	3.20E+01	3.95E+01	1.38E-01	6.76E-07	1.88E-06
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	6.00E+04	-	1.37E+00	2.13E+04	2.13E+04	9.54E+02	9.02E+02	8.40E-04	1.89E-02	2.73E+02	9.08E+00	1.12E+01	3.92E-02	1.92E-07	5.33E-07
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	1.30E+05	-	2.96E+00	4.61E+04	4.61E+04	2.06E+03	1.95E+03	1.81E-03	4.07E-02	5.88E+02	1.96E+01	2.42E+01	8.45E-02	4.14E-07	1.15E-06
15	1.50E+05	-	3.42E+00	5.32E+04	5.32E+04	2.38E+03	2.25E+03	2.09E-03	4.70E-02	6.79E+02	2.26E+01	2.79E+01	9.76E-02	4.78E-07	1.33E-06
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	1.10E+06	-	2.51E+01	3.91E+05	3.91E+05	1.75E+04	1.65E+04	1.54E-02	3.45E-01	4.99E+03	1.66E+02	2.05E+02	7.17E-01	3.51E-06	9.75E-06
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	6.00E+05	-	1.37E+01	2.14E+05	2.14E+05	9.54E+03	9.03E+03	8.41E-03	1.89E-01	2.73E+03	9.09E+01	1.12E+02	3.92E-01	1.92E-06	5.33E-06
28	1.03E+06	-	2.35E+01	3.66E+05	3.66E+05	1.64E+04	1.55E+04	1.44E-02	3.24E-01	4.68E+03	1.56E+02	1.92E+02	6.72E-01	3.29E-06	9.14E-06
29	1.02E+06	-	2.34E+01	3.64E+05	3.64E+05	1.63E+04	1.54E+04	1.43E-02	3.21E-01	4.65E+03	1.55E+02	1.91E+02	6.68E-01	3.27E-06	9.08E-06
30	2.50E+05	-	5.71E+00	8.88E+04	8.88E+04	3.97E+03	3.75E+03	3.50E-03	7.84E-02	1.13E+03	3.78E+01	4.66E+01	1.63E-01	7.98E-07	2.22E-06
31	1.15E+06	-	2.62E+01	4.08E+05	4.08E+05	1.82E+04	1.72E+04	1.61E-02	3.60E-01	5.21E+03	1.74E+02	2.14E+02	7.49E-01	3.66E-06	1.02E-05
32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
33	2.94E+05	-	6.72E+00	1.05E+05	1.05E+05	4.67E+03	4.42E+03	4.11E-03	9.23E-02	1.33E+03	4.45E+01	5.49E+01	1.92E-01	9.39E-07	2.61E-06
34	1.91E+05	-	4.37E+00	6.81E+04	6.81E+04	3.04E+03	2.88E+03	2.68E-03	6.01E-02	8.69E+02	2.90E+01	3.57E+01	1.25E-01	6.11E-07	1.70E-06
35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	1.04E+06	-	2.37E+01	3.68E+05	3.68E+05	1.65E+04	1.56E+04	1.45E-02	3.25E-01	4.70E+03	1.57E+02	1.93E+02	6.76E-01	3.31E-06	9.19E-06
37	1.14E+06	-	2.62E+01	4.07E+05	4.07E+05	1.82E+04	1.72E+04	1.60E-02	3.60E-01	5.20E+03	1.73E+02	2.14E+02	7.47E-01	3.66E-06	1.02E-05
38	8.28E+05	-	1.89E+01	2.95E+05	2.95E+05	1.32E+04	1.25E+04	1.16E-02	2.60E-01	3.76E+03	1.25E+02	1.55E+02	5.41E-01	2.65E-06	7.35E-06
39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
41	1.09E+06	-	2.50E+01	3.89E+05	3.89E+05	1.74E+04	1.64E+04	1.53E-02	3.43E-01	4.96E+03	1.65E+02	2.04E+02	7.13E-01	3.49E-06	9.70E-06
42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44	1.00E+06	-	2.29E+01	3.57E+05	3.57E+05	1.59E+04	1.51E+04	1.40E-02	3.15E-01	4.56E+03	1.52E+02	1.87E+02	6.55E-01	3.21E-06	8.90E-06
45	1.10E+06	-	2.53E+01	3.93E+05	3.93E+05	1.76E+04	1.66E+04	1.55E-02	3.47E-01	5.02E+03	1.67E+02	2.06E+02	7.21E-01	3.53E-06	9.81E-06
46	8.65E+05	-	1.98E+01	3.08E+05	3.08E+05	1.38E+04	1.30E+04	1.21E-02	2.72E-01	3.93E+03	1.31E+02	1.62E+02	5.65E-01	2.76E-06	7.68E-06
47	8.35E+05	-	1.91E+01	2.97E+05	2.97E+05	1.33E+04	1.26E+04	1.17E-02	2.62E-01	3.79E+03	1.26E+02	1.56E+02	5.45E-01	2.67E-06	7.41E-06
48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	2.99E+02	-	6.84E-03	1.06E+02	1.06E+02	4.75E+00	4.50E+00	4.19E-06	9.39E-05	1.36E+00	4.53E-02	5.58E-02	1.95E-04	9.56E-10	2.65E-09
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phase Totals	1.62E+07	-	3.71E+02	5.77E+06	5.77E+06	2.58E+05	2.44E+05	2.27E-01	5.09E+00	7.36E+04	2.45E+03	3.03E+03	1.06E+01	5.18E-05	1.44E-04

Table 6: Soluble Radionuclide Inventory by Tank

Tank	Total Supernate Volume, gal	H-3 (Ci)	C-14 (Ci)	Co-60 (Ci)	Ni-59 (Ci)	Ni-63 (Ci)	Se-79 (Ci)	Sr-90 (Ci)	Y-90 (Ci)	Nb-94 (Ci)	Tc-99 (Ci)	Ru-106 (Ci)	Rh-106 (Ci)	Sb-125 (Ci)	Sn-126 (Ci)	I-129 (Ci)
1	1.66E+05	6.28E+01	1.11E+00	6.47E-01	6.97E-02	1.57E+00	2.58E+00	8.09E+02	8.09E+02	2.03E-05	9.58E+02	6.61E+01	6.61E+01	2.68E+02	1.31E+01	5.17E-01
2	1.64E+05	6.20E+01	1.09E+00	6.38E-01	2.55E-02	1.55E+00	9.45E-01	2.96E+02	2.96E+02	7.43E-06	3.50E+02	2.42E+01	2.42E+01	9.80E+01	4.78E+00	1.89E-01
3	1.64E+05	6.20E+01	1.09E+00	6.38E-01	2.59E-02	1.55E+00	9.58E-01	3.00E+02	3.00E+02	7.53E-06	3.55E+02	2.45E+01	2.45E+01	9.93E+01	4.84E+00	1.92E-01
4	3.99E+05	1.51E+02	2.66E+00	1.55E+00	7.43E-02	3.77E+00	2.75E+00	8.62E+02	8.62E+02	2.16E-05	1.02E+03	7.04E+01	7.04E+01	2.85E+02	1.39E+01	5.50E-01
5	1.71E+04	6.49E+00	1.14E-01	6.69E-02	6.55E-04	1.62E-01	2.43E-02	7.60E+00	7.60E+00	1.91E-07	9.00E+00	6.21E-01	6.21E-01	2.52E+00	1.23E-01	4.85E-03
6	2.71E+05	7.23E+02	1.81E+00	1.06E+00	2.12E-03	2.57E+00	7.87E-02	2.47E+01	2.47E+01	6.19E-07	2.92E+01	2.01E+00	2.01E+00	8.16E+00	3.98E-01	1.57E-02
7	2.90E+05	1.19E+02	1.93E+00	1.13E+00	1.06E-02	2.75E+00	3.92E-01	1.11E+02	1.11E+02	3.09E-06	1.45E+02	1.00E+01	1.00E+01	4.07E+01	1.98E+00	7.84E-02
8	1.02E+04	2.34E+02	6.76E-02	3.96E-02	1.50E-04	9.61E-02	5.54E-03	1.74E+00	1.74E+00	4.36E-08	2.05E+00	1.42E-01	1.42E-01	5.74E-01	2.80E-02	1.11E-03
9	1.75E+05	6.63E+01	1.17E+00	6.83E-01	2.67E-02	1.66E+00	9.91E-01	3.10E+02	3.10E+02	7.79E-06	3.67E+02	2.54E+01	2.53E+01	1.03E+02	5.01E+00	1.98E-01
10	6.53E+04	2.47E+01	4.35E-01	2.55E-01	1.74E-03	6.18E-01	6.45E-02	2.02E+01	2.02E+01	5.07E-07	2.39E+01	1.65E+00	1.65E+00	6.69E+00	3.26E-01	1.29E-02
11	1.56E+05	5.89E+01	1.04E+00	6.07E-01	9.94E-07	1.47E+00	3.68E-05	1.04E-02	1.04E-02	2.90E-10	1.37E-02	9.42E-04	9.42E-04	3.82E-03	1.86E-04	7.36E-06
12	1.18E+05	4.48E+01	7.89E-01	4.62E-01	2.61E-03	1.12E+00	9.66E-02	3.02E+01	3.02E+01	7.59E-07	3.58E+01	2.47E+00	2.47E+00	1.00E+01	4.88E-01	1.93E-02
13	7.54E+05	2.85E+02	5.02E+00	2.94E+00	2.49E-01	7.13E+00	9.24E+00	2.89E+03	2.89E+03	7.27E-05	3.43E+03	2.36E+02	2.36E+02	9.58E+02	4.67E+01	1.85E+00
14	5.95E+04	2.25E+01	3.96E-01	2.32E-01	2.11E-02	5.63E-01	7.81E-01	2.45E+02	2.45E+02	6.14E-06	2.89E+02	2.00E+01	2.00E+01	8.09E+01	3.95E+00	1.56E-01
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	1.18E+06	4.47E+02	7.86E+00	4.60E+00	3.32E-05	1.12E+01	1.23E-03	3.85E-01	3.85E-01	9.69E-09	4.57E-01	3.15E-02	3.15E-02	1.28E-01	6.23E-03	2.94E-03
22	1.18E+06	4.45E+02	7.84E+00	4.59E+00	3.61E-05	1.11E+01	1.34E-03	4.16E-01	4.16E-01	1.05E-08	4.97E-01	3.43E-02	3.42E-02	1.39E-01	6.77E-03	2.93E-03
23	1.30E+06	5.06E+00	2.02E-01	4.22E-03	5.56E-06	1.84E-01	2.06E-04	1.57E+00	1.57E+00	1.62E-09	3.29E-01	5.27E-03	5.26E-03	2.13E-02	1.04E-03	2.84E-03
24	8.53E+05	3.23E+02	5.69E+00	3.33E+00	1.00E-02	8.08E+00	3.71E-01	1.16E+02	1.16E+02	2.92E-06	1.38E+02	9.50E+00	9.50E+00	3.85E+01	1.88E+00	2.47E-02
25	3.66E+05	1.39E+02	2.44E+00	1.43E+00	2.93E-02	3.47E+00	1.08E+00	3.40E+02	3.40E+02	8.52E-06	4.02E+02	2.77E+01	2.77E+01	1.12E+02	5.48E+00	2.17E-01
26	7.01E+05	2.65E+02	4.67E+00	2.73E+00	1.06E-01	6.63E+00	3.92E+00	1.28E+03	1.28E+03	3.08E-05	1.45E+03	1.00E+02	1.00E+02	4.06E+02	1.98E+01	7.83E-01
27	7.83E+05	2.96E+02	5.22E+00	3.05E+00	1.34E-01	7.41E+00	4.97E+00	1.54E+03	1.54E+03	3.91E-05	1.84E+03	1.27E+02	1.27E+02	5.16E+02	2.52E+01	9.95E-01
28	4.94E+05	1.87E+02	3.29E+00	1.93E+00	4.68E-02	4.68E+00	1.73E+00	5.43E+02	5.43E+02	1.36E-05	6.43E+02	4.44E+01	4.44E+01	1.80E+02	8.77E+00	3.47E-01
29	4.74E+05	1.79E+02	3.16E+00	1.85E+00	1.00E-02	4.49E+00	3.71E-01	1.16E+02	1.16E+02	2.92E-06	1.38E+02	9.49E+00	9.49E+00	3.85E+01	1.88E+00	7.42E-02
30	9.90E+05	3.75E+02	6.60E+00	3.86E+00	2.25E-01	9.37E+00	8.33E+00	2.61E+03	2.61E+03	6.55E-05	3.09E+03	2.13E+02	2.13E+02	8.63E+02	4.21E+01	1.66E+00
31	4.59E+05	1.74E+02	3.06E+00	1.79E+00	1.10E-01	4.35E+00	4.09E+00	1.28E+03	1.28E+03	3.22E-05	1.52E+03	1.05E+02	1.05E+02	4.24E+02	2.07E+01	8.19E-01
32	9.13E+05	3.46E+02	6.08E+00	3.56E+00	1.51E-01	8.64E+00	5.60E+00	1.51E+03	1.51E+03	4.40E-05	2.07E+03	1.43E+02	1.43E+02	5.80E+02	2.83E+01	1.12E+00
33	9.42E+05	4.80E+02	6.28E+00	3.67E+00	8.09E-02	8.92E+00	3.00E+00	9.39E+02	9.39E+02	2.36E-05	1.11E+03	7.67E+01	7.66E+01	3.11E+02	1.52E+01	5.99E-01
34	6.40E+05	2.42E+02	4.27E+00	2.50E+00	6.69E-02	6.06E+00	2.48E+00	7.76E+02	7.76E+02	1.95E-05	9.19E+02	6.34E+01	6.34E+01	2.57E+02	1.25E+01	4.95E-01
35	4.94E+05	1.87E+02	3.29E+00	1.93E+00	4.24E-02	4.68E+00	1.57E+00	4.92E+02	4.92E+02	1.24E-05	5.82E+02	4.02E+01	4.02E+01	1.63E+02	7.94E+00	3.14E-01
36	5.30E+05	2.01E+02	3.53E+00	2.07E+00	2.35E-01	5.02E+00	8.71E+00	2.73E+03	2.73E+03	6.85E-05	3.23E+03	2.23E+02	2.23E+02	9.03E+02	4.40E+01	1.74E+00
37	4.60E+05	1.74E+02	3.06E+00	1.79E+00	9.27E-02	4.35E+00	3.44E+00	9.85E+02	9.85E+02	2.70E-05	1.27E+03	8.79E+01	8.79E+01	3.56E+02	1.74E+01	6.87E-01
38	4.20E+05	1.59E+02	2.80E+00	1.64E+00	2.90E-03	3.97E+00	1.07E-01	3.36E+01	3.36E+01	8.44E-07	3.98E+01	2.75E+00	2.74E+00	1.11E+01	5.43E-01	2.15E-02
39	7.95E+05	3.01E+02	5.30E+00	3.10E+00	1.89E-02	7.52E+00	6.99E-01	1.64E+02	1.64E+02	5.49E-06	2.59E+02	1.79E+01	1.79E+01	7.24E+01	3.53E+00	1.40E-01
40	6.12E+05	2.32E+02	4.08E+00	2.39E+00	8.77E-04	5.80E+00	3.25E-02	1.06E+01	1.06E+01	2.56E-07	1.21E+01	8.31E-01	8.31E-01	3.37E+00	1.64E-01	6.50E-03
41	3.46E+05	1.31E+02	2.30E+00	1.35E+00	7.76E-03	3.27E+00	2.87E-01	3.17E+01	3.17E+01	2.26E-06	1.07E+02	7.35E+00	7.35E+00	2.98E+01	1.45E+00	5.75E-02
42	1.27E+06	4.80E+02	8.45E+00	4.94E+00	2.60E-01	1.20E+01	9.64E+00	3.02E+03	3.02E+03	7.58E-05	3.57E+03	2.46E+02	2.46E+02	9.99E+02	4.87E+01	1.93E+00
43	9.45E+05	3.58E+02	6.30E+00	3.69E+00	4.09E-03	8.95E+00	1.51E-01	4.10E+01	4.10E+01	1.19E-06	5.62E+01	3.88E+00	3.87E+00	1.57E+01	7.66E-01	3.03E-02
44	5.64E+05	2.14E+02	3.76E+00	2.20E+00	6.34E-02	5.34E+00	2.35E+00	7.35E+02	7.35E+02	1.85E-05	8.71E+02	6.01E+01	6.00E+01	2.43E+02	1.19E+01	4.69E-01
45	5.11E+05	1.93E+02	3.40E+00	1.99E+00	5.43E-02	4.84E+00	2.01E+00	6.30E+02	6.30E+02	1.58E-05	7.45E+02	5.14E+01	5.14E+01	2.08E+02	1.02E+01	4.02E-01
46	6.72E+05	2.55E+02	4.48E+00	2.62E+00	1.07E-01	6.36E+00	3.97E+00	1.24E+03	1.24E+03	3.12E-05	1.47E+03	1.01E+02	1.01E+02	4.11E+02	2.01E+01	7.93E-01
47	5.97E+05	2.26E+02	3.98E+00	2.33E+00	1.76E-02	5.65E+00	6.51E-01	2.04E+02	2.04E+02	5.12E-06	2.41E+02	1.66E+01	1.66E+01	6.74E+01	3.29E+00	1.30E-01
48	2.40E+05	9.10E+01	1.60E+00	9.37E-01	8.69E-03	2.28E+00	3.22E-01	2.98E+02	2.98E+02	2.53E-06	1.19E+02	8.23E+00	8.23E+00	3.34E+01	1.63E+00	6.44E-02
49	1.92E+05	7.26E+01	1.28E+00	7.48E-01	3.15E-04	1.82E+00	1.17E-02	2.68E+01	2.68E+01	9.19E-08	4.33E+00	2.99E-01	2.99E-01	1.21E+00	5.91E-02	2.34E-03
50	4.24E+05	5.67E+00	1.70E-02	8.49E-03	2.28E-07	2.63E-02	8.46E-06	2.65E-03	2.65E-03	6.65E-11	3.14E-03	2.16E-04	2.16E-04	8.77E-04	4.28E-05	3.45E-03
51	6.93E+05	2.62E+02	4.62E+00	2.70E+00	5.46E-03	6.56E+00	2.02E-01	5.07E+01	5.07E+01	1.59E-06	7.50E+01	5.18E+00	5.18E+00	2.10E+01	1.02E+00	4.05E-02
Phase Totals	2.39E+07	9.37E+03	1.48E+02	8.63E+01	2.40E+00	2.10E+02	8.90E+01	2.77E+04	2.77E+04	7.00E-04	3.30E+04	2.28E+03	2.28E+03	9.23E+03	4.50E+02	1.78E+01

Table 6: Soluble Radionuclide Inventory by Tank, continued

Tank	Total Supernate Volume, gal	Cs-134 (Ci)	Cs-135 (Ci)	Cs-137 (Ci)	Ba-137m (Ci)	Ce-144 (Ci)	Pr-144 (Ci)	Pm-147 (Ci)	Eu-154 (Ci)	Th-232 (Ci)	U-232 (Ci)	U-233 (Ci)	U-234 (Ci)	U-235 (Ci)	U-236 (Ci)	U-238 (Ci)	Np-237 (Ci)
1	1.66E+05	6.60E+03	1.12E+01	3.29E+06	3.11E+06	1.72E-01	1.72E-01	1.11E+02	2.64E+01	-	1.51E-04	-	-	2.33E-04	-	5.79E-03	8.45E-03
2	1.64E+05	2.42E+03	4.10E+00	1.20E+06	1.14E+06	6.30E-02	6.30E-02	4.07E+01	9.66E+00	-	1.25E-04	-	-	6.01E-05	-	1.50E-03	1.57E-02
3	1.64E+05	2.45E+03	4.16E+00	1.22E+06	1.15E+06	6.38E-02	6.38E-02	4.13E+01	9.79E+00	-	1.09E-04	-	-	1.54E-04	-	3.85E-03	2.88E-02
4	3.99E+05	7.04E+03	1.20E+01	3.51E+06	3.32E+06	1.83E-01	1.83E-01	1.19E+02	2.81E+01	-	1.81E-04	-	-	2.38E-04	-	1.02E-02	9.15E-03
5	1.71E+04	6.20E+01	1.05E-01	3.09E+04	2.92E+04	1.62E-03	1.62E-03	1.05E+00	2.48E-01	-	1.54E-05	-	-	2.99E-05	-	7.09E-04	1.20E-03
6	2.71E+05	2.01E+02	3.42E-01	1.00E+05	9.49E+04	5.25E-03	5.25E-03	3.39E+00	8.05E-01	-	2.87E-04	-	-	3.54E-04	-	1.33E-02	4.60E-03
7	2.90E+05	1.00E+03	1.70E+00	5.00E+05	4.73E+05	2.61E-02	2.61E-02	1.69E+01	4.01E+00	-	6.88E-05	-	-	3.22E-04	-	1.11E-02	5.54E-03
8	1.02E+04	1.42E+01	2.41E-02	7.06E+03	6.68E+03	3.69E-04	3.69E-04	2.39E-01	5.66E-02	-	3.02E-06	-	-	7.97E-06	-	3.67E-04	1.67E-04
9	1.75E+05	2.53E+03	4.30E+00	1.26E+06	1.19E+06	6.60E-02	6.60E-02	4.27E+01	1.01E+01	-	1.80E-04	-	-	1.17E-04	-	2.91E-03	1.99E-02
10	6.53E+04	1.65E+02	2.80E-01	8.22E+04	7.77E+04	4.30E-03	4.30E-03	2.78E+00	6.59E-01	-	4.31E-05	-	-	5.25E-05	-	1.31E-03	1.00E-02
11	1.56E+05	9.41E-02	1.60E-04	4.69E+01	4.44E+01	2.45E-06	2.45E-06	1.59E-03	3.76E-04	2.81E-06	-	4.01E-04	3.29E-04	6.22E-06	5.09E-05	1.15E-05	2.18E-04
12	1.18E+05	2.47E+02	4.19E-01	1.23E+05	1.16E+05	6.43E-03	6.43E-03	4.16E+00	9.87E-01	2.09E-04	2.11E-06	5.89E-03	5.51E-04	1.04E-05	4.37E-05	1.04E-04	1.22E-03
13	7.54E+05	2.36E+04	4.01E+01	1.18E+07	1.11E+07	6.16E-01	6.16E-01	3.98E+02	9.44E+01	4.08E-04	1.09E-04	8.37E-02	1.18E-02	3.23E-04	1.22E-03	3.77E-03	3.04E-02
14	5.95E+04	2.00E+03	3.39E+00	9.94E+05	9.40E+05	5.20E-02	5.20E-02	3.37E+01	7.98E+00	1.38E-04	4.08E-05	4.86E-03	6.67E-04	5.39E-05	5.73E-05	1.03E-03	7.12E-03
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	1.18E+06	3.15E+00	5.35E-03	1.57E+03	1.48E+03	8.21E-05	8.20E-05	5.31E-02	1.26E-02	1.20E-06	-	3.79E-02	4.05E-02	6.43E-04	7.43E-03	3.80E-03	3.36E-02
22	1.18E+06	3.42E+00	5.82E-03	1.71E+03	1.61E+03	8.92E-05	8.92E-05	5.77E-02	1.37E-02	-	-	1.57E-01	5.65E-02	8.64E-04	9.30E-03	1.92E-02	3.43E-02
23	1.30E+06	1.36E-02	2.01E-02	2.62E+02	2.48E+02	1.37E-05	1.37E-05	8.88E-03	2.10E-03	1.78E-07	-	1.18E-02	1.88E-02	1.05E-04	4.21E-04	3.13E-03	8.69E-04
24	8.53E+05	9.49E+02	1.61E+00	4.73E+05	4.47E+05	2.47E-02	2.47E-02	1.60E+01	3.80E+00	-	3.84E-09	1.17E-14	3.72E-14	1.10E-08	1.42E-09	1.32E-06	3.41E-09
25	3.66E+05	2.77E+03	4.71E+00	1.38E+06	1.31E+06	7.22E-02	7.22E-02	4.67E+01	1.11E+01	-	1.65E-09	5.01E-15	1.60E-14	4.73E-09	6.11E-10	5.68E-07	1.47E-09
26	7.01E+05	1.00E+04	1.70E+01	4.99E+06	4.72E+06	2.61E-01	2.61E-01	1.69E+02	4.00E+01	-	2.21E-03	6.71E-09	2.14E-08	6.34E-03	8.19E-04	7.61E-01	1.96E-03
27	7.83E+05	1.27E+04	2.16E+01	6.33E+06	5.99E+06	3.31E-01	3.31E-01	2.14E+02	5.08E+01	-	3.52E-09	1.07E-14	3.42E-14	1.01E-08	1.31E-09	1.21E-06	3.13E-09
28	4.94E+05	4.43E+03	7.53E+00	2.21E+06	2.09E+06	1.16E-01	1.16E-01	7.48E+01	1.77E+01	-	2.22E-09	6.76E-15	2.16E-14	6.38E-09	8.24E-10	7.66E-07	1.98E-09
29	4.74E+05	9.48E+02	1.61E+00	4.73E+05	4.47E+05	2.47E-02	2.47E-02	1.60E+01	3.79E+00	-	9.06E-11	6.98E-08	9.85E-09	2.69E-10	1.02E-09	3.15E-09	2.53E-08
30	9.90E+05	2.13E+04	3.61E+01	1.06E+07	1.00E+07	5.55E-01	5.55E-01	3.59E+02	8.51E+01	-	-	-	3.45E-02	6.13E-04	6.37E-03	2.27E-05	1.56E-02
31	4.59E+05	1.05E+04	1.78E+01	5.21E+06	4.93E+06	2.73E-01	2.73E-01	1.76E+02	4.18E+01	-	8.78E-11	6.76E-08	9.54E-09	2.61E-10	9.84E-10	3.05E-09	2.45E-08
32	9.13E+05	1.43E+04	2.43E+01	7.13E+06	6.74E+06	3.73E-01	3.73E-01	2.41E+02	5.72E+01	-	-	-	4.13E-02	5.91E-04	9.27E-03	2.77E-04	1.71E-02
33	9.42E+05	7.66E+03	1.30E+01	3.82E+06	3.61E+06	2.00E-01	2.00E-01	1.29E+02	3.06E+01	-	1.82E-02	8.74E-08	1.80E-03	3.38E-02	1.88E-02	4.90E+00	1.54E+00
34	6.40E+05	6.33E+03	1.08E+01	3.16E+06	2.99E+06	1.65E-01	1.65E-01	1.07E+02	2.53E+01	-	3.38E-03	-	-	3.42E-03	-	2.41E-01	1.87E-01
35	4.94E+05	4.01E+03	6.82E+00	2.00E+06	1.89E+06	1.05E-01	1.05E-01	6.77E+01	1.61E+01	-	-	-	2.18E-02	3.79E-04	6.44E-03	2.24E-04	7.89E-03
36	5.30E+05	2.23E+04	3.78E+01	1.11E+07	1.05E+07	5.80E-01	5.80E-01	3.75E+02	8.90E+01	-	-	-	4.07E-02	7.88E-04	1.44E-02	2.58E-04	1.14E-02
37	4.60E+05	8.78E+03	1.49E+01	4.38E+06	4.14E+06	2.29E-01	2.29E-01	1.48E+02	3.51E+01	-	8.79E-11	6.77E-08	9.55E-09	2.61E-10	9.85E-10	3.05E-09	2.46E-08
38	4.20E+05	2.74E+02	4.66E-01	1.37E+05	1.29E+05	7.15E-03	7.15E-03	4.63E+00	1.10E+00	-	-	-	1.25E-07	1.73E-09	2.38E-08	1.40E-10	1.33E-07
39	7.95E+05	1.79E+03	3.03E+00	8.90E+05	8.42E+05	4.65E-02	4.65E-02	3.01E+01	7.14E+00	-	-	-	9.44E-02	1.36E-03	1.62E-02	2.88E-04	5.93E-02
40	6.12E+05	8.31E+01	1.41E-01	4.14E+04	3.92E+04	2.17E-03	2.17E-03	1.40E+00	3.32E-01	1.46E-03	1.63E-03	4.16E-02	4.00E-02	7.55E-03	9.99E-03	2.36E-01	8.26E-01
41	3.46E+05	7.34E+02	1.25E+00	3.66E+05	3.46E+05	1.91E-02	1.91E-02	1.24E+01	2.94E+00	-	-	-	1.44E-01	1.66E-03	4.12E-02	1.14E-04	4.29E-01
42	1.27E+06	2.46E+04	4.18E+01	1.23E+07	1.16E+07	6.42E-01	6.42E-01	4.15E+02	9.85E+01	1.01E-01	3.58E-04	1.43E+00	5.24E-01	1.24E-02	7.01E-02	2.17E-01	4.31E-01
43	9.45E+05	3.87E+02	6.58E-01	1.93E+05	1.83E+05	1.01E-02	1.01E-02	6.53E+00	1.55E+00	-	-	-	2.67E-01	3.68E-03	5.08E-02	2.99E-04	2.84E-01
44	5.64E+05	6.00E+03	1.02E+01	2.99E+06	2.83E+06	1.56E-01	1.56E-01	1.01E+02	2.40E+01	-	2.54E-09	7.72E-15	2.46E-14	7.29E-09	9.41E-10	8.75E-07	2.26E-09
45	5.11E+05	5.14E+03	8.73E+00	2.56E+06	2.42E+06	1.34E-01	1.34E-01	8.67E+01	2.05E+01	-	2.30E-09	6.99E-15	2.23E-14	6.60E-09	8.52E-10	7.92E-07	2.04E-09
46	6.72E+05	1.01E+04	1.72E+01	5.05E+06	4.78E+06	2.64E-01	2.64E-01	1.71E+02	4.06E+01	-	3.02E-09	9.19E-15	2.93E-14	8.68E-09	1.12E-09	1.04E-06	2.69E-09
47	5.97E+05	1.66E+03	2.82E+00	8.29E+05	7.84E+05	4.34E-02	4.33E-02	2.80E+01	6.65E+00	-	1.52E-03	-	-	4.14E-03	-	3.28E-01	-
48	2.40E+05	8.23E+02	1.40E+00	4.10E+05	3.88E+05	2.14E-02	2.14E-02	1.39E+01	3.29E+00	-	-	8.21E-01	2.81E+00	1.89E-03	8.62E-02	1.86E-03	1.80E-01
49	1.92E+05	2.99E+01	5.07E-02	1.49E+04	1.41E+04	7.79E-04	7.78E-04	5.04E-01	1.19E-01	-	3.67E-11	2.82E-08	3.98E-09	1.09E-10	4.11E-10	1.27E-09	1.02E-08
50	4.24E+05	1.04E-02	3.52E-02	1.08E+01	1.02E+01	5.64E-07	5.64E-07	3.65E-04	8.65E-05	7.00E-07	8.11E-11	6.24E-08	8.81E-09	1.16E-04	1.45E-04	6.15E-03	2.27E-08
51	6.93E+05	5.17E+02	8.79E-01	2.58E+05	2.44E+05	1.35E-02	1.35E-02	8.73E+00	2.07E+00	4.80E-04	7.05E-05	5.84E-02	4.85E-02	1.26E-03	7.85E-03	1.15E-02	3.91E-02
Phase Totals	2.39E+07	2.27E+05	3.86E+02	1.13E+08	1.07E+08	5.93E+00	5.93E+00	3.84E+03	9.10E+02	1.04E-01	2.87E-02	2.65E+00	4.20E+00	8.36E-02	3.57E-01	6.79E+00	4.24E+00

Table 6: Soluble Radionuclide Inventory by Tank, continued

Tank	Total Supernate Volume, gal	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Pu-241 (Ci)	Pu-242 (Ci)	Am-241 (Ci)	Am-242m (Ci)	Cm-244 (Ci)	Cm-245 (Ci)	Na-22 (Ci)	Al-26 (Ci)	Te-125m (Ci)	Sb-126 (Ci)	Sb-126m (Ci)	Sm-151 (Ci)	Eu-152 (Ci)	Eu-155 (Ci)
1	1.66E+05	6.55E+00	1.75E+00	3.92E-01	2.15E+00	8.06E-05	1.05E+01	6.08E-03	4.22E+00	4.16E-04	5.87E+01	3.76E-01	6.54E+01	1.83E+00	1.31E+01	1.25E+02	6.04E-01	7.06E+00
2	1.64E+05	1.02E+01	1.46E+00	3.27E-01	1.37E+00	6.73E-05	3.86E+00	2.22E-03	1.54E+00	1.52E-04	2.15E+01	1.37E-01	2.39E+01	6.69E-01	4.78E+00	4.57E+01	2.21E-01	2.58E+00
3	1.64E+05	1.27E+01	1.81E+00	4.05E-01	2.04E+00	8.32E-05	3.91E+00	2.25E-03	1.57E+00	1.54E-04	2.18E+01	1.39E-01	2.42E+01	6.78E-01	4.84E+00	4.63E+01	2.24E-01	2.62E+00
4	3.99E+05	1.86E+00	1.83E+00	4.09E-01	3.46E+00	8.42E-05	1.12E+01	6.48E-03	4.50E+00	4.43E-04	6.26E+01	4.00E-01	6.97E+01	1.95E+00	1.39E+01	1.33E+02	6.43E-01	7.52E+00
5	1.71E+04	8.26E-01	1.38E-01	3.29E-02	2.21E-01	9.72E-06	9.91E-02	5.71E-05	3.97E-02	3.91E-06	5.52E-01	3.53E-03	6.14E-01	1.72E-02	1.23E-01	1.17E+00	5.67E-03	6.63E-02
6	2.71E+05	-	1.36E+00	4.72E-01	5.29E+00	9.28E-04	3.21E-01	1.85E-04	1.29E-01	1.27E-05	1.79E+00	1.14E-02	1.99E+00	5.57E-02	3.98E-01	3.80E+00	1.84E-02	2.15E-01
7	2.90E+05	2.72E+01	4.89E+00	1.20E+00	1.15E+01	1.11E-03	1.60E+00	9.23E-04	6.41E-01	6.32E-05	8.92E+00	5.70E-02	9.93E+00	2.78E-01	1.98E+00	1.90E+01	9.17E-02	1.07E+00
8	1.02E+04	4.77E-01	1.05E-01	2.46E-02	2.35E-01	3.11E-05	2.26E-02	1.30E-05	9.06E-03	8.92E-07	1.26E-01	8.05E-04	1.40E-01	3.92E-03	2.80E-02	2.68E-01	1.30E-03	1.51E-02
9	1.75E+05	4.31E+00	6.16E-01	1.38E-01	5.72E-01	2.83E-05	4.05E+00	2.33E-03	1.62E+00	1.60E-04	2.25E+01	1.44E-01	2.51E+01	7.02E-01	5.01E+00	4.79E+01	2.32E-01	2.71E+00
10	6.53E+04	5.08E+00	7.26E-01	1.62E-01	7.22E-01	3.34E-05	2.63E-01	1.52E-04	1.05E-01	1.04E-05	1.47E+00	9.38E-03	1.63E+00	4.57E-02	3.26E-01	3.12E+00	1.51E-02	1.76E-01
11	1.56E+05	2.94E+01	2.93E-01	1.84E-01	1.05E+01	3.91E-04	1.50E-04	8.67E-08	6.02E-05	5.93E-09	8.37E-04	5.35E-06	9.32E-04	2.61E-05	1.86E-04	1.78E-03	8.61E-06	1.01E-04
12	1.18E+05	2.12E+01	3.56E-01	1.97E-01	5.00E+00	2.84E-04	3.94E-01	2.27E-04	1.58E-01	1.55E-05	2.19E+00	1.40E-02	2.44E+00	6.84E-02	4.88E-01	4.67E+00	2.26E-02	2.64E-01
13	7.54E+05	1.11E+02	3.00E+00	1.24E+00	2.19E+01	8.25E-04	3.77E+01	2.17E-02	1.51E+01	1.49E-03	2.10E+02	1.34E+00	2.34E+02	6.54E+00	4.67E+01	4.46E+02	2.16E+00	2.52E+01
14	5.95E+04	3.19E+00	7.86E-01	2.54E-01	1.28E+00	4.65E-05	3.19E+00	1.84E-03	1.28E+00	1.26E-04	1.77E+01	1.13E-01	1.98E+01	5.53E-01	3.95E+00	3.77E+01	1.82E-01	2.13E+00
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	1.18E+06	2.02E+02	2.97E+00	1.01E+00	1.77E+01	1.13E-04	5.03E-03	2.90E-06	2.01E-03	1.98E-07	2.80E-02	1.79E-04	3.12E-02	8.72E-04	6.23E-03	5.95E-02	2.88E-04	3.36E-03
22	1.18E+06	2.33E+02	-	-	-	-	5.47E-03	3.15E-06	2.19E-03	2.16E-07	3.04E-02	1.95E-04	3.39E-02	9.48E-04	6.77E-03	6.47E-02	3.13E-04	3.66E-03
23	1.30E+06	9.48E-01	3.25E-03	8.10E-04	9.48E-02	4.83E-03	1.24E-02	4.85E-07	3.64E-04	3.31E-08	4.68E-03	2.99E-05	5.21E-03	1.46E-04	1.04E-03	9.95E-03	4.81E-05	5.62E-04
24	8.53E+05	7.05E-03	1.10E-03	2.47E-04	5.81E-03	4.92E-08	1.52E+00	8.74E-04	6.07E-01	5.98E-05	8.44E+00	5.40E-02	9.40E+00	2.63E-01	1.88E+00	1.79E+01	8.68E-02	1.01E+00
25	3.66E+05	3.03E-03	4.74E-04	1.06E-04	2.49E-03	2.11E-08	4.42E+00	2.55E-03	1.77E+00	1.74E-04	2.46E+01	1.58E-01	2.74E+01	7.67E-01	5.48E+00	5.24E+01	2.53E-01	2.96E+00
26	7.01E+05	4.05E+03	6.35E+02	1.42E+02	3.34E+03	2.83E-02	1.60E+01	9.22E-03	6.40E+00	6.31E-04	8.90E+01	5.69E-01	9.92E+01	2.77E+00	1.98E+01	1.89E+02	9.16E-01	1.07E+01
27	7.83E+05	6.47E-03	1.01E-03	2.27E-04	5.33E-03	4.51E-08	2.03E+01	1.17E-02	8.13E+00	8.01E-04	1.13E+02	7.23E-01	1.26E+02	3.52E+00	2.52E+01	2.40E+02	1.16E+00	1.36E+01
28	4.94E+05	4.08E-03	6.40E-04	1.43E-04	3.36E-03	2.85E-08	7.08E+00	4.08E-03	2.84E+00	2.79E-04	3.94E+01	2.52E-01	4.39E+01	1.23E+00	8.77E+00	8.38E+01	4.05E-01	4.74E+00
29	4.74E+05	9.26E-05	2.51E-06	1.04E-06	1.83E-05	6.88E-10	1.51E+00	8.73E-04	6.06E-01	5.97E-05	8.43E+00	5.39E-02	9.39E+00	2.63E-01	1.88E+00	1.79E+01	8.67E-02	1.01E+00
30	9.90E+05	6.65E+03	5.78E+01	4.15E+01	4.27E+03	9.94E-02	3.40E+01	1.96E-02	1.36E+01	1.34E-03	1.89E+02	1.21E+00	2.11E+02	5.89E+00	4.21E+01	4.02E+02	1.95E+00	2.27E+01
31	4.59E+05	8.97E-05	2.43E-06	1.00E-06	1.77E-05	6.66E-10	1.67E+01	9.63E-03	6.69E+00	6.59E-04	9.30E+01	5.95E-01	1.04E+02	2.90E+00	2.07E+01	1.98E+02	9.57E-01	1.12E+01
32	9.13E+05	5.99E+03	5.26E+01	3.90E+01	2.68E+03	8.23E-02	2.28E+01	1.32E-02	9.15E+00	9.01E-04	1.27E+02	8.13E-01	1.42E+02	3.96E+00	2.83E+01	2.70E+02	1.31E+00	1.53E+01
33	9.42E+05	2.51E+03	1.37E+03	2.40E+02	7.13E+03	1.39E-02	1.22E+01	7.05E-03	4.90E+00	4.82E-04	6.81E+01	4.36E-01	7.59E+01	2.12E+00	1.52E+01	1.45E+02	7.00E-01	8.18E+00
34	6.40E+05	-	3.90E+01	8.72E+00	1.80E+02	1.81E-03	1.01E+01	5.83E-03	4.05E+00	3.99E-04	5.63E+01	3.60E-01	6.27E+01	1.75E+00	1.25E+01	1.20E+02	5.79E-01	6.77E+00
35	4.94E+05	3.27E+03	2.64E+01	2.02E+01	1.57E+03	4.54E-02	6.41E+00	3.70E-03	2.57E+00	2.53E-04	3.57E+01	2.28E-01	3.98E+01	1.11E+00	7.94E+00	7.59E+01	3.67E-01	4.29E+00
36	5.30E+05	3.53E+03	2.75E+01	2.19E+01	1.43E+03	4.72E-02	3.55E+01	2.05E-02	1.42E+01	1.40E-03	1.98E+02	1.27E+00	2.20E+02	6.16E+00	4.40E+01	4.21E+02	2.04E+00	2.38E+01
37	4.60E+05	8.98E-05	2.43E-06	1.01E-06	1.77E-05	6.67E-10	1.40E+01	8.09E-03	5.62E+00	5.53E-04	7.81E+01	4.99E-01	8.70E+01	2.43E+00	1.74E+01	1.66E+02	8.03E-01	9.38E+00
38	4.20E+05	3.03E-03	1.20E-05	1.01E-05	2.60E-03	1.49E-07	4.38E-01	2.53E-04	1.75E-01	1.73E-05	2.44E+00	1.56E-02	2.72E+00	7.60E-02	5.43E-01	5.19E+00	2.51E-02	2.93E-01
39	7.95E+05	5.26E+03	6.54E+01	4.07E+01	4.67E+03	8.67E-02	2.85E+00	1.64E-03	1.14E+00	1.12E-04	1.59E+01	1.02E-01	1.77E+01	4.94E-01	3.53E+00	3.38E+01	1.63E-01	1.91E+00
40	6.12E+05	7.55E+02	2.44E+02	9.22E+01	1.30E+03	4.66E-02	1.33E-01	7.65E-05	5.31E-02	5.23E-06	7.39E-01	4.72E-03	8.23E-01	2.30E-02	1.64E-01	1.57E+00	7.60E-03	8.87E-02
41	3.46E+05	2.35E+03	-	-	-	-	1.17E+00	6.76E-04	4.70E-01	4.63E-05	6.53E+00	4.18E-02	7.27E+00	2.03E-01	1.45E+00	1.39E+01	6.72E-02	7.85E-01
42	1.27E+06	6.81E+03	2.43E+02	8.72E+01	1.49E+03	7.98E-02	3.93E+01	2.27E-02	1.57E+01	1.55E-03	2.19E+02	1.40E+00	2.44E+02	6.82E+00	4.87E+01	4.66E+02	2.25E+00	2.63E+01
43	9.45E+05	6.46E+03	2.55E+01	2.15E+01	5.53E+03	3.18E-01	6.18E-01	3.56E-04	2.48E-01	2.44E-05	3.44E+00	2.20E-02	3.83E+00	1.07E-01	7.66E-01	7.32E+00	3.54E-02	4.14E-01
44	5.64E+05	4.66E-03	7.30E-04	1.63E-04	3.84E-03	3.25E-08	9.58E+00	5.53E-03	3.84E+00	3.78E-04	5.34E+01	3.41E-01	5.94E+01	1.66E+00	1.19E+01	1.13E+02	5.49E-01	6.41E+00
45	5.11E+05	4.22E-03	6.61E-04	1.48E-04	3.48E-03	2.95E-08	8.21E+00	4.73E-03	3.29E+00	3.24E-04	4.57E+01	2.92E-01	5.09E+01	1.42E+00	1.02E+01	9.71E+01	4.70E-01	5.49E+00
46	6.72E+05	5.55E-03	8.70E-04	1.94E-04	4.58E-03	3.88E-08	1.62E+01	9.34E-03	6.49E+00	6.39E-04	9.02E+01	5.77E-01	1.00E+02	2.81E+00	2.01E+01	1.92E+02	9.27E-01	1.08E+01
47	5.97E+05	3.50E+03	5.03E+02	1.12E+02	2.18E+03	2.31E-02	2.66E+00	1.53E-03	1.06E+00	1.05E-04	1.48E+01	9.46E-02	1.65E+01	4.61E-01	3.29E+00	3.14E+01	1.52E-01	1.78E+00
48	2.40E+05	1.36E+03	2.46E+00	-	-	-	1.31E+00	7.57E-04	5.26E-01	5.18E-05	7.31E+00	4.68E-02	8.15E+00	2.28E-01	1.63E+00	1.55E+01	7.52E-02	8.79E-01
49	1.92E+05	3.75E-05	1.01E-06	4.19E-07	7.39E-06	2.78E-10	4.77E-02	2.75E-05	1.91E-02	1.88E-06	2.66E-01	1.70E-03	2.96E-01	8.27E-03	5.91E-02	5.65E-01	2.73E-03	3.19E-02
50	4.24E+05	1.62E-02	1.03E-01	1.12E-03	1.63E-05	6.15E-10	6.53E-03	1.99E-08	7.56E-04	1.36E-09	1.92E-04	1.23E-06	2.14E-04	5.99E-06	4.28E-05	4.09E-04	1.98E-06	2.31E-05
51	6.93E+05	4.23E+03	5.66E+01	3.21E+01	1.61E+03	5.80E-02	8.26E-01	4.76E-04	3.31E-01	3.26E-05	4.60E+00	2.94E-02	5.12E+00	1.43E-01	1.02E+00	9.78E+00	4.73E-02	5.53E-01
Phase Totals	2.39E+07	5.74E+04	3.37E+03	9.06E+02	3.75E+04	9.39E-01	3.63E+02	2.09E-01	1.45E+02	1.43E-02	2.02E+03	1.29E+01	2.25E+03	6.30E+01	4.50E+02	4.30E+03	2.08E+01	2.43E+02

Table 6: Soluble Radionuclide Inventory by Tank, continued

Tank	Total Supernate Volume, gal	Ra-226 (Ci)	Ra-228 (Ci)	Ac-227 (Ci)	Th-229 (Ci)	Th-230 (Ci)	Pa-231 (Ci)	Pu-244 (Ci)	Am-243 (Ci)	Cm-242 (Ci)	Cm-243 (Ci)	Cm-247 (Ci)	Cm-248 (Ci)	Bk-249 (Ci)	Cf-249 (Ci)	Cf-251 (Ci)	Cf-252 (Ci)
1	1.66E+05	-	-	5.31E-08	-	-	1.47E-07	3.68E-07	2.02E-03	4.99E-03	1.18E-03	2.28E-13	2.37E-13	1.73E-20	1.32E-12	4.50E-14	1.46E-15
2	1.64E+05	-	-	1.37E-08	-	-	3.81E-08	3.07E-07	7.38E-04	1.82E-03	4.32E-04	8.32E-14	8.67E-14	6.34E-21	4.81E-13	1.65E-14	5.34E-16
3	1.64E+05	-	-	3.52E-08	-	-	9.79E-08	3.80E-07	7.48E-04	1.85E-03	4.38E-04	8.44E-14	8.79E-14	6.43E-21	4.88E-13	1.67E-14	5.41E-16
4	3.99E+05	-	-	5.43E-08	-	-	1.51E-07	3.85E-07	2.15E-03	5.31E-03	1.26E-03	2.42E-13	2.53E-13	1.85E-20	1.40E-12	4.79E-14	1.56E-15
5	1.71E+04	-	-	6.83E-09	-	-	1.90E-08	4.44E-08	1.90E-05	4.68E-05	1.11E-05	2.14E-15	2.23E-15	1.63E-22	1.24E-14	4.23E-16	1.37E-17
6	2.71E+05	-	-	8.09E-08	-	-	2.25E-07	4.24E-06	6.15E-05	1.52E-04	3.60E-05	6.94E-15	7.23E-15	5.28E-22	4.01E-14	1.37E-15	4.45E-17
7	2.90E+05	-	-	7.34E-08	-	-	2.04E-07	5.09E-06	3.06E-04	7.57E-04	1.79E-04	3.46E-14	3.60E-14	2.63E-21	2.00E-13	6.83E-15	2.22E-16
8	1.02E+04	-	-	1.82E-09	-	-	5.05E-09	1.42E-07	4.33E-06	1.07E-05	2.53E-06	4.88E-16	5.09E-16	3.72E-23	2.82E-15	9.65E-17	3.13E-18
9	1.75E+05	-	-	2.66E-08	-	-	7.39E-08	1.30E-07	7.74E-04	1.91E-03	4.53E-04	8.73E-14	9.10E-14	6.65E-21	5.04E-13	1.73E-14	5.60E-16
10	6.53E+04	-	-	1.20E-08	-	-	3.33E-08	1.53E-07	5.04E-05	1.24E-04	2.95E-05	5.68E-15	5.92E-15	4.33E-22	3.28E-14	1.12E-15	3.65E-17
11	1.56E+05	7.42E-10	2.81E-06	1.42E-09	1.14E-06	9.08E-08	3.94E-09	1.79E-06	2.88E-08	7.11E-08	1.68E-08	3.24E-18	3.38E-18	2.47E-25	1.87E-17	6.41E-19	2.08E-20
12	1.18E+05	1.24E-09	2.09E-04	2.37E-09	1.67E-05	1.52E-07	6.57E-09	1.30E-06	7.54E-05	1.86E-04	4.42E-05	8.51E-15	8.86E-15	6.48E-22	4.92E-14	1.68E-15	5.46E-17
13	7.54E+05	2.66E-08	4.08E-04	7.37E-08	2.38E-04	3.26E-06	2.05E-07	3.77E-06	7.22E-03	1.78E-02	4.23E-03	8.14E-13	8.48E-13	6.20E-20	4.70E-12	1.61E-13	5.22E-15
14	5.95E+04	1.50E-09	1.38E-04	1.23E-08	1.38E-05	1.84E-07	3.42E-08	2.12E-07	6.10E-04	1.51E-03	3.57E-04	6.88E-14	7.17E-14	5.24E-21	3.97E-13	1.36E-14	4.41E-16
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	1.18E+06	9.13E-08	1.20E-06	1.47E-07	1.08E-04	1.12E-05	4.07E-07	5.17E-07	9.62E-07	2.38E-06	5.63E-07	1.08E-16	1.13E-16	8.26E-24	6.27E-16	2.14E-17	6.96E-19
22	1.18E+06	1.27E-07	-	1.97E-07	4.47E-04	1.56E-05	5.48E-07	-	1.05E-06	2.58E-06	6.13E-07	1.18E-16	1.23E-16	8.98E-24	6.82E-16	2.33E-17	7.57E-19
23	1.30E+06	1.30E+01	1.78E-07	2.39E-08	3.37E-05	3.42E-02	6.63E-08	4.91E-05	1.61E-07	3.97E-07	9.42E-08	1.81E-17	1.89E-17	1.38E-24	1.05E-16	3.59E-18	1.16E-19
24	8.53E+05	8.39E-20	-	2.52E-12	3.32E-17	1.03E-17	6.99E-12	2.25E-10	2.90E-04	7.17E-04	1.70E-04	3.27E-14	3.41E-14	2.49E-21	1.89E-13	6.47E-15	2.10E-16
25	3.66E+05	3.60E-20	-	1.08E-12	1.43E-17	4.41E-18	3.00E-12	9.65E-11	8.46E-04	2.09E-03	4.96E-04	9.55E-14	9.95E-14	7.27E-21	5.52E-13	1.89E-14	6.13E-16
26	7.01E+05	4.83E-14	-	1.45E-06	1.91E-11	5.91E-12	4.02E-06	1.29E-04	3.06E-03	7.56E-03	1.79E-03	3.45E-13	3.60E-13	2.63E-20	1.99E-12	6.82E-14	2.21E-15
27	7.83E+05	7.70E-20	-	2.31E-12	3.05E-17	9.42E-18	6.41E-12	2.06E-10	3.88E-03	9.60E-03	2.27E-03	4.38E-13	4.57E-13	3.34E-20	2.53E-12	8.66E-14	2.81E-15
28	4.94E+05	4.86E-20	-	1.46E-12	1.92E-17	5.95E-18	4.05E-12	1.30E-10	1.35E-03	3.35E-03	7.93E-04	1.53E-13	1.59E-13	1.16E-20	8.83E-13	3.02E-14	9.80E-16
29	4.74E+05	2.22E-14	-	6.14E-14	1.99E-10	2.72E-12	1.71E-13	3.14E-12	2.90E-04	7.16E-04	1.70E-04	3.27E-14	3.41E-14	2.49E-21	1.89E-13	6.46E-15	2.10E-16
30	9.90E+05	7.78E-08	-	1.40E-07	-	9.52E-06	3.88E-07	4.54E-04	6.50E-03	1.61E-02	3.81E-03	7.33E-13	7.64E-13	5.58E-20	4.24E-12	1.45E-13	4.71E-15
31	4.59E+05	2.15E-14	-	5.95E-14	1.92E-10	2.63E-12	1.65E-13	3.04E-12	3.20E-03	7.90E-03	1.87E-03	3.61E-13	3.76E-13	2.75E-20	2.08E-12	7.13E-14	2.31E-15
32	9.13E+05	9.31E-08	-	1.35E-07	-	1.14E-05	3.74E-07	3.76E-04	4.37E-03	1.08E-02	2.56E-03	4.93E-13	5.14E-13	3.75E-20	2.85E-12	9.75E-14	3.16E-15
33	9.42E+05	4.06E-09	-	7.72E-06	2.49E-10	4.97E-07	2.14E-05	6.36E-05	2.34E-03	5.78E-03	1.37E-03	2.64E-13	2.75E-13	2.01E-20	1.53E-12	5.22E-14	1.69E-15
34	6.40E+05	-	-	7.80E-07	-	-	2.17E-06	8.27E-06	1.94E-03	4.78E-03	1.13E-03	2.18E-13	2.27E-13	1.66E-20	1.26E-12	4.32E-14	1.40E-15
35	4.94E+05	4.91E-08	-	8.65E-08	-	6.01E-06	2.40E-07	2.07E-04	1.23E-03	3.03E-03	7.18E-04	1.38E-13	1.44E-13	1.05E-20	7.99E-13	2.73E-14	8.88E-16
36	5.30E+05	9.17E-08	-	1.80E-07	-	1.12E-05	5.00E-07	2.16E-04	6.80E-03	1.68E-02	3.98E-03	7.67E-13	7.99E-13	5.84E-20	4.43E-12	1.52E-13	4.92E-15
37	4.60E+05	2.15E-14	-	5.96E-14	1.93E-10	2.63E-12	1.66E-13	3.05E-12	2.68E-03	6.63E-03	1.57E-03	3.03E-13	3.15E-13	2.30E-20	1.75E-12	5.98E-14	1.94E-15
38	4.20E+05	2.82E-13	-	3.94E-13	-	3.45E-11	1.09E-12	6.82E-10	8.38E-05	2.07E-04	4.91E-05	9.45E-15	9.85E-15	7.20E-22	5.46E-14	1.87E-15	6.07E-17
39	7.95E+05	2.13E-07	-	3.11E-07	-	2.60E-05	8.64E-07	3.96E-04	5.46E-04	1.35E-03	3.19E-04	6.15E-14	6.41E-14	4.69E-21	3.56E-13	1.22E-14	3.95E-16
40	6.12E+05	9.02E-08	1.46E-03	1.72E-06	1.18E-04	1.10E-05	4.78E-06	2.13E-04	2.54E-05	6.27E-05	1.49E-05	2.86E-15	2.98E-15	2.18E-22	1.65E-14	5.66E-16	1.84E-17
41	3.46E+05	3.24E-07	-	3.79E-07	-	3.96E-05	1.05E-06	-	2.24E-04	5.55E-04	1.31E-04	2.53E-14	2.64E-14	1.93E-21	1.46E-13	5.00E-15	1.62E-16
42	1.27E+06	1.18E-06	1.01E-01	2.82E-06	4.05E-03	1.45E-04	7.84E-06	3.65E-04	7.52E-03	1.86E-02	4.41E-03	8.49E-13	8.85E-13	6.46E-20	4.90E-12	1.68E-13	5.45E-15
43	9.45E+05	6.01E-07	-	8.39E-07	-	7.35E-05	2.33E-06	1.45E-03	1.18E-04	2.92E-04	6.93E-05	1.33E-14	1.39E-14	1.02E-21	7.71E-14	2.64E-15	8.56E-17
44	5.64E+05	5.55E-20	-	1.66E-12	2.20E-17	6.79E-18	4.62E-12	1.49E-10	1.83E-03	4.53E-03	1.07E-03	2.07E-13	2.16E-13	1.57E-20	1.20E-12	4.09E-14	1.33E-15
45	5.11E+05	5.02E-20	-	1.51E-12	1.99E-17	6.15E-18	4.18E-12	1.35E-10	1.57E-03	3.88E-03	9.19E-04	1.77E-13	1.85E-13	1.35E-20	1.02E-12	3.50E-14	1.14E-15
46	6.72E+05	6.61E-20	-	1.98E-12	2.62E-17	8.09E-18	5.50E-12	1.77E-10	3.10E-03	7.66E-03	1.81E-03	3.50E-13	3.64E-13	2.66E-20	2.02E-12	6.91E-14	2.24E-15
47	5.97E+05	-	-	9.45E-07	-	-	2.62E-06	1.06E-04	5.08E-04	1.26E-03	2.98E-04	5.73E-14	5.97E-14	4.36E-21	3.31E-13	1.13E-14	3.68E-16
48	2.40E+05	6.34E-06	-	4.31E-07	2.33E-03	7.76E-04	1.20E-06	-	2.51E-04	6.21E-04	1.47E-04	2.84E-14	2.95E-14	2.16E-21	1.64E-13	5.61E-15	1.82E-16
49	1.92E+05	8.98E-15	-	2.49E-14	8.03E-11	1.10E-12	6.91E-14	1.27E-12	9.12E-06	2.25E-05	5.34E-06	1.03E-15	1.07E-15	7.84E-23	5.95E-15	2.03E-16	6.60E-18
50	4.24E+05	1.99E-14	7.00E-07	2.64E-08	1.78E-10	2.43E-12	7.33E-08	1.96E-06	6.61E-09	1.63E-08	3.87E-09	7.45E-19	7.77E-19	5.68E-26	4.31E-18	1.47E-19	4.78E-21
51	6.93E+05	1.09E-07	4.80E-04	2.89E-07	1.66E-04	1.34E-05	8.01E-07	2.65E-04	1.58E-04	3.91E-04	9.26E-05	1.78E-14	1.86E-14	1.36E-21	1.03E-13	3.52E-15	1.14E-16
Phase Totals	2.39E+07	1.30E+01	1.04E-01	1.91E-05	7.53E-03	3.53E-02	5.30E-05	4.32E-03	6.95E-02	1.72E-01	4.07E-02	7.84E-12	8.17E-12	5.97E-19	4.53E-11	1.55E-12	5.03E-14

Table 6: Soluble Radionuclide Inventory by Tank, continued

Tank	Free Supernate Volume, gal	H-3 (Ci)	C-14 (Ci)	Co-60 (Ci)	Ni-59 (Ci)	Ni-63 (Ci)	Se-79 (Ci)	Sr-90 (Ci)	Y-90 (Ci)	Nb-94 (Ci)	Tc-99 (Ci)	Ru-106 (Ci)	Rh-106 (Ci)	Sb-125 (Ci)	Sn-126 (Ci)	I-129 (Ci)
1	1.71E+04	6.46E+00	1.14E-01	6.66E-02	7.17E-03	1.62E-01	2.66E-01	8.33E+01	8.33E+01	2.09E-06	9.86E+01	6.80E+00	6.80E+00	2.76E+01	1.34E+00	5.31E-02
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	2.99E+05	1.13E+02	2.00E+00	1.17E+00	5.58E-02	2.83E+00	2.07E+00	6.48E+02	6.48E+02	1.63E-05	7.67E+02	5.29E+01	5.29E+01	2.14E+02	1.05E+01	4.14E-01
5	3.64E-12	1.38E-15	2.42E-17	1.42E-17	1.39E-19	3.44E-17	5.15E-18	1.61E-15	1.61E-15	4.05E-23	1.91E-15	1.32E-16	1.32E-16	5.34E-16	2.60E-17	1.03E-18
6	2.54E+05	6.76E+02	1.69E+00	9.90E-01	1.99E-03	2.40E+00	7.37E-02	2.31E+01	2.31E+01	5.79E-07	2.73E+01	1.88E+00	1.88E+00	7.64E+00	3.72E-01	1.47E-02
7	2.76E+05	1.13E+02	1.84E+00	1.08E+00	1.01E-02	2.62E+00	3.74E-01	1.05E+02	1.05E+02	2.94E-06	1.39E+02	9.56E+00	9.56E+00	3.87E+01	1.89E+00	7.47E-02
8	7.28E+03	1.68E+02	4.85E-02	2.84E-02	1.07E-04	6.89E-02	3.97E-03	1.25E+00	1.25E+00	3.13E-08	1.47E+00	1.02E-01	1.02E-01	4.12E-01	2.01E-02	7.95E-04
9	1.30E+04	4.92E+00	8.67E-02	5.07E-02	1.99E-03	1.23E-01	7.36E-02	2.31E+01	2.31E+01	5.79E-07	2.73E+01	1.88E+00	1.88E+00	7.63E+00	3.72E-01	1.47E-02
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	1.42E+05	5.36E+01	9.44E-01	5.53E-01	9.05E-07	1.34E+00	3.35E-05	9.47E-03	9.47E-03	2.64E-10	1.24E-02	8.58E-04	8.58E-04	3.48E-03	1.70E-04	6.71E-06
12	2.46E+04	9.33E+00	1.64E-01	9.61E-02	5.42E-04	2.33E-01	2.01E-02	6.29E+00	6.29E+00	1.58E-07	7.45E+00	5.14E-01	5.14E-01	2.08E+00	1.02E-01	4.02E-03
13	5.78E+05	2.19E+02	3.85E+00	2.25E+00	1.91E-01	5.47E+00	7.08E+00	2.22E+03	2.22E+03	5.57E-05	2.62E+03	1.81E+02	1.81E+02	7.34E+02	3.58E+01	1.42E+00
14	1.05E+03	3.97E-01	7.00E-03	4.09E-03	3.72E-04	9.94E-03	1.38E-02	4.32E+00	4.32E+00	1.08E-07	5.11E+00	3.52E-01	3.52E-01	1.43E+00	6.97E-02	2.75E-03
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	1.18E+06	4.45E+02	7.83E+00	4.58E+00	3.31E-05	1.11E+01	1.23E-03	3.83E-01	3.83E-01	9.65E-09	4.55E-01	3.14E-02	3.14E-02	1.27E-01	6.20E-03	2.93E-03
22	1.17E+06	4.43E+02	7.79E+00	4.56E+00	3.59E-05	1.11E+01	1.33E-03	4.13E-01	4.13E-01	1.05E-08	4.94E-01	3.41E-02	3.40E-02	1.38E-01	6.73E-03	2.91E-03
23	1.26E+06	4.90E+00	1.96E-01	4.10E-03	5.39E-06	1.79E-01	2.00E-04	1.52E+00	1.52E+00	1.57E-09	3.20E-01	5.11E-03	5.11E-03	2.07E-02	1.01E-03	2.76E-03
24	8.51E+05	3.22E+02	5.67E+00	3.32E+00	9.99E-03	8.05E+00	3.70E-01	1.16E+02	1.16E+02	2.91E-06	1.37E+02	9.47E+00	9.47E+00	3.84E+01	1.87E+00	2.47E-02
25	3.69E+04	1.40E+01	2.46E-01	1.44E-01	2.94E-03	3.49E-01	1.09E-01	3.41E+01	3.41E+01	8.57E-07	4.04E+01	2.79E+00	2.79E+00	1.13E+01	5.51E-01	2.18E-02
26	5.19E+05	1.96E+02	3.46E+00	2.02E+00	7.83E-02	4.91E+00	2.90E+00	9.51E+02	9.51E+02	2.28E-05	1.08E+03	7.42E+01	7.42E+01	3.01E+02	1.47E+01	5.80E-01
27	6.00E+05	2.27E+02	4.00E+00	2.34E+00	1.03E-01	5.68E+00	3.81E+00	1.18E+03	1.18E+03	3.00E-05	1.41E+03	9.75E+01	9.75E+01	3.95E+02	1.93E+01	7.62E-01
28	1.85E+05	7.02E+01	1.23E+00	7.23E-01	1.76E-02	1.75E+00	6.50E-01	2.04E+02	2.04E+02	5.12E-06	2.41E+02	1.66E+01	1.66E+01	6.74E+01	3.29E+00	1.30E-01
29	1.67E+05	6.32E+01	1.11E+00	6.51E-01	3.53E-03	1.58E+00	1.31E-01	4.10E+01	4.10E+01	1.03E-06	4.85E+01	3.35E+00	3.34E+00	1.36E+01	6.61E-01	2.61E-02
30	9.15E+05	3.46E+02	6.10E+00	3.57E+00	2.08E-01	8.66E+00	7.69E+00	2.41E+03	2.41E+03	6.05E-05	2.85E+03	1.97E+02	1.97E+02	7.97E+02	3.89E+01	1.54E+00
31	1.15E+05	4.36E+01	7.67E-01	4.49E-01	2.77E-02	1.09E+00	1.03E+00	3.22E+02	3.22E+02	8.07E-06	3.81E+02	2.63E+01	2.62E+01	1.06E+02	5.19E+00	2.05E-01
32	8.44E+05	3.20E+02	5.63E+00	3.29E+00	1.40E-01	7.99E+00	5.17E+00	1.40E+03	1.40E+03	4.07E-05	1.92E+03	1.32E+02	1.32E+02	5.36E+02	2.62E+01	1.03E+00
33	7.95E+05	4.05E+02	5.30E+00	3.10E+00	6.83E-02	7.52E+00	2.53E+00	7.92E+02	7.92E+02	1.99E-05	9.38E+02	6.47E+01	6.47E+01	2.62E+02	1.28E+01	5.06E-01
34	5.69E+05	2.15E+02	3.79E+00	2.22E+00	5.94E-02	5.38E+00	2.20E+00	6.90E+02	6.90E+02	1.73E-05	8.16E+02	5.63E+01	5.63E+01	2.28E+02	1.11E+01	4.40E-01
35	4.50E+05	1.70E+02	3.00E+00	1.75E+00	3.86E-02	4.26E+00	1.43E+00	4.48E+02	4.48E+02	1.12E-05	5.30E+02	3.66E+01	3.66E+01	1.48E+02	7.23E+00	2.86E-01
36	2.20E+05	8.32E+01	1.46E+00	8.57E-01	9.74E-02	2.08E+00	3.61E+00	1.13E+03	1.13E+03	2.84E-05	1.34E+03	9.23E+01	9.22E+01	3.74E+02	1.82E+01	7.21E-01
37	1.16E+05	4.40E+01	7.75E-01	4.54E-01	2.35E-02	1.10E+00	8.69E-01	2.49E+02	2.49E+02	6.84E-06	3.22E+02	2.22E+01	2.22E+01	9.01E+01	4.39E+00	1.74E-01
38	1.71E+05	6.49E+01	1.14E+00	6.68E-01	1.18E-03	1.62E+00	4.38E-02	1.37E+01	1.37E+01	3.45E-07	1.62E+01	1.12E+00	1.12E+00	4.54E+00	2.22E-01	8.76E-03
39	7.22E+05	2.73E+02	4.81E+00	2.82E+00	1.71E-02	6.84E+00	6.35E-01	1.49E+02	1.49E+02	4.99E-06	2.35E+02	1.62E+01	1.62E+01	6.58E+01	3.21E+00	1.27E-01
40	3.05E+05	1.15E+02	2.03E+00	1.19E+00	4.37E-04	2.89E+00	1.62E-02	5.28E+00	5.28E+00	1.27E-07	6.00E+00	4.14E-01	4.14E-01	1.68E+00	8.18E-02	3.24E-03
41	1.24E+05	4.70E+01	8.28E-01	4.84E-01	2.79E-03	1.18E+00	1.03E-01	1.14E+01	1.14E+01	8.12E-07	3.83E+01	2.64E+00	2.64E+00	1.07E+01	5.22E-01	2.06E-02
42	1.25E+06	4.75E+02	8.36E+00	4.89E+00	2.57E-01	1.19E+01	9.53E+00	2.98E+03	2.98E+03	7.49E-05	3.53E+03	2.44E+02	2.44E+02	9.88E+02	4.82E+01	1.91E+00
43	7.76E+05	2.94E+02	5.17E+00	3.03E+00	3.36E-03	7.34E+00	1.24E-01	3.37E+01	3.37E+01	9.78E-07	4.61E+01	3.18E+00	3.18E+00	1.29E+01	6.29E-01	2.49E-02
44	2.63E+05	9.97E+01	1.75E+00	1.03E+00	2.96E-02	2.49E+00	1.10E+00	3.43E+02	3.43E+02	8.62E-06	4.06E+02	2.80E+01	2.80E+01	1.14E+02	5.54E+00	2.19E-01
45	1.80E+05	6.79E+01	1.20E+00	7.00E-01	1.91E-02	1.70E+00	7.06E-01	2.21E+02	2.21E+02	5.55E-06	2.62E+02	1.81E+01	1.81E+01	7.32E+01	3.57E+00	1.41E-01
46	4.13E+05	1.56E+02	2.75E+00	1.61E+00	6.58E-02	3.91E+00	2.44E+00	7.63E+02	7.63E+02	1.92E-05	9.03E+02	6.23E+01	6.23E+01	2.53E+02	1.23E+01	4.87E-01
47	1.73E+05	6.55E+01	1.15E+00	6.74E-01	5.09E-03	1.64E+00	1.88E-01	5.90E+01	5.90E+01	1.48E-06	6.99E+01	4.82E+00	4.82E+00	1.95E+01	9.53E-01	3.77E-02
48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	1.92E+05	7.26E+01	1.28E+00	7.47E-01	3.15E-04	1.81E+00	1.17E-02	2.68E+01	2.68E+01	9.18E-08	4.33E+00	2.99E-01	2.99E-01	1.21E+00	5.90E-02	2.34E-03
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	5.82E+05	2.20E+02	3.88E+00	2.27E+00	4.59E-03	5.51E+00	1.70E-01	4.25E+01	4.25E+01	1.34E-06	6.30E+01	4.35E+00	4.35E+00	1.76E+01	8.59E-01	3.40E-02
Phase Totals	1.66E+07	6.73E+03	1.03E+02	6.04E+01	1.55E+00	1.47E+02	5.75E+01	1.77E+04	1.77E+04	4.53E-04	2.13E+04	1.47E+03	1.47E+03	5.96E+03	2.91E+02	1.15E+01

Table 6: Soluble Radionuclide Inventory by Tank, continued

Tank	Free Supernate Volume, gal	Cs-134 (Ci)	Cs-135 (Ci)	Cs-137 (Ci)	Ba-137m (Ci)	Ce-144 (Ci)	Pr-144 (Ci)	Pm-147 (Ci)	Eu-154 (Ci)	Th-232 (Ci)	U-232 (Ci)	U-233 (Ci)	U-234 (Ci)	U-235 (Ci)	U-236 (Ci)	U-238 (Ci)	Np-237 (Ci)
1	1.71E+04	6.79E+02	1.15E+00	3.39E+05	3.20E+05	1.77E-02	1.77E-02	1.15E+01	2.72E+00	-	1.55E-05	-	-	2.39E-05	-	5.96E-04	8.69E-04
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	2.99E+05	5.29E+03	8.98E+00	2.63E+06	2.49E+06	1.38E-01	1.38E-01	8.92E+01	2.11E+01	-	1.36E-04	-	-	1.79E-04	-	7.70E-03	6.87E-03
5	3.64E-12	1.32E-14	2.24E-17	6.56E-12	6.20E-12	3.43E-19	3.43E-19	2.22E-16	5.26E-17	-	3.27E-21	-	-	6.35E-21	-	1.50E-19	2.54E-19
6	2.54E+05	1.88E+02	3.20E-01	9.38E+04	8.88E+04	4.91E-03	4.91E-03	3.18E+00	7.53E-01	-	2.68E-04	-	-	3.32E-04	-	1.24E-02	4.30E-03
7	2.76E+05	9.55E+02	1.62E+00	4.76E+05	4.50E+05	2.49E-02	2.49E-02	1.61E+01	3.82E+00	-	6.56E-05	-	-	3.07E-04	-	1.06E-02	5.28E-03
8	7.28E+03	1.02E+01	1.73E-02	5.06E+03	4.79E+03	2.65E-04	2.65E-04	1.71E-01	4.06E-02	-	2.16E-06	-	-	5.72E-06	-	2.63E-04	1.19E-04
9	1.30E+04	1.88E+02	3.20E-01	9.38E+04	8.87E+04	4.91E-03	4.91E-03	3.17E+00	7.53E-01	-	1.34E-05	-	-	8.66E-06	-	2.16E-04	1.48E-03
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	1.42E+05	8.57E-02	1.46E-04	4.27E+01	4.04E+01	2.24E-06	2.23E-06	1.45E-03	3.43E-04	2.56E-06	-	3.66E-04	3.00E-04	5.66E-06	4.64E-05	1.05E-05	1.98E-04
12	2.46E+04	5.13E+01	8.72E-02	2.56E+04	2.42E+04	1.34E-03	1.34E-03	8.66E-01	2.05E-01	4.35E-05	4.38E-07	1.22E-03	1.15E-04	2.16E-06	9.09E-06	2.17E-05	2.54E-04
13	5.78E+05	1.81E+04	3.07E+01	9.01E+06	8.53E+06	4.72E-01	4.72E-01	3.05E+02	7.23E+01	3.13E-04	8.32E-05	6.41E-02	9.05E-03	2.47E-04	9.33E-04	2.89E-03	2.33E-02
14	1.05E+03	3.52E+01	5.98E-02	1.75E+04	1.66E+04	9.18E-04	9.18E-04	5.94E-01	1.41E-01	2.43E-06	7.20E-07	8.57E-05	1.18E-05	9.52E-07	1.01E-06	1.82E-05	1.26E-04
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	1.18E+06	3.14E+00	5.33E-03	1.56E+03	1.48E+03	8.18E-05	8.18E-05	5.29E-02	1.25E-02	1.20E-06	-	3.78E-02	4.04E-02	6.40E-04	7.40E-03	3.79E-03	3.35E-02
22	1.17E+06	3.40E+00	5.78E-03	1.70E+03	1.60E+03	8.87E-05	8.87E-05	5.74E-02	1.36E-02	-	-	1.56E-01	5.62E-02	8.59E-04	9.25E-03	1.91E-02	3.41E-02
23	1.26E+06	1.32E-02	1.95E-02	2.54E+02	2.41E+02	1.33E-05	1.33E-05	8.61E-03	2.04E-03	1.72E-07	-	1.15E-02	1.82E-02	1.01E-04	4.09E-04	3.04E-03	8.43E-04
24	8.51E+05	9.46E+02	1.61E+00	4.72E+05	4.46E+05	2.47E-02	2.47E-02	1.60E+01	3.79E+00	-	3.82E-09	1.16E-14	3.71E-14	1.10E-08	1.42E-09	1.32E-06	3.40E-09
25	3.69E+04	2.79E+02	4.73E-01	1.39E+05	1.31E+05	7.26E-03	7.26E-03	4.70E+00	1.11E+00	-	1.66E-10	5.04E-16	1.61E-15	4.76E-10	6.15E-11	5.71E-08	1.47E-10
26	5.19E+05	7.42E+03	1.26E+01	3.70E+06	3.50E+06	1.93E-01	1.93E-01	1.25E+02	2.97E+01	-	1.63E-03	4.97E-09	1.59E-08	4.70E-03	6.06E-04	5.64E-01	1.45E-03
27	6.00E+05	9.75E+03	1.66E+01	4.86E+06	4.59E+06	2.54E-01	2.54E-01	1.64E+02	3.90E+01	-	2.70E-09	8.21E-15	2.62E-14	7.75E-09	1.00E-09	9.31E-07	2.40E-09
28	1.85E+05	1.66E+03	2.82E+00	8.28E+05	7.84E+05	4.33E-02	4.33E-02	2.80E+01	6.65E+00	-	8.33E-10	2.53E-15	8.09E-15	2.39E-09	3.09E-10	2.87E-07	7.41E-10
29	1.67E+05	3.34E+02	5.68E-01	1.67E+05	1.58E+05	8.71E-03	8.71E-03	5.64E+00	1.34E+00	-	3.19E-11	2.46E-08	3.47E-09	9.49E-11	3.58E-10	1.11E-09	8.93E-09
30	9.15E+05	1.97E+04	3.34E+01	9.80E+06	9.27E+06	5.13E-01	5.12E-01	3.32E+02	7.86E+01	-	-	-	3.19E-02	5.66E-04	5.89E-03	2.10E-05	1.44E-02
31	1.15E+05	2.62E+03	4.46E+00	1.31E+06	1.24E+06	6.84E-02	6.84E-02	4.43E+01	1.05E+01	-	2.20E-11	1.70E-08	2.39E-09	6.54E-11	2.47E-10	7.65E-10	6.15E-09
32	8.44E+05	1.32E+04	2.25E+01	6.59E+06	6.23E+06	3.45E-01	3.45E-01	2.23E+02	5.29E+01	-	-	-	3.82E-02	5.46E-04	8.57E-03	2.57E-04	1.58E-02
33	7.95E+05	6.46E+03	1.10E+01	3.22E+06	3.05E+06	1.69E-01	1.68E-01	1.09E+02	2.59E+01	-	1.54E-02	7.38E-08	1.52E-03	2.85E-02	1.58E-02	4.13E+00	1.30E+00
34	5.69E+05	5.63E+03	9.56E+00	2.80E+06	2.65E+06	1.47E-01	1.47E-01	9.49E+01	2.25E+01	-	3.01E-03	-	-	3.04E-03	-	2.15E-01	1.66E-01
35	4.50E+05	3.65E+03	6.21E+00	1.82E+06	1.72E+06	9.53E-02	9.53E-02	6.16E+01	1.46E+01	-	-	-	1.99E-02	3.45E-04	5.86E-03	2.04E-04	7.18E-03
36	2.20E+05	9.22E+03	1.57E+01	4.59E+06	4.35E+06	2.40E-01	2.40E-01	1.56E+02	3.69E+01	-	-	-	1.69E-02	3.27E-04	5.95E-03	1.07E-04	4.72E-03
37	1.16E+05	2.22E+03	3.77E+00	1.11E+06	1.05E+06	5.79E-02	5.79E-02	3.75E+01	8.88E+00	-	2.22E-11	1.71E-08	2.42E-09	6.61E-11	2.49E-10	7.73E-10	6.21E-09
38	1.71E+05	1.12E+02	1.90E-01	5.58E+04	5.28E+04	2.92E-03	2.92E-03	1.89E+00	4.48E-01	-	-	-	5.11E-08	7.05E-10	9.74E-09	5.73E-11	5.45E-08
39	7.22E+05	1.62E+03	2.76E+00	8.09E+05	7.65E+05	4.23E-02	4.23E-02	2.74E+01	6.49E+00	-	-	-	8.58E-02	1.24E-03	1.47E-02	2.62E-04	5.39E-02
40	3.05E+05	4.14E+01	7.03E-02	2.06E+04	1.95E+04	1.08E-03	1.08E-03	6.98E-01	1.65E-01	7.28E-04	8.09E-04	2.07E-02	1.99E-02	3.76E-03	4.97E-03	1.18E-01	4.11E-01
41	1.24E+05	2.64E+02	4.48E-01	1.31E+05	1.24E+05	6.88E-03	6.88E-03	4.45E+00	1.06E+00	-	-	-	5.16E-02	5.97E-04	1.48E-02	4.09E-05	1.54E-01
42	1.25E+06	2.44E+04	4.14E+01	1.21E+07	1.15E+07	6.35E-01	6.35E-01	4.11E+02	9.74E+01	1.00E-01	3.54E-04	1.41E+00	5.19E-01	1.22E-02	6.93E-02	2.15E-01	4.27E-01
43	7.76E+05	3.18E+02	5.40E-01	1.58E+05	1.50E+05	8.29E-03	8.28E-03	5.36E+00	1.27E+00	-	-	-	2.19E-01	3.02E-03	4.17E-02	2.45E-04	2.33E-01
44	2.63E+05	2.80E+03	4.76E+00	1.40E+06	1.32E+06	7.30E-02	7.30E-02	4.72E+01	1.12E+01	-	1.18E-09	3.60E-15	1.15E-14	3.40E-09	4.39E-10	4.08E-07	1.05E-09
45	1.80E+05	1.81E+03	3.07E+00	8.99E+05	8.51E+05	4.71E-02	4.70E-02	3.04E+01	7.22E+00	-	8.07E-10	2.45E-15	7.83E-15	2.32E-09	2.99E-10	2.78E-07	7.18E-10
46	4.13E+05	6.23E+03	1.06E+01	3.10E+06	2.94E+06	1.62E-01	1.62E-01	1.05E+02	2.49E+01	-	1.86E-09	5.64E-15	1.80E-14	5.33E-09	6.88E-10	6.40E-07	1.65E-09
47	1.73E+05	4.82E+02	8.18E-01	2.40E+05	2.27E+05	1.26E-02	1.26E-02	8.13E+00	1.93E+00	-	4.41E-04	-	-	1.20E-03	-	9.50E-02	-
48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	1.92E+05	2.98E+01	5.07E-02	1.49E+04	1.41E+04	7.78E-04	7.78E-04	5.03E-01	1.19E-01	-	3.67E-11	2.82E-08	3.98E-09	1.09E-10	4.11E-10	1.27E-09	1.02E-08
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	5.82E+05	4.34E+02	7.38E-01	2.16E+05	2.05E+05	1.13E-02	1.13E-02	7.33E+00	1.74E+00	4.03E-04	5.91E-05	4.91E-02	4.07E-02	1.06E-03	6.59E-03	9.69E-03	3.29E-02
Phase Totals	1.66E+07	1.47E+05	2.50E+02	7.33E+07	6.93E+07	3.83E+00	3.83E+00	2.48E+03	5.88E+02	1.02E-01	2.23E-02	1.75E+00	1.17E+00	6.39E-02	2.13E-01	5.41E+00	2.93E+00

Table 6: Soluble Radionuclide Inventory by Tank, continued

Tank	Free Supernate Volume, gal	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Pu-241 (Ci)	Pu-242 (Ci)	Am-241 (Ci)	Am-242m (Ci)	Cm-244 (Ci)	Cm-245 (Ci)	Na-22 (Ci)	Al-26 (Ci)	Te-125m (Ci)	Sb-126 (Ci)	Sb-126m (Ci)	Sm-151 (Ci)	Eu-152 (Ci)	Eu-155 (Ci)
1	1.71E+04	6.74E-01	1.80E-01	4.03E-02	2.21E-01	8.29E-06	1.08E+00	6.25E-04	4.34E-01	4.28E-05	6.04E+00	3.86E-02	6.73E+00	1.88E-01	1.34E+00	1.28E+01	6.21E-02	7.26E-01
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	2.99E+05	1.39E+00	1.38E+00	3.08E-01	2.60E+00	6.33E-05	8.44E+00	4.87E-03	3.38E+00	3.33E-04	4.70E+01	3.01E-01	5.24E+01	1.46E+00	1.05E+01	9.99E+01	4.83E-01	5.65E+00
5	3.64E-12	1.75E-16	2.92E-17	6.99E-18	4.68E-17	2.06E-21	2.10E-17	1.21E-20	8.42E-18	8.29E-22	1.17E-16	7.48E-19	1.30E-16	3.64E-18	2.60E-17	2.49E-16	1.20E-18	1.41E-17
6	2.54E+05	-	1.27E+00	4.41E-01	4.95E+00	8.68E-04	3.01E-01	1.73E-04	1.20E-01	1.19E-05	1.67E+00	1.07E-02	1.86E+00	5.21E-02	3.72E-01	3.56E+00	1.72E-02	2.01E-01
7	2.76E+05	2.59E+01	4.66E+00	1.15E+00	1.10E+01	1.06E-03	1.53E+00	8.79E-04	6.11E-01	6.02E-05	8.49E+00	5.43E-02	9.46E+00	2.65E-01	1.89E+00	1.81E+01	8.73E-02	1.02E+00
8	7.28E+03	3.42E-01	7.51E-02	1.77E-02	1.68E-01	2.23E-05	1.62E-02	9.35E-06	6.50E-03	6.40E-07	9.03E-02	5.78E-04	1.01E-01	2.81E-03	2.01E-02	1.92E-01	9.29E-04	1.09E-02
9	1.30E+04	3.21E-01	4.58E-02	1.02E-02	4.25E-02	2.11E-06	3.01E-01	1.73E-04	1.20E-01	1.19E-05	1.67E+00	1.07E-02	1.86E+00	5.21E-02	3.72E-01	3.56E+00	1.72E-02	2.01E-01
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	1.42E+05	2.68E+01	2.66E-01	1.67E-01	9.58E+00	3.56E-04	1.37E-04	7.89E-08	5.48E-05	5.40E-09	7.62E-04	4.88E-06	8.49E-04	2.37E-05	1.70E-04	1.62E-03	7.84E-06	9.16E-05
12	2.46E+04	4.42E+00	7.41E-02	4.09E-02	1.04E+00	5.92E-05	8.20E-02	4.73E-05	3.28E-02	3.23E-06	4.57E-01	2.92E-03	5.09E-01	1.42E-02	1.02E-01	9.71E-01	4.70E-03	5.49E-02
13	5.78E+05	8.51E+01	2.30E+00	9.52E-01	1.68E+01	6.32E-04	2.89E+01	1.67E-02	1.16E+01	1.14E-03	1.61E+02	1.03E+00	1.79E+02	5.01E+00	3.58E+01	3.42E+02	1.65E+00	1.93E+01
14	1.05E+03	5.63E-02	1.39E-02	4.48E-03	2.27E-02	8.20E-07	5.62E-02	3.24E-05	2.25E-02	2.22E-06	3.13E-01	2.00E-03	3.49E-01	9.75E-03	6.97E-02	6.66E-01	3.22E-03	3.76E-02
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	1.18E+06	2.01E+02	2.96E+00	1.01E+00	1.77E+01	1.13E-04	5.01E-03	2.89E-06	2.01E-03	1.98E-07	2.79E-02	1.78E-04	3.11E-02	8.69E-04	6.20E-03	5.93E-02	2.87E-04	3.35E-03
22	1.17E+06	2.31E+02	-	-	-	-	5.43E-03	3.13E-06	2.18E-03	2.14E-07	3.03E-02	1.94E-04	3.37E-02	9.42E-04	6.73E-03	6.43E-02	3.11E-04	3.64E-03
23	1.26E+06	9.19E-01	3.15E-03	7.86E-04	9.19E-02	4.68E-03	1.20E-02	4.70E-07	3.53E-04	3.21E-08	4.54E-03	2.90E-05	5.05E-03	1.41E-04	1.01E-03	9.65E-03	4.67E-05	5.45E-04
24	8.51E+05	7.03E-03	1.10E-03	2.46E-04	5.79E-03	4.91E-08	1.51E+00	8.71E-04	6.05E-01	5.96E-05	8.42E+00	5.38E-02	9.37E+00	2.62E-01	1.87E+00	1.79E+01	8.65E-02	1.01E+00
25	3.69E+04	3.04E-04	4.77E-05	1.07E-05	2.51E-04	2.12E-09	4.45E-01	2.57E-04	1.78E-01	1.76E-05	2.48E+00	1.58E-02	2.76E+00	7.72E-02	5.51E-01	5.27E+00	2.55E-02	2.98E-01
26	5.19E+05	3.00E+03	4.71E+02	1.05E+02	2.48E+03	2.10E-02	1.18E+01	6.83E-03	4.74E+00	4.67E-04	6.60E+01	4.22E-01	7.35E+01	2.05E+00	1.47E+01	1.40E+02	6.78E-01	7.92E+00
27	6.00E+05	4.96E-03	7.77E-04	1.74E-04	4.09E-03	3.46E-08	1.56E+01	8.97E-03	6.23E+00	6.14E-04	8.67E+01	5.54E-01	9.65E+01	2.70E+00	1.93E+01	1.84E+02	8.91E-01	1.04E+01
28	1.85E+05	1.53E-03	2.40E-04	5.36E-05	1.26E-03	1.07E-08	2.65E+00	1.53E-03	1.06E+00	1.05E-04	1.48E+01	9.45E-02	1.65E+01	4.60E-01	3.29E+00	3.14E+01	1.52E-01	1.78E+00
29	1.67E+05	3.26E-05	8.83E-07	3.65E-07	6.44E-06	2.42E-10	5.34E-01	3.08E-04	2.14E-01	2.11E-05	2.97E+00	1.90E-02	3.31E+00	9.26E-02	6.61E-01	6.32E+00	3.06E-02	3.57E-01
30	9.15E+05	6.15E+03	5.34E+01	3.84E+01	3.95E+03	9.18E-02	3.14E+01	1.81E-02	1.26E+01	1.24E-03	1.75E+02	1.12E+00	1.95E+02	5.45E+00	3.89E+01	3.72E+02	1.80E+00	2.10E+01
31	1.15E+05	2.25E-05	6.09E-07	2.52E-07	4.44E-06	1.67E-10	4.19E+00	2.42E-03	1.68E+00	1.65E-04	2.33E+01	1.49E-01	2.60E+01	7.27E-01	5.19E+00	4.96E+01	2.40E-01	2.80E+00
32	8.44E+05	5.54E+03	4.86E+01	3.61E+01	2.47E+03	7.61E-02	2.11E+01	1.22E-02	8.46E+00	8.33E-04	1.18E+02	7.52E-01	1.31E+02	3.66E+00	2.62E+01	2.50E+02	1.21E+00	1.41E+01
33	7.95E+05	2.12E+03	1.16E+03	2.03E+02	6.02E+03	1.17E-02	1.03E+01	5.95E-03	4.13E+00	4.07E-04	5.75E+01	3.68E-01	6.40E+01	1.79E+00	1.28E+01	1.22E+02	5.91E-01	6.91E+00
34	5.69E+05	-	3.47E+01	7.74E+00	1.60E+02	1.61E-03	8.98E+00	5.18E-03	3.60E+00	3.54E-04	5.00E+01	3.20E-01	5.57E+01	1.56E+00	1.11E+01	1.06E+02	5.14E-01	6.01E+00
35	4.50E+05	2.97E+03	2.41E+01	1.84E+01	1.43E+03	4.13E-02	5.84E+00	3.36E-03	2.34E+00	2.30E-04	3.25E+01	2.08E-01	3.62E+01	1.01E+00	7.23E+00	6.91E+01	3.34E-01	3.90E+00
36	2.20E+05	1.46E+03	1.14E+01	9.05E+00	5.93E+02	1.96E-02	1.47E+01	8.49E-03	5.90E+00	5.81E-04	8.20E+01	5.24E-01	9.13E+01	2.55E+00	1.82E+01	1.74E+02	8.43E-01	9.85E+00
37	1.16E+05	2.27E-05	6.15E-07	2.54E-07	4.48E-06	1.69E-10	3.55E+00	2.05E-03	1.42E+00	1.40E-04	1.98E+01	1.26E-01	2.20E+01	6.15E-01	4.39E+00	4.20E+01	2.03E-01	2.37E+00
38	1.71E+05	1.24E-03	4.89E-06	4.13E-06	1.06E-03	6.10E-08	1.79E-01	1.03E-04	7.16E-02	7.05E-06	9.96E-01	6.37E-03	1.11E+00	3.10E-02	2.22E-01	2.12E+00	1.02E-02	1.20E-01
39	7.22E+05	4.78E+03	5.95E+01	3.69E+01	4.24E+03	7.88E-02	2.59E+00	1.49E-03	1.04E+00	1.02E-04	1.44E+01	9.23E-02	1.61E+01	4.49E-01	3.21E+00	3.07E+01	1.48E-01	1.73E+00
40	3.05E+05	3.76E+02	1.21E+02	4.59E+01	6.46E+02	2.32E-02	6.60E-02	3.81E-05	2.64E-02	2.61E-06	3.68E-01	2.35E-03	4.10E-01	1.15E-02	8.18E-02	7.82E-01	3.78E-03	4.42E-02
41	1.24E+05	8.43E+02	-	-	-	-	4.21E-01	2.43E-04	1.69E-01	1.66E-05	2.35E+00	1.50E-02	2.61E+00	7.31E-02	5.22E-01	4.99E+00	2.41E-02	2.82E-01
42	1.25E+06	6.74E+03	2.40E+02	8.62E+01	1.48E+03	7.90E-02	3.89E+01	2.24E-02	1.56E+01	1.53E-03	2.17E+02	1.39E+00	2.41E+02	6.75E+00	4.82E+01	4.60E+02	2.23E+00	2.60E+01
43	7.76E+05	5.30E+03	2.09E+01	1.77E+01	4.54E+03	2.61E-01	5.08E-01	2.93E-04	2.03E-01	2.00E-05	2.83E+00	1.81E-02	3.15E+00	8.80E-02	6.29E-01	6.01E+00	2.91E-02	3.40E-01
44	2.63E+05	2.17E-03	3.41E-04	7.62E-05	1.79E-03	1.52E-08	4.47E+00	2.58E-03	1.79E+00	1.76E-04	2.49E+01	1.59E-01	2.77E+01	7.76E-01	5.54E+00	5.29E+01	2.56E-01	2.99E+00
45	1.80E+05	1.48E-03	2.32E-04	5.19E-05	1.22E-03	1.03E-08	2.88E+00	1.66E-03	1.15E+00	1.14E-04	1.60E+01	1.03E-01	1.79E+01	5.00E-01	3.57E+00	3.41E+01	1.65E-01	1.93E+00
46	4.13E+05	3.41E-03	5.34E-04	1.19E-04	2.81E-03	2.38E-08	9.94E+00	5.73E-03	3.98E+00	3.92E-04	5.54E+01	3.54E-01	6.17E+01	1.72E+00	1.23E+01	1.18E+02	5.69E-01	6.65E+00
47	1.73E+05	1.01E+03	1.46E+02	3.25E+01	6.33E+02	6.70E-03	7.69E-01	4.44E-04	3.08E-01	3.03E-05	4.28E+00	2.74E-02	4.77E+00	1.33E-01	9.53E-01	9.11E+00	4.41E-02	5.15E-01
48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	1.92E+05	3.75E-05	1.01E-06	4.19E-07	7.39E-06	2.78E-10	4.77E-02	2.75E-05	1.91E-02	1.88E-06	2.65E-01	1.70E-03	2.96E-01	8.27E-03	5.90E-02	5.64E-01	2.73E-03	3.19E-02
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	5.82E+05	3.55E+03	4.75E+01	2.70E+01	1.35E+03	4.87E-02	6.94E-01	4.00E-04	2.78E-01	2.74E-05	3.86E+00	2.47E-02	4.30E+00	1.20E-01	8.59E-01	8.21E+00	3.97E-02	4.64E-01
Phase Totals	1.66E+07	4.44E+04	2.45E+03	6.68E+02	3.01E+04	7.69E-01	2.35E+02	1.35E-01	9.40E+01	9.26E-03	1.31E+03	8.36E+00	1.46E+03	4.07E+01	2.91E+02	2.78E+03	1.34E+01	1.57E+02

Table 6: Soluble Radionuclide Inventory by Tank, continued

Tank	Free Supernate Volume, gal	Ra-226 (Ci)	Ra-228 (Ci)	Ac-227 (Ci)	Th-229 (Ci)	Th-230 (Ci)	Pa-231 (Ci)	Pu-244 (Ci)	Am-243 (Ci)	Cm-242 (Ci)	Cm-243 (Ci)	Cm-247 (Ci)	Cm-248 (Ci)	Bk-249 (Ci)	Cf-249 (Ci)	Cf-251 (Ci)	Cf-252 (Ci)
1	1.71E+04	-	-	5.46E-09	-	-	1.52E-08	3.79E-08	2.08E-04	5.13E-04	1.22E-04	2.34E-14	2.44E-14	1.78E-21	1.35E-13	4.63E-15	1.50E-16
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	2.99E+05	-	-	4.08E-08	-	-	1.13E-07	2.89E-07	1.62E-03	3.99E-03	9.46E-04	1.82E-13	1.90E-13	1.39E-20	1.05E-12	3.60E-14	1.17E-15
5	3.64E-12	-	-	1.45E-24	-	-	4.03E-24	9.42E-24	4.02E-21	9.93E-21	2.35E-21	4.54E-31	4.73E-31	3.45E-38	2.62E-30	8.97E-32	2.91E-33
6	2.54E+05	-	-	7.57E-08	-	-	2.10E-07	3.97E-06	5.75E-05	1.42E-04	3.37E-05	6.49E-15	6.76E-15	4.94E-22	3.75E-14	1.28E-15	4.16E-17
7	2.76E+05	-	-	6.99E-08	-	-	1.94E-07	4.85E-06	2.92E-04	7.21E-04	1.71E-04	3.29E-14	3.43E-14	2.51E-21	1.90E-13	6.51E-15	2.11E-16
8	7.28E+03	-	-	1.30E-09	-	-	3.62E-09	1.02E-07	3.10E-06	7.67E-06	1.82E-06	3.50E-16	3.65E-16	2.67E-23	2.02E-15	6.92E-17	2.25E-18
9	1.30E+04	-	-	1.98E-09	-	-	5.49E-09	9.63E-09	5.75E-05	1.42E-04	3.37E-05	6.49E-15	6.76E-15	4.94E-22	3.75E-14	1.28E-15	4.16E-17
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	1.42E+05	6.76E-10	2.56E-06	1.29E-09	1.04E-06	8.28E-08	3.59E-09	1.63E-06	2.62E-08	6.47E-08	1.53E-08	2.95E-18	3.08E-18	2.25E-25	1.71E-17	5.84E-19	1.90E-20
12	2.46E+04	2.58E-10	4.35E-05	4.92E-10	3.48E-06	3.16E-08	1.37E-09	2.70E-07	1.57E-05	3.88E-05	9.19E-06	1.77E-15	1.84E-15	1.35E-22	1.02E-14	3.50E-16	1.14E-17
13	5.78E+05	2.04E-08	3.13E-04	5.64E-08	1.82E-04	2.49E-06	1.57E-07	2.89E-06	5.53E-03	1.37E-02	3.24E-03	6.23E-13	6.50E-13	4.75E-20	3.60E-12	1.23E-13	4.00E-15
14	1.05E+03	2.65E-11	2.43E-06	2.17E-10	2.44E-07	3.25E-09	6.03E-10	3.75E-09	1.08E-05	2.66E-05	6.30E-06	1.21E-15	1.26E-15	9.24E-23	7.01E-15	2.40E-16	7.79E-18
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	1.18E+06	9.10E-08	1.20E-06	1.46E-07	1.08E-04	1.11E-05	4.06E-07	5.15E-07	9.58E-07	2.37E-06	5.61E-07	1.08E-16	1.13E-16	8.23E-24	6.25E-16	2.14E-17	6.94E-19
22	1.17E+06	1.27E-07	-	1.96E-07	4.45E-04	1.55E-05	5.45E-07	-	1.04E-06	2.57E-06	6.09E-07	1.17E-16	1.22E-16	8.93E-24	6.78E-16	2.32E-17	7.52E-19
23	1.26E+06	1.26E+01	1.72E-07	2.31E-08	3.26E-05	3.31E-02	6.43E-08	4.76E-05	1.56E-07	3.85E-07	9.13E-08	1.76E-17	1.83E-17	1.34E-24	1.02E-16	3.48E-18	1.13E-19
24	8.51E+05	8.37E-20	-	2.51E-12	3.31E-17	1.02E-17	6.97E-12	2.24E-10	2.89E-04	7.15E-04	1.69E-04	3.26E-14	3.40E-14	2.48E-21	1.88E-13	6.45E-15	2.09E-16
25	3.69E+04	3.62E-21	-	1.09E-13	1.43E-18	4.43E-19	3.02E-13	9.71E-12	8.51E-05	2.10E-04	4.99E-05	9.60E-15	1.00E-14	7.31E-22	5.55E-14	1.90E-15	6.16E-17
26	5.19E+05	3.58E-14	-	1.07E-06	1.41E-11	4.38E-12	2.98E-06	9.58E-05	2.27E-03	5.60E-03	1.33E-03	2.56E-13	2.66E-13	1.95E-20	1.48E-12	5.05E-14	1.64E-15
27	6.00E+05	5.90E-20	-	1.77E-12	2.34E-17	7.22E-18	4.91E-12	1.58E-10	2.98E-03	7.36E-03	1.74E-03	3.36E-13	3.50E-13	2.56E-20	1.94E-12	6.64E-14	2.16E-15
28	1.85E+05	1.82E-20	-	5.46E-13	7.21E-18	2.23E-18	1.52E-12	4.88E-11	5.08E-04	1.26E-03	2.97E-04	5.73E-14	5.97E-14	4.36E-21	3.31E-13	1.13E-14	3.68E-16
29	1.67E+05	7.82E-15	-	2.17E-14	7.00E-11	9.57E-13	6.02E-14	1.11E-12	1.02E-04	2.52E-04	5.98E-05	1.15E-14	1.20E-14	8.77E-22	6.66E-14	2.28E-15	7.39E-17
30	9.15E+05	7.19E-08	-	1.29E-07	-	8.80E-06	3.59E-07	4.20E-04	6.01E-03	1.48E-02	3.52E-03	6.78E-13	7.06E-13	5.16E-20	3.92E-12	1.34E-13	4.35E-15
31	1.15E+05	5.39E-15	-	1.49E-14	4.82E-11	6.60E-13	4.15E-14	7.64E-13	8.02E-04	1.98E-03	4.69E-04	9.04E-14	9.42E-14	6.89E-21	5.22E-13	1.79E-14	5.80E-16
32	8.44E+05	8.60E-08	-	1.25E-07	-	1.05E-05	3.46E-07	3.48E-04	4.04E-03	9.98E-03	2.37E-03	4.56E-13	4.75E-13	3.47E-20	2.63E-12	9.01E-14	2.92E-15
33	7.95E+05	3.43E-09	-	6.51E-06	2.10E-10	4.19E-07	1.81E-05	5.36E-05	1.97E-03	4.88E-03	1.16E-03	2.23E-13	2.32E-13	1.70E-20	1.29E-12	4.40E-14	1.43E-15
34	5.69E+05	-	-	6.93E-07	-	-	1.93E-06	7.34E-06	1.72E-03	4.25E-03	1.01E-03	1.94E-13	2.02E-13	1.48E-20	1.12E-12	3.83E-14	1.24E-15
35	4.50E+05	4.47E-08	-	7.87E-08	-	5.48E-06	2.19E-07	1.89E-04	1.12E-03	2.76E-03	6.54E-04	1.26E-13	1.31E-13	9.59E-21	7.28E-13	2.49E-14	8.08E-16
36	2.20E+05	3.80E-08	-	7.45E-08	-	4.65E-06	2.07E-07	8.94E-05	2.82E-03	6.96E-03	1.65E-03	3.18E-13	3.31E-13	2.42E-20	1.84E-12	6.28E-14	2.04E-15
37	1.16E+05	5.45E-15	-	1.51E-14	4.87E-11	6.66E-13	4.19E-14	7.71E-13	6.79E-04	1.68E-03	3.97E-04	7.66E-14	7.98E-14	5.83E-21	4.42E-13	1.51E-14	4.91E-16
38	1.71E+05	1.15E-13	-	1.61E-13	-	1.41E-11	4.47E-13	2.79E-10	3.42E-05	8.45E-05	2.00E-05	3.86E-15	4.02E-15	2.94E-22	2.23E-14	7.63E-16	2.48E-17
39	7.22E+05	1.93E-07	-	2.83E-07	-	2.37E-05	7.86E-07	3.60E-04	4.96E-04	1.23E-03	2.90E-04	5.59E-14	5.83E-14	4.26E-21	3.23E-13	1.11E-14	3.59E-16
40	3.05E+05	4.49E-08	7.28E-04	8.58E-07	5.89E-05	5.50E-06	2.38E-06	1.06E-04	1.26E-05	3.12E-05	7.40E-06	1.43E-15	1.49E-15	1.09E-22	8.24E-15	2.82E-16	9.15E-18
41	1.24E+05	1.16E-07		1.36E-07	-	1.42E-05	3.78E-07	-	8.06E-05	1.99E-04	4.72E-05	9.09E-15	9.48E-15	6.92E-22	5.25E-14	1.80E-15	5.83E-17
42	1.25E+06	1.17E-06	1.00E-01	2.79E-06	4.01E-03	1.43E-04	7.75E-06	3.61E-04	7.44E-03	1.84E-02	4.36E-03	8.39E-13	8.75E-13	6.39E-20	4.85E-12	1.66E-13	5.39E-15
43	7.76E+05	4.93E-07	-	6.89E-07	-	6.04E-05	1.91E-06	1.19E-03	9.71E-05	2.40E-04	5.69E-05	1.10E-14	1.14E-14	8.34E-22	6.33E-14	2.17E-15	7.03E-17
44	2.63E+05	2.59E-20	-	7.76E-13	1.02E-17	3.17E-18	2.16E-12	6.94E-11	8.56E-04	2.11E-03	5.01E-04	9.65E-14	1.01E-13	7.35E-21	5.58E-13	1.91E-14	6.19E-16
45	1.80E+05	1.77E-20	-	5.29E-13	6.98E-18	2.16E-18	1.47E-12	4.73E-11	5.51E-04	1.36E-03	3.23E-04	6.22E-14	6.48E-14	4.74E-21	3.59E-13	1.23E-14	3.99E-16
46	4.13E+05	4.06E-20	-	1.22E-12	1.61E-17	4.97E-18	3.38E-12	1.09E-10	1.90E-03	4.70E-03	1.11E-03	2.15E-13	2.24E-13	1.63E-20	1.24E-12	4.24E-14	1.38E-15
47	1.73E+05	-	-	2.74E-07	-	-	7.60E-07	3.06E-05	1.47E-04	3.64E-04	8.62E-05	1.66E-14	1.73E-14	1.26E-21	9.59E-14	3.28E-15	1.07E-16
48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	1.92E+05	8.98E-15	-	2.48E-14	8.03E-11	1.10E-12	6.90E-14	1.27E-12	9.12E-06	2.25E-05	5.34E-06	1.03E-15	1.07E-15	7.83E-23	5.94E-15	2.03E-16	6.60E-18
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	5.82E+05	9.18E-08	4.03E-04	2.42E-07	1.40E-04	1.12E-05	6.73E-07	2.23E-04	1.33E-04	3.28E-04	7.77E-05	1.50E-14	1.56E-14	1.14E-21	8.65E-14	2.96E-15	9.60E-17
Phase Totals	1.66E+07	1.26E+01	1.02E-01	1.46E-05	4.99E-03	3.35E-02	4.05E-05	3.54E-03	4.49E-02	1.11E-01	2.63E-02	5.07E-12	5.28E-12	3.86E-19	2.93E-11	1.00E-12	3.25E-14

Table 6: Soluble Radionuclide Inventory by Tank, continued

Tank	Sludge IL Volume, gal	H-3 (Ci)	C-14 (Ci)	Co-60 (Ci)	Ni-59 (Ci)	Ni-63 (Ci)	Se-79 (Ci)	Sr-90 (Ci)	Y-90 (Ci)	Nb-94 (Ci)	Tc-99 (Ci)	Ru-106 (Ci)	Rh-106 (Ci)	Sb-125 (Ci)	Sn-126 (Ci)	I-129 (Ci)
1	4.93E+03	1.87E+00	3.29E-02	1.92E-02	2.07E-03	4.67E-02	7.68E-02	2.41E+01	2.41E+01	6.04E-07	2.85E+01	1.96E+00	1.96E+00	7.96E+00	3.88E-01	1.54E-02
2	2.85E+03	1.08E+00	1.90E-02	1.11E-02	4.43E-04	2.69E-02	1.64E-02	5.15E+00	5.15E+00	1.29E-07	6.09E+00	4.20E-01	4.20E-01	1.70E+00	8.31E-02	3.29E-03
3	2.85E+03	1.08E+00	1.90E-02	1.11E-02	4.50E-04	2.69E-02	1.67E-02	5.22E+00	5.22E+00	1.31E-07	6.18E+00	4.26E-01	4.26E-01	1.73E+00	8.42E-02	3.33E-03
4	8.90E+04	3.37E+01	5.93E-01	3.47E-01	1.66E-02	8.42E-01	6.14E-01	1.92E+02	1.92E+02	4.83E-06	2.28E+02	1.57E+01	1.57E+01	6.37E+01	3.11E+00	1.23E-01
5	1.71E+04	6.49E+00	1.14E-01	6.69E-02	6.55E-04	1.62E-01	2.43E-02	7.60E+00	7.60E+00	1.91E-07	9.00E+00	6.21E-01	6.21E-01	2.52E+00	1.23E-01	4.85E-03
6	1.75E+04	4.65E+01	1.16E-01	6.80E-02	1.37E-04	1.65E-01	5.06E-03	1.59E+00	1.59E+00	3.98E-08	1.88E+00	1.30E-01	1.29E-01	5.25E-01	2.56E-02	1.01E-03
7	1.38E+04	5.65E+00	9.19E-02	5.38E-02	5.03E-04	1.31E-01	1.86E-02	5.25E+00	5.25E+00	1.47E-07	6.91E+00	4.77E-01	4.77E-01	1.93E+00	9.43E-02	3.73E-03
8	2.87E+03	6.61E+01	1.91E-02	1.12E-02	4.23E-05	2.72E-02	1.57E-03	4.91E-01	4.91E-01	1.23E-08	5.81E-01	4.01E-02	4.01E-02	1.62E-01	7.92E-03	3.13E-04
9	1.90E+03	7.18E-01	1.26E-02	7.40E-03	2.90E-04	1.80E-02	1.07E-02	3.36E+00	3.36E+00	8.45E-08	3.98E+00	2.75E-01	2.75E-01	1.11E+00	5.43E-02	2.15E-03
10	1.90E+03	7.18E-01	1.26E-02	7.40E-03	5.06E-05	1.80E-02	1.87E-03	5.87E-01	5.87E-01	1.47E-08	6.95E-01	4.79E-02	4.79E-02	1.94E-01	9.48E-03	3.75E-04
11	1.39E+04	5.25E+00	9.24E-02	5.41E-02	8.86E-08	1.31E-01	3.28E-06	9.27E-04	9.27E-04	2.58E-11	1.22E-03	8.39E-05	8.39E-05	3.40E-04	1.66E-05	6.56E-07
12	7.58E+04	2.87E+01	5.05E-01	2.96E-01	1.67E-03	7.17E-01	6.18E-02	1.94E+01	1.94E+01	4.86E-07	2.29E+01	1.58E+00	1.58E+00	6.41E+00	3.12E-01	1.24E-02
13	1.76E+05	6.68E+01	1.18E+00	6.88E-01	5.83E-02	1.67E+00	2.16E+00	6.77E+02	6.77E+02	1.70E-05	8.02E+02	5.53E+01	5.53E+01	2.24E+02	1.09E+01	4.32E-01
14	1.96E+04	7.42E+00	1.31E-01	7.64E-02	6.94E-03	1.85E-01	2.57E-01	8.05E+01	8.05E+01	2.02E-06	9.53E+01	6.58E+00	6.58E+00	2.67E+01	1.30E+00	5.14E-02
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	4.26E+03	1.61E+00	2.84E-02	1.66E-02	1.20E-07	4.03E-02	4.45E-06	1.39E-03	1.39E-03	3.50E-11	1.65E-03	1.14E-04	1.14E-04	4.61E-04	2.25E-05	1.06E-05
22	6.99E+03	2.65E+00	4.66E-02	2.72E-02	2.15E-07	6.61E-02	7.96E-06	2.47E-03	2.47E-03	6.26E-11	2.95E-03	2.04E-04	2.03E-04	8.25E-04	4.02E-05	1.74E-05
23	3.93E+04	1.53E-01	6.11E-03	1.28E-04	1.68E-07	5.58E-03	6.23E-06	4.76E-02	4.76E-02	4.90E-11	9.98E-03	1.59E-04	1.59E-04	6.46E-04	3.15E-05	8.61E-05
24	2.48E+03	9.38E-01	1.65E-02	9.66E-03	2.91E-05	2.35E-02	1.08E-03	3.38E-01	3.38E-01	8.48E-09	4.00E-01	2.76E-02	2.76E-02	1.12E-01	5.45E-03	7.19E-05
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	1.82E+05	6.87E+01	1.21E+00	7.08E-01	2.74E-02	1.72E+00	1.01E+00	3.33E+02	3.33E+02	7.98E-06	3.76E+02	2.60E+01	2.60E+01	1.05E+02	5.13E+00	2.03E-01
27	2.70E+03	1.02E+00	1.80E-02	1.05E-02	4.63E-04	2.56E-02	1.72E-02	5.31E+00	5.31E+00	1.35E-07	6.36E+00	4.39E-01	4.39E-01	1.78E+00	8.68E-02	3.43E-03
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	4.42E+02	1.67E-01	2.95E-03	1.72E-03	1.00E-04	4.19E-03	3.72E-03	1.16E+00	1.16E+00	2.92E-08	1.38E+00	9.51E-02	9.51E-02	3.85E-01	1.88E-02	7.43E-04
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	6.89E+04	2.61E+01	4.59E-01	2.69E-01	1.14E-02	6.52E-01	4.22E-01	1.14E+02	1.14E+02	3.32E-06	1.57E+02	1.08E+01	1.08E+01	4.38E+01	2.14E+00	8.44E-02
33	5.90E+04	3.00E+01	3.93E-01	2.30E-01	5.06E-03	5.58E-01	1.88E-01	5.88E+01	5.88E+01	1.48E-06	6.96E+01	4.80E+00	4.80E+00	1.94E+01	9.48E-01	3.75E-02
34	1.41E+04	5.35E+00	9.41E-02	5.51E-02	1.48E-03	1.34E-01	5.47E-02	1.71E+01	1.71E+01	4.30E-07	2.03E+01	1.40E+00	1.40E+00	5.67E+00	2.76E-01	1.09E-02
35	4.42E+04	1.67E+01	2.95E-01	1.72E-01	3.79E-03	4.19E-01	1.41E-01	4.40E+01	4.40E+01	1.11E-06	5.21E+01	3.59E+00	3.59E+00	1.46E+01	7.11E-01	2.81E-02
36	1.30E+02	4.93E-02	8.68E-04	5.08E-04	5.77E-05	1.23E-03	2.14E-03	6.70E-01	6.70E-01	1.68E-08	7.93E-01	5.47E-02	5.47E-02	2.22E-01	1.08E-02	4.27E-04
37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39	7.25E+04	2.74E+01	4.83E-01	2.83E-01	1.72E-03	6.86E-01	6.37E-02	1.50E+01	1.50E+01	5.01E-07	2.36E+01	1.63E+00	1.63E+00	6.60E+00	3.22E-01	1.27E-02
40	3.07E+05	1.16E+02	2.05E+00	1.20E+00	4.40E-04	2.91E+00	1.63E-02	5.33E+00	5.33E+00	1.28E-07	6.05E+00	4.17E-01	4.17E-01	1.69E+00	8.25E-02	3.26E-03
41	1.87E+03	7.07E-01	1.24E-02	7.28E-03	4.19E-05	1.77E-02	1.55E-03	1.71E-01	1.71E-01	1.22E-08	5.75E-01	3.97E-02	3.97E-02	1.61E-01	7.84E-03	3.10E-04
42	1.40E+04	5.31E+00	9.35E-02	5.47E-02	2.88E-03	1.33E-01	1.07E-01	3.34E+01	3.34E+01	8.39E-07	3.96E+01	2.73E+00	2.73E+00	1.11E+01	5.39E-01	2.13E-02
43	1.69E+05	6.41E+01	1.13E+00	6.60E-01	7.32E-04	1.60E+00	2.71E-02	7.35E+00	7.35E+00	2.13E-07	1.01E+01	6.94E-01	6.94E-01	2.81E+00	1.37E-01	5.43E-03
44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
47	1.74E+05	6.57E+01	1.16E+00	6.77E-01	5.11E-03	1.64E+00	1.89E-01	5.93E+01	5.93E+01	1.49E-06	7.01E+01	4.84E+00	4.84E+00	1.96E+01	9.56E-01	3.78E-02
48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	1.11E+05	4.21E+01	7.41E-01	4.34E-01	8.76E-04	1.05E+00	3.25E-02	8.13E+00	8.13E+00	2.55E-07	1.20E+01	8.31E-01	8.30E-01	3.37E+00	1.64E-01	6.49E-03
Phase Totals	1.73E+06	7.52E+02	1.13E+01	6.58E+00	1.50E-01	1.60E+01	5.55E+00	1.73E+03	1.73E+03	4.36E-05	2.06E+03	1.42E+02	1.42E+02	5.75E+02	2.81E+01	1.11E+00

Table 6: Soluble Radionuclide Inventory by Tank, continued

Tank	Sludge IL Volume, gal	Cs-134 (Ci)	Cs-135 (Ci)	Cs-137 (Ci)	Ba-137m (Ci)	Ce-144 (Ci)	Pr-144 (Ci)	Pm-147 (Ci)	Eu-154 (Ci)	Th-232 (Ci)	U-232 (Ci)	U-233 (Ci)	U-234 (Ci)	U-235 (Ci)	U-236 (Ci)	U-238 (Ci)	Np-237 (Ci)
1	4.93E+03	1.96E+02	3.33E-01	9.78E+04	9.25E+04	5.12E-03	5.12E-03	3.31E+00	7.85E-01	-	4.47E-06	-	-	6.91E-06	-	1.72E-04	2.51E-04
2	2.85E+03	4.20E+01	7.13E-02	2.09E+04	1.98E+04	1.09E-03	1.09E-03	7.08E-01	1.68E-01	-	2.17E-06	-	-	1.05E-06	-	2.61E-05	2.73E-04
3	2.85E+03	4.26E+01	7.23E-02	2.12E+04	2.01E+04	1.11E-03	1.11E-03	7.18E-01	1.70E-01	-	1.90E-06	-	-	2.68E-06	-	6.70E-05	5.00E-04
4	8.90E+04	1.57E+03	2.67E+00	7.83E+05	7.40E+05	4.09E-02	4.09E-02	2.65E+01	6.28E+00	-	4.05E-05	-	-	5.31E-05	-	2.29E-03	2.04E-03
5	1.71E+04	6.20E+01	1.05E-01	3.09E+04	2.92E+04	1.62E-03	1.62E-03	1.05E+00	2.48E-01	-	1.54E-05	-	-	2.99E-05	-	7.09E-04	1.20E-03
6	1.75E+04	1.29E+01	2.20E-02	6.45E+03	6.10E+03	3.37E-04	3.37E-04	2.18E-01	5.18E-02	-	1.84E-05	-	-	2.28E-05	-	8.52E-04	2.96E-04
7	1.38E+04	4.77E+01	8.10E-02	2.37E+04	2.25E+04	1.24E-03	1.24E-03	8.04E-01	1.91E-01	-	3.27E-06	-	-	1.53E-05	-	5.30E-04	2.63E-04
8	2.87E+03	4.00E+00	6.80E-03	2.00E+03	1.89E+03	1.04E-04	1.04E-04	6.75E-02	1.60E-02	-	8.53E-07	-	-	2.25E-06	-	1.04E-04	4.71E-05
9	1.90E+03	2.74E+01	4.66E-02	1.37E+04	1.29E+04	7.16E-04	7.15E-04	4.63E-01	1.10E-01	-	1.95E-06	-	-	1.26E-06	-	3.15E-05	2.15E-04
10	1.90E+03	4.79E+00	8.14E-03	2.39E+03	2.26E+03	1.25E-04	1.25E-04	8.08E-02	1.92E-02	-	1.25E-06	-	-	1.52E-06	-	3.80E-05	2.91E-04
11	1.39E+04	8.39E-03	1.42E-05	4.18E+00	3.95E+00	2.19E-07	2.19E-07	1.41E-04	3.35E-05	2.51E-07	-	3.58E-05	2.94E-05	5.54E-07	4.54E-06	1.03E-06	1.94E-05
12	7.58E+04	1.58E+02	2.68E-01	7.87E+04	7.45E+04	4.12E-03	4.12E-03	2.66E+00	6.32E-01	1.34E-04	1.35E-06	3.77E-03	3.53E-04	6.64E-06	2.79E-05	6.68E-05	7.81E-04
13	1.76E+05	5.53E+03	9.39E+00	2.75E+06	2.60E+06	1.44E-01	1.44E-01	9.32E+01	2.21E+01	9.56E-05	2.54E-05	1.96E-02	2.76E-03	7.55E-05	2.85E-04	8.83E-04	7.10E-03
14	1.96E+04	6.57E+02	1.12E+00	3.27E+05	3.10E+05	1.71E-02	1.71E-02	1.11E+01	2.63E+00	4.53E-05	1.34E-05	1.60E-03	2.20E-04	1.78E-05	1.89E-05	3.39E-04	2.35E-03
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	4.26E+03	1.14E-02	1.93E-05	5.66E+00	5.36E+00	2.96E-07	2.96E-07	1.92E-04	4.55E-05	4.34E-09	-	1.37E-04	1.46E-04	2.32E-06	2.68E-05	1.37E-05	1.21E-04
22	6.99E+03	2.03E-02	3.46E-05	1.01E+01	9.59E+00	5.30E-07	5.30E-07	3.43E-04	8.13E-05	-	-	9.34E-04	3.36E-04	5.13E-06	5.53E-05	1.14E-04	2.04E-04
23	3.93E+04	4.12E-04	6.08E-04	7.94E+00	7.51E+00	4.15E-07	4.15E-07	2.69E-04	6.37E-05	5.38E-09	-	3.58E-04	5.68E-04	3.17E-06	1.28E-05	9.49E-05	2.63E-05
24	2.48E+03	2.76E+00	4.68E-03	1.37E+03	1.30E+03	7.19E-05	7.18E-05	4.65E-02	1.10E-02	-	1.11E-11	3.39E-17	1.08E-16	3.20E-11	4.13E-12	3.84E-09	9.91E-12
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	1.82E+05	2.59E+03	4.41E+00	1.29E+06	1.22E+06	6.76E-02	6.76E-02	4.38E+01	1.04E+01	-	5.72E-04	1.74E-09	5.55E-09	1.64E-03	2.12E-04	1.97E-01	5.09E-04
27	2.70E+03	4.39E+01	7.45E-02	2.19E+04	2.07E+04	1.14E-03	1.14E-03	7.40E-01	1.75E-01	-	1.21E-11	3.70E-17	1.18E-16	3.49E-11	4.51E-12	4.19E-09	1.08E-11
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	4.42E+02	9.50E+00	1.61E-02	4.74E+03	4.48E+03	2.48E-04	2.48E-04	1.60E-01	3.80E-02	-	-	-	1.54E-05	2.74E-07	2.85E-06	1.02E-08	6.96E-06
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	6.89E+04	1.08E+03	1.83E+00	5.38E+05	5.09E+05	2.81E-02	2.81E-02	1.82E+01	4.32E+00	-	-	-	3.12E-03	4.46E-05	6.99E-04	2.09E-05	1.29E-03
33	5.90E+04	4.79E+02	8.14E-01	2.39E+05	2.26E+05	1.25E-02	1.25E-02	8.09E+00	1.92E+00	-	1.14E-03	5.47E-09	1.13E-04	2.12E-03	1.17E-03	3.07E-01	9.63E-02
34	1.41E+04	1.40E+02	2.37E-01	6.96E+04	6.59E+04	3.64E-03	3.64E-03	2.36E+00	5.59E-01	-	7.47E-05	-	-	7.54E-05	-	5.33E-03	4.12E-03
35	4.42E+04	3.59E+02	6.10E-01	1.79E+05	1.69E+05	9.36E-03	9.36E-03	6.06E+00	1.44E+00	-	-	-	1.95E-03	3.39E-05	5.76E-04	2.00E-05	7.06E-04
36	1.30E+02	5.46E+00	9.28E-03	2.72E+03	2.58E+03	1.42E-04	1.42E-04	9.22E-02	2.19E-02	-	-	-	9.99E-06	1.94E-07	3.53E-06	6.33E-08	2.79E-06
37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39	7.25E+04	1.63E+02	2.77E-01	8.11E+04	7.67E+04	4.24E-03	4.24E-03	2.75E+00	6.51E-01	-	-	-	8.61E-03	1.24E-04	1.48E-03	2.63E-05	5.40E-03
40	3.07E+05	4.17E+01	7.08E-02	2.08E+04	1.97E+04	1.09E-03	1.09E-03	7.03E-01	1.67E-01	7.34E-04	8.16E-04	2.09E-02	2.01E-02	3.79E-03	5.01E-03	1.19E-01	4.15E-01
41	1.87E+03	3.96E+00	6.74E-03	1.98E+03	1.87E+03	1.03E-04	1.03E-04	6.69E-02	1.59E-02	-	-	-	7.76E-04	8.97E-06	2.23E-04	6.14E-07	2.32E-03
42	1.40E+04	2.73E+02	4.63E-01	1.36E+05	1.29E+05	7.11E-03	7.11E-03	4.60E+00	1.09E+00	1.12E-03	3.97E-06	1.58E-02	5.81E-03	1.37E-04	7.76E-04	2.40E-03	4.78E-03
43	1.69E+05	6.94E+01	1.18E-01	3.46E+04	3.27E+04	1.81E-03	1.81E-03	1.17E+00	2.77E-01	-	-	-	4.78E-02	6.59E-04	9.10E-03	5.35E-05	5.09E-02
44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
47	1.74E+05	4.83E+02	8.21E-01	2.41E+05	2.28E+05	1.26E-02	1.26E-02	8.15E+00	1.93E+00	-	4.43E-04	-	-	1.20E-03	-	9.53E-02	-
48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	1.11E+05	8.30E+01	1.41E-01	4.14E+04	3.91E+04	2.16E-03	2.16E-03	1.40E+00	3.32E-01	7.71E-05	1.13E-05	9.38E-03	7.78E-03	2.03E-04	1.26E-03	1.85E-03	6.28E-03
Phase Totals	1.73E+06	1.42E+04	2.41E+01	7.07E+06	6.69E+06	3.70E-01	3.70E-01	2.39E+02	5.67E+01	2.21E-03	3.19E-03	7.38E-02	1.01E-01	1.03E-02	2.10E-02	7.35E-01	6.03E-01

Table 6: Soluble Radionuclide Inventory by Tank, continued

Tank	Sludge IL Volume, gal	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Pu-241 (Ci)	Pu-242 (Ci)	Am-241 (Ci)	Am-242m (Ci)	Cm-244 (Ci)	Cm-245 (Ci)	Na-22 (Ci)	Al-26 (Ci)	Te-125m (Ci)	Sb-126 (Ci)	Sb-126m (Ci)	Sm-151 (Ci)	Eu-152 (Ci)	Eu-155 (Ci)
1	4.93E+03	1.95E-01	5.21E-02	1.16E-02	6.39E-02	2.40E-06	3.13E-01	1.81E-04	1.26E-01	1.24E-05	1.74E+00	1.12E-02	1.94E+00	5.44E-02	3.88E-01	3.71E+00	1.79E-02	2.10E-01
2	2.85E+03	1.78E-01	2.54E-02	5.68E-03	2.39E-02	1.17E-06	6.71E-02	3.87E-05	2.69E-02	2.65E-06	3.73E-01	2.39E-03	4.16E-01	1.16E-02	8.31E-02	7.94E-01	3.84E-03	4.49E-02
3	2.85E+03	2.20E-01	3.15E-02	7.03E-03	3.55E-02	1.45E-06	6.80E-02	3.92E-05	2.72E-02	2.68E-06	3.79E-01	2.42E-03	4.22E-01	1.18E-02	8.42E-02	8.05E-01	3.89E-03	4.55E-02
4	8.90E+04	4.14E-01	4.09E-01	9.14E-02	7.73E-01	1.88E-05	2.51E+00	1.45E-03	1.00E+00	9.89E-05	1.40E+01	8.93E-02	1.56E+01	4.35E-01	3.11E+00	2.97E+01	1.44E-01	1.68E+00
5	1.71E+04	8.26E-01	1.38E-01	3.29E-02	2.21E-01	9.72E-06	9.91E-02	5.71E-05	3.97E-02	3.91E-06	5.52E-01	3.53E-03	6.14E-01	1.72E-02	1.23E-01	1.17E+00	5.67E-03	6.63E-02
6	1.75E+04	-	8.73E-02	3.03E-02	3.40E-01	5.97E-05	2.07E-02	1.19E-05	8.28E-03	8.15E-07	1.15E-01	7.36E-04	1.28E-01	3.58E-03	2.56E-02	2.45E-01	1.18E-03	1.38E-02
7	1.38E+04	1.29E+00	2.33E-01	5.72E-02	5.46E-01	5.29E-05	7.61E-02	4.39E-05	3.05E-02	3.00E-06	4.24E-01	2.71E-03	4.72E-01	1.32E-02	9.43E-02	9.01E-01	4.36E-03	5.09E-02
8	2.87E+03	1.35E-01	2.96E-02	6.97E-03	6.63E-02	8.79E-06	6.39E-03	3.69E-06	2.56E-03	2.52E-07	3.56E-02	2.28E-04	3.97E-02	1.11E-03	7.92E-03	7.57E-02	3.66E-04	4.28E-03
9	1.90E+03	4.68E-02	6.68E-03	1.49E-03	6.20E-03	3.07E-07	4.38E-02	2.53E-05	1.76E-02	1.73E-06	2.44E-01	1.56E-03	2.72E-01	7.60E-03	5.43E-02	5.19E-01	2.51E-03	2.93E-02
10	1.90E+03	1.48E-01	2.11E-02	4.71E-03	2.10E-02	9.70E-07	7.65E-03	4.41E-06	3.06E-03	3.02E-07	4.26E-02	2.72E-04	4.74E-02	1.33E-03	9.48E-03	9.05E-02	4.38E-04	5.12E-03
11	1.39E+04	2.62E+00	2.61E-02	1.64E-02	9.38E-01	3.49E-05	1.34E-05	7.72E-09	5.36E-06	5.28E-10	7.46E-05	4.77E-07	8.31E-05	2.32E-06	1.66E-05	1.59E-04	7.67E-07	8.96E-06
12	7.58E+04	1.36E+01	2.28E-01	1.26E-01	3.20E+00	1.82E-04	2.52E-01	1.45E-04	1.01E-01	9.95E-06	1.40E+00	8.98E-03	1.56E+00	4.37E-02	3.12E-01	2.99E+00	1.44E-02	1.69E-01
13	1.76E+05	2.60E+01	7.03E-01	2.91E-01	5.12E+00	1.93E-04	8.82E+00	5.09E-03	3.53E+00	3.48E-04	4.91E+01	3.14E-01	5.47E+01	1.53E+00	1.09E+01	1.04E+02	5.05E-01	5.90E+00
14	1.96E+04	1.05E+00	2.59E-01	8.36E-02	4.23E-01	1.53E-05	1.05E+00	6.05E-04	4.20E-01	4.14E-05	5.84E+00	3.74E-02	6.51E+00	1.82E-01	1.30E+00	1.24E+01	6.01E-02	7.02E-01
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	4.26E+03	7.29E-01	1.07E-02	3.65E-03	6.40E-02	4.08E-07	1.82E-05	1.05E-08	7.27E-06	7.16E-10	1.01E-04	6.46E-07	1.13E-04	3.15E-06	2.25E-05	2.15E-04	1.04E-06	1.21E-05
22	6.99E+03	1.38E+00	-	-	-	-	3.25E-05	1.87E-08	1.30E-05	1.28E-09	1.81E-04	1.16E-06	2.01E-04	5.63E-06	4.02E-05	3.84E-04	1.86E-06	2.17E-05
23	3.93E+04	2.87E-02	9.84E-05	2.45E-05	2.87E-03	1.46E-04	3.76E-04	1.47E-08	1.10E-05	1.00E-09	1.42E-04	9.06E-07	1.58E-04	4.41E-06	3.15E-05	3.01E-04	1.46E-06	1.70E-05
24	2.48E+03	2.05E-05	3.21E-06	7.17E-07	1.69E-05	1.43E-10	4.40E-03	2.54E-06	1.76E-03	1.74E-07	2.45E-02	1.57E-04	2.73E-02	7.63E-04	5.45E-03	5.21E-02	2.52E-04	2.94E-03
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	1.82E+05	1.05E+03	1.65E+02	3.68E+01	8.66E+02	7.33E-03	4.14E+00	2.39E-03	1.66E+00	1.63E-04	2.31E+01	1.48E-01	2.57E+01	7.18E-01	5.13E+00	4.90E+01	2.37E-01	2.77E+00
27	2.70E+03	2.23E-05	3.50E-06	7.82E-07	1.84E-05	1.56E-10	7.01E-02	4.04E-05	2.81E-02	2.76E-06	3.90E-01	2.49E-03	4.35E-01	1.22E-02	8.68E-02	8.29E-01	4.01E-03	4.69E-02
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	4.42E+02	2.97E+00	2.58E-02	1.85E-02	1.91E+00	4.44E-05	1.52E-02	8.75E-06	6.08E-03	5.99E-07	8.45E-02	5.40E-04	9.41E-02	2.63E-03	1.88E-02	1.80E-01	8.69E-04	1.02E-02
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	6.89E+04	4.52E+02	3.97E+00	2.95E+00	2.02E+02	6.21E-03	1.72E+00	9.94E-04	6.90E-01	6.80E-05	9.60E+00	6.14E-02	1.07E+01	2.99E-01	2.14E+00	2.04E+01	9.87E-02	1.15E+00
33	5.90E+04	1.57E+02	8.57E+01	1.50E+01	4.46E+02	8.70E-04	7.66E-01	4.41E-04	3.07E-01	3.02E-05	4.26E+00	2.73E-02	4.75E+00	1.33E-01	9.48E-01	9.06E+00	4.38E-02	5.12E-01
34	1.41E+04	-	8.61E-01	1.92E-01	3.98E+00	3.99E-05	2.23E-01	1.29E-04	8.94E-02	8.80E-06	1.24E+00	7.95E-03	1.38E+00	3.87E-02	2.76E-01	2.64E+00	1.28E-02	1.49E-01
35	4.42E+04	2.92E+02	2.36E+00	1.81E+00	1.40E+02	4.06E-03	5.74E-01	3.31E-04	2.30E-01	2.26E-05	3.19E+00	2.04E-02	3.56E+00	9.95E-02	7.11E-01	6.79E+00	3.28E-02	3.84E-01
36	1.30E+02	8.67E-01	6.75E-03	5.37E-03	3.51E-01	1.16E-05	8.73E-03	5.03E-06	3.49E-03	3.44E-07	4.86E-02	3.11E-04	5.41E-02	1.51E-03	1.08E-02	1.03E-01	5.00E-04	5.84E-03
37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39	7.25E+04	4.80E+02	5.97E+00	3.71E+00	4.26E+02	7.90E-03	2.60E-01	1.50E-04	1.04E-01	1.03E-05	1.45E+00	9.26E-03	1.61E+00	4.51E-02	3.22E-01	3.08E+00	1.49E-02	1.74E-01
40	3.07E+05	3.79E+02	1.22E+02	4.63E+01	6.52E+02	2.34E-02	6.66E-02	3.84E-05	2.67E-02	2.63E-06	3.71E-01	2.37E-03	4.13E-01	1.16E-02	8.25E-02	7.88E-01	3.81E-03	4.46E-02
41	1.87E+03	1.27E+01	-	-	-	-	6.33E-03	3.65E-06	2.54E-03	2.50E-07	3.53E-02	2.25E-04	3.93E-02	1.10E-03	7.84E-03	7.50E-02	3.63E-04	4.24E-03
42	1.40E+04	7.54E+01	2.69E+00	9.65E-01	1.65E+01	8.84E-04	4.35E-01	2.51E-04	1.74E-01	1.72E-05	2.42E+00	1.55E-02	2.70E+00	7.55E-02	5.39E-01	5.15E+00	2.49E-02	2.91E-01
43	1.69E+05	1.16E+03	4.57E+00	3.86E+00	9.91E+02	5.69E-02	1.11E-01	6.39E-05	4.44E-02	4.37E-06	6.17E-01	3.94E-03	6.87E-01	1.92E-02	1.37E-01	1.31E+00	6.34E-03	7.41E-02
44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
47	1.74E+05	1.02E+03	1.46E+02	3.27E+01	6.35E+02	6.72E-03	7.72E-01	4.45E-04	3.09E-01	3.05E-05	4.30E+00	2.75E-02	4.79E+00	1.34E-01	9.56E-01	9.14E+00	4.42E-02	5.16E-01
48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	1.11E+05	6.79E+02	9.08E+00	5.15E+00	2.58E+02	9.31E-03	1.33E-01	7.64E-05	5.31E-02	5.23E-06	7.38E-01	4.72E-03	8.22E-01	2.30E-02	1.64E-01	1.57E+00	7.59E-03	8.87E-02
Phase Totals	1.73E+06	5.81E+03	5.51E+02	1.50E+02	4.66E+03	1.25E-01	2.26E+01	1.31E-02	9.07E+00	8.93E-04	1.26E+02	8.07E-01	1.40E+02	3.93E+00	2.81E+01	2.68E+02	1.30E+00	1.52E+01

Table 6: Soluble Radionuclide Inventory by Tank, continued

Tank	Sludge IL Volume, gal	Ra-226 (Ci)	Ra-228 (Ci)	Ac-227 (Ci)	Th-229 (Ci)	Th-230 (Ci)	Pa-231 (Ci)	Pu-244 (Ci)	Am-243 (Ci)	Cm-242 (Ci)	Cm-243 (Ci)	Cm-247 (Ci)	Cm-248 (Ci)	Bk-249 (Ci)	Cf-249 (Ci)	Cf-251 (Ci)	Cf-252 (Ci)
1	4.93E+03	-	-	1.58E-09	-	-	4.38E-09	1.09E-08	6.00E-05	1.48E-04	3.51E-05	6.76E-15	7.05E-15	5.15E-22	3.91E-14	1.34E-15	4.34E-17
2	2.85E+03	-	-	2.39E-10	-	-	6.63E-10	5.35E-09	1.28E-05	3.17E-05	7.51E-06	1.45E-15	1.51E-15	1.10E-22	8.36E-15	2.86E-16	9.29E-18
3	2.85E+03	-	-	6.13E-10	-	-	1.70E-09	6.62E-09	1.30E-05	3.21E-05	7.62E-06	1.47E-15	1.53E-15	1.12E-22	8.48E-15	2.90E-16	9.41E-18
4	8.90E+04	-	-	1.21E-08	-	-	3.37E-08	8.59E-08	4.80E-04	1.19E-03	2.81E-04	5.41E-14	5.64E-14	4.12E-21	3.13E-13	1.07E-14	3.47E-16
5	1.71E+04	-	-	6.83E-09	-	-	1.90E-08	4.44E-08	1.90E-05	4.68E-05	1.11E-05	2.14E-15	2.23E-15	1.63E-22	1.24E-14	4.23E-16	1.37E-17
6	1.75E+04	-	-	5.20E-09	-	-	1.44E-08	2.73E-07	3.95E-06	9.77E-06	2.32E-06	4.46E-16	4.65E-16	3.40E-23	2.58E-15	8.82E-17	2.86E-18
7	1.38E+04	-	-	3.49E-09	-	-	9.69E-09	2.42E-07	1.46E-05	3.60E-05	8.53E-06	1.64E-15	1.71E-15	1.25E-22	9.49E-15	3.25E-16	1.05E-17
8	2.87E+03	-	-	5.14E-10	-	-	1.43E-09	4.02E-08	1.22E-06	3.02E-06	7.16E-07	1.38E-16	1.44E-16	1.05E-23	7.97E-16	2.73E-17	8.85E-19
9	1.90E+03	-	-	2.88E-10	-	-	8.00E-10	1.40E-09	8.39E-06	2.07E-05	4.91E-06	9.46E-16	9.86E-16	7.20E-23	5.47E-15	1.87E-16	6.07E-18
10	1.90E+03	-	-	3.48E-10	-	-	9.66E-10	4.43E-09	1.46E-06	3.62E-06	8.57E-07	1.65E-16	1.72E-16	1.26E-23	9.54E-16	3.26E-17	1.06E-18
11	1.39E+04	6.62E-11	2.51E-07	1.26E-10	1.02E-07	8.10E-09	3.51E-10	1.59E-07	2.56E-09	6.33E-09	1.50E-09	2.89E-19	3.01E-19	2.20E-26	1.67E-18	5.72E-20	1.85E-21
12	7.58E+04	7.95E-10	1.34E-04	1.51E-09	1.07E-05	9.73E-08	4.21E-09	8.32E-07	4.83E-05	1.19E-04	2.83E-05	5.44E-15	5.67E-15	4.15E-22	3.15E-14	1.08E-15	3.49E-17
13	1.76E+05	6.23E-09	9.56E-05	1.72E-08	5.57E-05	7.62E-07	4.79E-08	8.82E-07	1.69E-03	4.17E-03	9.89E-04	1.90E-13	1.98E-13	1.45E-20	1.10E-12	3.77E-14	1.22E-15
14	1.96E+04	4.95E-10	4.53E-05	4.05E-09	4.55E-06	6.06E-08	1.13E-08	7.00E-08	2.01E-04	4.96E-04	1.18E-04	2.27E-14	2.36E-14	1.72E-21	1.31E-13	4.48E-15	1.45E-16
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	4.26E+03	3.30E-10	4.34E-09	5.30E-10	3.90E-07	4.03E-08	1.47E-09	1.87E-09	3.47E-09	8.58E-09	2.03E-09	3.92E-19	4.08E-19	2.98E-26	2.26E-18	7.75E-20	2.51E-21
22	6.99E+03	7.57E-10	-	1.17E-09	2.66E-06	9.26E-08	3.25E-09	-	6.21E-09	1.54E-08	3.64E-09	7.01E-19	7.30E-19	5.34E-26	4.05E-18	1.39E-19	4.50E-21
23	3.93E+04	3.93E-01	5.38E-09	7.23E-10	1.02E-06	1.03E-03	2.01E-09	1.49E-06	4.87E-09	1.20E-08	2.85E-09	5.49E-19	5.72E-19	4.18E-26	3.17E-18	1.09E-19	3.52E-21
24	2.48E+03	2.44E-22	-	7.30E-15	9.64E-20	2.98E-20	2.03E-14	6.53E-13	8.42E-07	2.08E-06	4.93E-07	9.50E-17	9.90E-17	7.23E-24	5.49E-16	1.88E-17	6.09E-19
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	1.82E+05	1.25E-14	-	3.75E-07	4.95E-12	1.53E-12	1.04E-06	3.35E-05	7.93E-04	1.96E-03	4.64E-04	8.94E-14	9.32E-14	6.81E-21	5.17E-13	1.77E-14	5.74E-16
27	2.70E+03	2.66E-22	-	7.96E-15	1.05E-19	3.25E-20	2.21E-14	7.12E-13	1.34E-05	3.31E-05	7.85E-06	1.51E-15	1.58E-15	1.15E-22	8.74E-15	2.99E-16	9.70E-18
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	4.42E+02	3.47E-11	-	6.25E-11	-	4.25E-09	1.73E-10	2.03E-07	2.90E-06	7.17E-06	1.70E-06	3.28E-16	3.41E-16	2.49E-23	1.89E-15	6.48E-17	2.10E-18
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	6.89E+04	7.02E-09	-	1.02E-08	-	8.59E-07	2.83E-08	2.84E-05	3.30E-04	8.15E-04	1.93E-04	3.72E-14	3.88E-14	2.83E-21	2.15E-13	7.35E-15	2.39E-16
33	5.90E+04	2.54E-10	-	4.83E-07	1.56E-11	3.11E-08	1.34E-06	3.98E-06	1.46E-04	3.62E-04	8.58E-05	1.65E-14	1.72E-14	1.26E-21	9.55E-14	3.27E-15	1.06E-16
34	1.41E+04	-	-	1.72E-08	-	-	4.78E-08	1.82E-07	4.27E-05	1.06E-04	2.50E-05	4.82E-15	5.02E-15	3.67E-22	2.78E-14	9.52E-16	3.09E-17
35	4.42E+04	4.40E-09	-	7.74E-09	-	5.38E-07	2.15E-08	1.86E-05	1.10E-04	2.71E-04	6.43E-05	1.24E-14	1.29E-14	9.43E-22	7.15E-14	2.45E-15	7.94E-17
36	1.30E+02	2.25E-11	-	4.42E-11	-	2.76E-09	1.23E-10	5.30E-08	1.67E-06	4.13E-06	9.78E-07	1.88E-16	1.96E-16	1.43E-23	1.09E-15	3.72E-17	1.21E-18
37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39	7.25E+04	1.94E-08	-	2.84E-08	-	2.37E-06	7.88E-08	3.61E-05	4.97E-05	1.23E-04	2.91E-05	5.61E-15	5.85E-15	4.27E-22	3.24E-14	1.11E-15	3.60E-17
40	3.07E+05	4.53E-08	7.34E-04	8.65E-07	5.94E-05	5.54E-06	2.40E-06	1.07E-04	1.27E-05	3.15E-05	7.46E-06	1.44E-15	1.50E-15	1.09E-22	8.31E-15	2.84E-16	9.22E-18
41	1.87E+03	1.75E-09	-	2.05E-09	-	2.14E-07	5.69E-09	-	1.21E-06	2.99E-06	7.09E-07	1.37E-16	1.42E-16	1.04E-23	7.90E-16	2.70E-17	8.77E-19
42	1.40E+04	1.31E-08	1.12E-03	3.12E-08	4.49E-05	1.60E-06	8.68E-08	4.04E-06	8.33E-05	2.06E-04	4.88E-05	9.40E-15	9.79E-15	7.16E-22	5.43E-14	1.86E-15	6.03E-17
43	1.69E+05	1.08E-07	-	1.50E-07	-	1.32E-05	4.17E-07	2.60E-04	2.12E-05	5.24E-05	1.24E-05	2.39E-15	2.49E-15	1.82E-22	1.38E-14	4.73E-16	1.53E-17
44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
47	1.74E+05	-	-	2.75E-07	-	-	7.63E-07	3.07E-05	1.48E-04	3.65E-04	8.65E-05	1.67E-14	1.74E-14	1.27E-21	9.63E-14	3.29E-15	1.07E-16
48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	1.11E+05	1.75E-08	7.71E-05	4.63E-08	2.67E-05	2.15E-06	1.29E-07	4.26E-05	2.54E-05	6.27E-05	1.49E-05	2.86E-15	2.98E-15	2.18E-22	1.65E-14	5.66E-16	1.84E-17
Phase Totals	1.73E+06	3.93E-01	2.21E-03	2.35E-06	2.10E-04	1.06E-03	6.53E-06	5.73E-04	4.33E-03	1.07E-02	2.54E-03	4.89E-13	5.09E-13	3.72E-20	2.82E-12	9.66E-14	3.14E-15

Table 6: Soluble Radionuclide Inventory by Tank, continued

Tank	Salt IL Volume, gal	H-3 (Ci)	C-14 (Ci)	Co-60 (Ci)	Ni-59 (Ci)	Ni-63 (Ci)	Se-79 (Ci)	Sr-90 (Ci)	Y-90 (Ci)	Nb-94 (Ci)	Tc-99 (Ci)	Ru-106 (Ci)	Rh-106 (Ci)	Sb-125 (Ci)	Sn-126 (Ci)	I-129 (Ci)
1	1.44E+05	5.45E+01	9.59E-01	5.61E-01	6.05E-02	1.36E+00	2.24E+00	7.02E+02	7.02E+02	1.76E-05	8.31E+02	5.73E+01	5.73E+01	2.32E+02	1.13E+01	4.48E-01
2	1.61E+05	6.09E+01	1.07E+00	6.27E-01	2.51E-02	1.52E+00	9.29E-01	2.91E+02	2.91E+02	7.30E-06	3.44E+02	2.38E+01	2.37E+01	9.63E+01	4.70E+00	1.86E-01
3	1.61E+05	6.09E+01	1.07E+00	6.27E-01	2.54E-02	1.52E+00	9.41E-01	2.95E+02	2.95E+02	7.40E-06	3.49E+02	2.41E+01	2.41E+01	9.76E+01	4.76E+00	1.88E-01
4	1.02E+04	3.85E+00	6.77E-02	3.96E-02	1.89E-03	9.62E-02	7.02E-02	2.20E+01	2.20E+01	5.52E-07	2.60E+01	1.80E+00	1.79E+00	7.28E+00	3.55E-01	1.40E-02
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	1.60E+05	6.06E+01	1.07E+00	6.24E-01	2.45E-02	1.52E+00	9.07E-01	2.84E+02	2.84E+02	7.13E-06	3.36E+02	2.32E+01	2.32E+01	9.40E+01	4.58E+00	1.81E-01
10	6.34E+04	2.40E+01	4.22E-01	2.47E-01	1.69E-03	6.00E-01	6.26E-02	1.96E+01	1.96E+01	4.93E-07	2.32E+01	1.60E+00	1.60E+00	6.49E+00	3.17E-01	1.25E-02
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	1.80E+04	6.81E+00	1.20E-01	7.02E-02	3.96E-04	1.70E-01	1.47E-02	4.60E+00	4.60E+00	1.15E-07	5.44E+00	3.75E-01	3.75E-01	1.52E+00	7.42E-02	2.93E-03
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	3.89E+04	1.47E+01	2.59E-01	1.51E-01	1.38E-02	3.68E-01	5.10E-01	1.60E+02	1.60E+02	4.01E-06	1.89E+02	1.30E+01	1.30E+01	5.28E+01	2.58E+00	1.02E-01
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	3.30E+05	1.25E+02	2.20E+00	1.29E+00	2.63E-02	3.12E+00	9.75E-01	3.05E+02	3.05E+02	7.67E-06	3.61E+02	2.49E+01	2.49E+01	1.01E+02	4.93E+00	1.95E-01
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	1.80E+05	6.82E+01	1.20E+00	7.02E-01	3.09E-02	1.70E+00	1.14E+00	3.54E+02	3.54E+02	9.00E-06	4.24E+02	2.93E+01	2.92E+01	1.19E+02	5.78E+00	2.29E-01
28	3.09E+05	1.17E+02	2.06E+00	1.20E+00	2.93E-02	2.92E+00	1.08E+00	3.40E+02	3.40E+02	8.53E-06	4.02E+02	2.77E+01	2.77E+01	1.12E+02	5.48E+00	2.17E-01
29	3.07E+05	1.16E+02	2.05E+00	1.20E+00	6.48E-03	2.90E+00	2.40E-01	7.53E+01	7.53E+01	1.89E-06	8.91E+01	6.15E+00	6.14E+00	2.49E+01	1.21E+00	4.80E-02
30	7.49E+04	2.83E+01	4.99E-01	2.92E-01	1.70E-02	7.09E-01	6.30E-01	1.97E+02	1.97E+02	4.95E-06	2.33E+02	1.61E+01	1.61E+01	6.53E+01	3.18E+00	1.26E-01
31	3.44E+05	1.30E+02	2.29E+00	1.34E+00	8.28E-02	3.26E+00	3.07E+00	9.61E+02	9.61E+02	2.41E-05	1.14E+03	7.85E+01	7.84E+01	3.18E+02	1.55E+01	6.13E-01
32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
33	8.81E+04	4.49E+01	5.87E-01	3.44E-01	7.57E-03	8.34E-01	2.80E-01	8.78E+01	8.78E+01	2.20E-06	1.04E+02	7.17E+00	7.17E+00	2.91E+01	1.42E+00	5.61E-02
34	5.74E+04	2.17E+01	3.82E-01	2.24E-01	5.99E-03	5.43E-01	2.22E-01	6.96E+01	6.96E+01	1.75E-06	8.24E+01	5.68E+00	5.68E+00	2.30E+01	1.12E+00	4.44E-02
35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	3.11E+05	1.18E+02	2.07E+00	1.21E+00	1.38E-01	2.94E+00	5.10E+00	1.60E+03	1.60E+03	4.01E-05	1.89E+03	1.30E+02	1.30E+02	5.29E+02	2.58E+01	1.02E+00
37	3.43E+05	1.30E+02	2.29E+00	1.34E+00	6.93E-02	3.25E+00	2.57E+00	7.36E+02	7.36E+02	2.02E-05	9.52E+02	6.57E+01	6.56E+01	2.66E+02	1.30E+01	5.13E-01
38	2.48E+05	9.40E+01	1.65E+00	9.69E-01	1.71E-03	2.35E+00	6.35E-02	1.99E+01	1.99E+01	4.99E-07	2.35E+01	1.62E+00	1.62E+00	6.58E+00	3.21E-01	1.27E-02
39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
41	2.20E+05	8.32E+01	1.46E+00	8.57E-01	4.93E-03	2.08E+00	1.83E-01	2.02E+01	2.02E+01	1.44E-06	6.77E+01	4.67E+00	4.67E+00	1.89E+01	9.23E-01	3.65E-02
42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44	3.01E+05	1.14E+02	2.00E+00	1.17E+00	3.38E-02	2.85E+00	1.25E+00	3.92E+02	3.92E+02	9.85E-06	4.64E+02	3.20E+01	3.20E+01	1.30E+02	6.33E+00	2.50E-01
45	3.31E+05	1.25E+02	2.21E+00	1.29E+00	3.52E-02	3.14E+00	1.30E+00	4.08E+02	4.08E+02	1.03E-05	4.84E+02	3.34E+01	3.33E+01	1.35E+02	6.59E+00	2.61E-01
46	2.60E+05	9.83E+01	1.73E+00	1.01E+00	4.13E-02	2.46E+00	1.53E+00	4.80E+02	4.80E+02	1.20E-05	5.68E+02	3.92E+01	3.92E+01	1.59E+02	7.75E+00	3.06E-01
47	2.50E+05	9.48E+01	1.67E+00	9.77E-01	7.37E-03	2.37E+00	2.73E-01	8.55E+01	8.55E+01	2.15E-06	1.01E+02	6.98E+00	6.98E+00	2.83E+01	1.38E+00	5.46E-02
48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	8.97E+01	3.40E-02	5.98E-04	3.50E-04	1.47E-07	8.49E-04	5.46E-06	1.25E-02	1.25E-02	4.30E-11	2.03E-03	1.40E-04	1.40E-04	5.66E-04	2.76E-05	1.09E-06
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phase Totals	4.71E+06	1.79E+03	3.14E+01	1.84E+01	6.91E-01	4.46E+01	2.56E+01	7.91E+03	7.91E+03	2.01E-04	9.49E+03	6.55E+02	6.54E+02	2.65E+03	1.29E+02	5.12E+00

Table 6: Soluble Radionuclide Inventory by Tank, continued

Tank	Salt IL Volume, gal	Cs-134 (Ci)	Cs-135 (Ci)	Cs-137 (Ci)	Ba-137m (Ci)	Ce-144 (Ci)	Pr-144 (Ci)	Pm-147 (Ci)	Eu-154 (Ci)	Th-232 (Ci)	U-232 (Ci)	U-233 (Ci)	U-234 (Ci)	U-235 (Ci)	U-236 (Ci)	U-238 (Ci)	Np-237 (Ci)
1	1.44E+05	5.73E+03	9.73E+00	2.85E+06	2.70E+06	1.49E-01	1.49E-01	9.66E+01	2.29E+01	-	1.31E-04	-	-	2.02E-04	-	5.02E-03	7.33E-03
2	1.61E+05	2.37E+03	4.03E+00	1.18E+06	1.12E+06	6.19E-02	6.19E-02	4.00E+01	9.49E+00	-	1.23E-04	-	-	5.91E-05	-	1.47E-03	1.54E-02
3	1.61E+05	2.41E+03	4.09E+00	1.20E+06	1.13E+06	6.27E-02	6.27E-02	4.06E+01	9.62E+00	-	1.08E-04	-	-	1.52E-04	-	3.78E-03	2.83E-02
4	1.02E+04	1.79E+02	3.05E-01	8.94E+04	8.46E+04	4.68E-03	4.68E-03	3.03E+00	7.17E-01	-	4.63E-06	-	-	6.07E-06	-	2.61E-04	2.33E-04
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	1.60E+05	2.32E+03	3.94E+00	1.15E+06	1.09E+06	6.04E-02	6.04E-02	3.91E+01	9.27E+00	-	1.64E-04	-	-	1.07E-04	-	2.66E-03	1.82E-02
10	6.34E+04	1.60E+02	2.72E-01	7.98E+04	7.55E+04	4.17E-03	4.17E-03	2.70E+00	6.40E-01	-	4.18E-05	-	-	5.10E-05	-	1.27E-03	9.72E-03
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	1.80E+04	3.75E+01	6.37E-02	1.87E+04	1.77E+04	9.78E-04	9.78E-04	6.33E-01	1.50E-01	3.18E-05	3.20E-07	8.95E-04	8.38E-05	1.58E-06	6.64E-06	1.59E-05	1.85E-04
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	3.89E+04	1.30E+03	2.21E+00	6.49E+05	6.14E+05	3.40E-02	3.40E-02	2.20E+01	5.21E+00	8.99E-05	2.67E-05	3.17E-03	4.35E-04	3.52E-05	3.74E-05	6.72E-04	4.65E-03
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	3.30E+05	2.49E+03	4.23E+00	1.24E+06	1.17E+06	6.50E-02	6.49E-02	4.20E+01	9.96E+00	-	1.48E-09	4.51E-15	1.44E-14	4.26E-09	5.50E-10	5.11E-07	1.32E-09
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	1.80E+05	2.92E+03	4.97E+00	1.46E+06	1.38E+06	7.62E-02	7.62E-02	4.93E+01	1.17E+01	-	8.09E-10	2.46E-15	7.86E-15	2.33E-09	3.00E-10	2.79E-07	7.20E-10
28	3.09E+05	2.77E+03	4.71E+00	1.38E+06	1.31E+06	7.23E-02	7.22E-02	4.67E+01	1.11E+01	-	1.39E-09	4.22E-15	1.35E-14	3.99E-09	5.15E-10	4.79E-07	1.24E-09
29	3.07E+05	6.14E+02	1.04E+00	3.06E+05	2.89E+05	1.60E-02	1.60E-02	1.04E+01	2.46E+00	-	5.87E-11	4.52E-08	6.38E-09	1.74E-10	6.58E-10	2.04E-09	1.64E-08
30	7.49E+04	1.61E+03	2.73E+00	8.02E+05	7.58E+05	4.20E-02	4.19E-02	2.71E+01	6.44E+00	-	-	-	2.61E-03	4.64E-05	4.82E-04	1.72E-06	1.18E-03
31	3.44E+05	7.84E+03	1.33E+01	3.91E+06	3.70E+06	2.04E-01	2.04E-01	1.32E+02	3.14E+01	-	6.58E-11	5.07E-08	7.15E-09	1.95E-10	7.37E-10	2.28E-09	1.84E-08
32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
33	8.81E+04	7.17E+02	1.22E+00	3.57E+05	3.38E+05	1.87E-02	1.87E-02	1.21E+01	2.87E+00	-	1.71E-03	8.18E-09	1.69E-04	3.16E-03	1.75E-03	4.58E-01	1.44E-01
34	5.74E+04	5.68E+02	9.64E-01	2.83E+05	2.68E+05	1.48E-02	1.48E-02	9.57E+00	2.27E+00	-	3.03E-04	-	-	3.06E-04	-	2.16E-02	1.67E-02
35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	3.11E+05	1.30E+04	2.21E+01	6.49E+06	6.14E+06	3.40E-01	3.40E-01	2.20E+02	5.21E+01	-	-	-	2.38E-02	4.62E-04	8.41E-03	1.51E-04	6.67E-03
37	3.43E+05	6.56E+03	1.11E+01	3.27E+06	3.09E+06	1.71E-01	1.71E-01	1.11E+02	2.62E+01	-	6.57E-11	5.06E-08	7.14E-09	1.95E-10	7.36E-10	2.28E-09	1.84E-08
38	2.48E+05	1.62E+02	2.76E-01	8.09E+04	7.65E+04	4.23E-03	4.23E-03	2.74E+00	6.49E-01	-	-	-	7.41E-08	1.02E-09	1.41E-08	8.30E-11	7.89E-08
39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
41	2.20E+05	4.67E+02	7.93E-01	2.33E+05	2.20E+05	1.22E-02	1.22E-02	7.87E+00	1.87E+00	-	-	-	9.13E-02	1.06E-03	2.62E-02	7.23E-05	2.73E-01
42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44	3.01E+05	3.20E+03	5.44E+00	1.59E+06	1.51E+06	8.34E-02	8.34E-02	5.40E+01	1.28E+01	-	1.35E-09	4.11E-15	1.31E-14	3.89E-09	5.02E-10	4.66E-07	1.20E-09
45	3.31E+05	3.33E+03	5.66E+00	1.66E+06	1.57E+06	8.69E-02	8.69E-02	5.62E+01	1.33E+01	-	1.49E-09	4.53E-15	1.45E-14	4.28E-09	5.53E-10	5.14E-07	1.33E-09
46	2.60E+05	3.92E+03	6.65E+00	1.95E+06	1.85E+06	1.02E-01	1.02E-01	6.60E+01	1.57E+01	-	1.17E-09	3.55E-15	1.13E-14	3.35E-09	4.33E-10	4.02E-07	1.04E-09
47	2.50E+05	6.98E+02	1.19E+00	3.48E+05	3.29E+05	1.82E-02	1.82E-02	1.18E+01	2.79E+00	-	6.39E-04	-	-	1.74E-03	-	1.38E-01	-
48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	8.97E+01	1.40E-02	2.37E-05	6.96E+00	6.58E+00	3.64E-07	3.64E-07	2.36E-04	5.59E-05	-	1.72E-14	1.32E-11	1.86E-12	5.10E-14	1.92E-13	5.96E-13	4.79E-12
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phase Totals	4.71E+06	6.54E+04	1.11E+02	3.26E+07	3.08E+07	1.71E+00	1.70E+00	1.10E+03	2.62E+02	1.22E-04	3.25E-03	4.07E-03	1.18E-01	7.39E-03	3.69E-02	6.33E-01	5.25E-01

Table 6: Soluble Radionuclide Inventory by Tank, continued

Tank	Salt IL Volume, gal	Pu-238 (Ci)	Pu-239 (Ci)	Pu-240 (Ci)	Pu-241 (Ci)	Pu-242 (Ci)	Am-241 (Ci)	Am-242m (Ci)	Cm-244 (Ci)	Cm-245 (Ci)	Na-22 (Ci)	Al-26 (Ci)	Te-125m (Ci)	Sb-126 (Ci)	Sb-126m (Ci)	Sm-151 (Ci)	Eu-152 (Ci)	Eu-155 (Ci)
1	1.44E+05	5.68E+00	1.52E+00	3.40E-01	1.87E+00	6.99E-05	9.15E+00	5.27E-03	3.66E+00	3.61E-04	5.09E+01	3.26E-01	5.67E+01	1.59E+00	1.13E+01	1.08E+02	5.24E-01	6.12E+00
2	1.61E+05	1.01E+01	1.44E+00	3.21E-01	1.35E+00	6.61E-05	3.79E+00	2.19E-03	1.52E+00	1.49E-04	2.11E+01	1.35E-01	2.35E+01	6.57E-01	4.70E+00	4.49E+01	2.17E-01	2.54E+00
3	1.61E+05	1.25E+01	1.78E+00	3.98E-01	2.01E+00	8.18E-05	3.84E+00	2.22E-03	1.54E+00	1.52E-04	2.14E+01	1.37E-01	2.38E+01	6.66E-01	4.76E+00	4.55E+01	2.20E-01	2.57E+00
4	1.02E+04	4.73E-02	4.67E-02	1.04E-02	8.83E-02	2.15E-06	2.86E-01	1.65E-04	1.15E-01	1.13E-05	1.59E+00	1.02E-02	1.78E+00	4.97E-02	3.55E-01	3.39E+00	1.64E-02	1.92E-01
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	1.60E+05	3.95E+00	5.64E-01	1.26E-01	5.23E-01	2.59E-05	3.70E+00	2.13E-03	1.48E+00	1.46E-04	2.06E+01	1.32E-01	2.30E+01	6.42E-01	4.58E+00	4.38E+01	2.12E-01	2.48E+00
10	6.34E+04	4.94E+00	7.05E-01	1.58E-01	7.01E-01	3.24E-05	2.56E-01	1.47E-04	1.02E-01	1.01E-05	1.42E+00	9.11E-03	1.59E+00	4.43E-02	3.17E-01	3.03E+00	1.46E-02	1.71E-01
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	1.80E+04	3.23E+00	5.41E-02	2.99E-02	7.59E-01	4.32E-05	5.99E-02	3.45E-05	2.40E-02	2.36E-06	3.34E-01	2.13E-03	3.72E-01	1.04E-02	7.42E-02	7.09E-01	3.43E-03	4.01E-02
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	3.89E+04	2.08E+00	5.13E-01	1.66E-01	8.38E-01	3.03E-05	2.08E+00	1.20E-03	8.33E-01	8.21E-05	1.16E+01	7.41E-02	1.29E+01	3.61E-01	2.58E+00	2.46E+01	1.19E-01	1.39E+00
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	3.30E+05	2.72E-03	4.26E-04	9.53E-05	2.24E-03	1.90E-08	3.98E+00	2.29E-03	1.59E+00	1.57E-04	2.22E+01	1.42E-01	2.47E+01	6.90E-01	4.93E+00	4.71E+01	2.28E-01	2.66E+00
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	1.80E+05	1.49E-03	2.33E-04	5.21E-05	1.23E-03	1.04E-08	4.67E+00	2.69E-03	1.87E+00	1.84E-04	2.60E+01	1.66E-01	2.90E+01	8.10E-01	5.78E+00	5.53E+01	2.67E-01	3.12E+00
28	3.09E+05	2.55E-03	4.00E-04	8.94E-05	2.10E-03	1.78E-08	4.43E+00	2.55E-03	1.77E+00	1.75E-04	2.46E+01	1.58E-01	2.74E+01	7.68E-01	5.48E+00	5.24E+01	2.53E-01	2.96E+00
29	3.07E+05	6.00E-05	1.62E-06	6.71E-07	1.18E-05	4.45E-10	9.81E-01	5.65E-04	3.93E-01	3.87E-05	5.46E+00	3.49E-02	6.08E+00	1.70E-01	1.21E+00	1.16E+01	5.62E-02	6.56E-01
30	7.49E+04	5.03E+02	4.37E+00	3.14E+00	3.23E+02	7.52E-03	2.57E+00	1.48E-03	1.03E+00	1.01E-04	1.43E+01	9.15E-02	1.59E+01	4.46E-01	3.18E+00	3.04E+01	1.47E-01	1.72E+00
31	3.44E+05	6.72E-05	1.82E-06	7.52E-07	1.33E-05	4.99E-10	1.25E+01	7.22E-03	5.01E+00	4.94E-04	6.97E+01	4.46E-01	7.76E+01	2.17E+00	1.55E+01	1.48E+02	7.17E-01	8.37E+00
32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
33	8.81E+04	2.35E+02	1.28E+02	2.25E+01	6.67E+02	1.30E-03	1.14E+00	6.60E-04	4.58E-01	4.51E-05	6.37E+00	4.08E-02	7.10E+00	1.98E-01	1.42E+00	1.35E+01	6.55E-02	7.66E-01
34	5.74E+04	-	3.50E+00	7.81E-01	1.62E+01	1.62E-04	9.07E-01	5.23E-04	3.63E-01	3.58E-05	5.05E+00	3.23E-02	5.62E+00	1.57E-01	1.12E+00	1.07E+01	5.19E-02	6.06E-01
35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	3.11E+05	2.07E+03	1.61E+01	1.28E+01	8.38E+02	2.77E-02	2.08E+01	1.20E-02	8.33E+00	8.21E-04	1.16E+02	7.41E-01	1.29E+02	3.61E+00	2.58E+01	2.46E+02	1.19E+00	1.39E+01
37	3.43E+05	6.71E-05	1.82E-06	7.51E-07	1.32E-05	4.98E-10	1.05E+01	6.04E-03	4.20E+00	4.13E-04	5.83E+01	3.73E-01	6.50E+01	1.82E+00	1.30E+01	1.24E+02	6.00E-01	7.01E+00
38	2.48E+05	1.80E-03	7.09E-06	5.99E-06	1.54E-03	8.83E-08	2.59E-01	1.49E-04	1.04E-01	1.02E-05	1.44E+00	9.23E-03	1.61E+00	4.50E-02	3.21E-01	3.07E+00	1.48E-02	1.73E-01
39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
41	2.20E+05	1.49E+03	-	-	-	-	7.45E-01	4.30E-04	2.98E-01	2.94E-05	4.15E+00	2.65E-02	4.62E+00	1.29E-01	9.23E-01	8.82E+00	4.27E-02	4.99E-01
42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44	3.01E+05	2.48E-03	3.89E-04	8.70E-05	2.05E-03	1.73E-08	5.11E+00	2.95E-03	2.05E+00	2.02E-04	2.85E+01	1.82E-01	3.17E+01	8.86E-01	6.33E+00	6.05E+01	2.93E-01	3.42E+00
45	3.31E+05	2.74E-03	4.29E-04	9.59E-05	2.26E-03	1.91E-08	5.32E+00	3.07E-03	2.13E+00	2.10E-04	2.96E+01	1.90E-01	3.30E+01	9.23E-01	6.59E+00	6.30E+01	3.05E-01	3.56E+00
46	2.60E+05	2.14E-03	3.36E-04	7.51E-05	1.77E-03	1.50E-08	6.25E+00	3.60E-03	2.50E+00	2.47E-04	3.48E+01	2.23E-01	3.88E+01	1.08E+00	7.75E+00	7.40E+01	3.58E-01	4.18E+00
47	2.50E+05	1.47E+03	2.11E+02	4.71E+01	9.16E+02	9.70E-03	1.11E+00	6.42E-04	4.46E-01	4.39E-05	6.20E+00	3.97E-02	6.91E+00	1.93E-01	1.38E+00	1.32E+01	6.38E-02	7.45E-01
48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	8.97E+01	1.75E-08	4.74E-10	1.96E-10	3.46E-09	1.30E-13	2.23E-05	1.29E-08	8.93E-06	8.80E-10	1.24E-04	7.94E-07	1.38E-04	3.87E-06	2.76E-05	2.64E-04	1.28E-06	1.49E-05
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phase Totals	4.71E+06	5.81E+03	3.70E+02	8.79E+01	2.77E+03	4.67E-02	1.04E+02	6.02E-02	4.18E+01	4.12E-03	5.82E+02	3.72E+00	6.48E+02	1.81E+01	1.29E+02	1.24E+03	5.98E+00	6.99E+01

Table 6: Soluble Radionuclide Inventory by Tank, continued

Tank	Salt IL Volume, gal	Ra-226 (Ci)	Ra-228 (Ci)	Ac-227 (Ci)	Th-229 (Ci)	Th-230 (Ci)	Pa-231 (Ci)	Pu-244 (Ci)	Am-243 (Ci)	Cm-242 (Ci)	Cm-243 (Ci)	Cm-247 (Ci)	Cm-248 (Ci)	Bk-249 (Ci)	Cf-249 (Ci)	Cf-251 (Ci)	Cf-252 (Ci)
1	1.44E+05	-	-	4.60E-08	-	-	1.28E-07	3.20E-07	1.75E-03	4.33E-03	1.03E-03	1.97E-13	2.06E-13	1.50E-20	1.14E-12	3.90E-14	1.27E-15
2	1.61E+05	-	-	1.35E-08	-	-	3.74E-08	3.02E-07	7.25E-04	1.79E-03	4.25E-04	8.18E-14	8.52E-14	6.23E-21	4.73E-13	1.62E-14	5.25E-16
3	1.61E+05	-	-	3.46E-08	-	-	9.62E-08	3.74E-07	7.35E-04	1.82E-03	4.30E-04	8.29E-14	8.64E-14	6.31E-21	4.79E-13	1.64E-14	5.32E-16
4	1.02E+04	-	-	1.39E-09	-	-	3.85E-09	9.82E-09	5.48E-05	1.35E-04	3.21E-05	6.18E-15	6.44E-15	4.71E-22	3.57E-14	1.22E-15	3.97E-17
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	1.60E+05	-	-	2.43E-08	-	-	6.76E-08	1.19E-07	7.08E-04	1.75E-03	4.15E-04	7.99E-14	8.32E-14	6.08E-21	4.61E-13	1.58E-14	5.12E-16
10	6.34E+04	-	-	1.16E-08	-	-	3.23E-08	1.48E-07	4.89E-05	1.21E-04	2.86E-05	5.52E-15	5.75E-15	4.20E-22	3.19E-14	1.09E-15	3.54E-17
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	1.80E+04	1.89E-10	3.18E-05	3.60E-10	2.54E-06	2.31E-08	9.99E-10	1.98E-07	1.15E-05	2.83E-05	6.71E-06	1.29E-15	1.35E-15	9.84E-23	7.47E-15	2.56E-16	8.29E-18
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	3.89E+04	9.81E-10	8.99E-05	8.04E-09	9.02E-06	1.20E-07	2.23E-08	1.39E-07	3.98E-04	9.84E-04	2.33E-04	4.49E-14	4.68E-14	3.42E-21	2.59E-13	8.88E-15	2.88E-16
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	3.30E+05	3.24E-20	-	9.71E-13	1.28E-17	3.97E-18	2.70E-12	8.68E-11	7.61E-04	1.88E-03	4.46E-04	8.59E-14	8.95E-14	6.54E-21	4.96E-13	1.70E-14	5.51E-16
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	1.80E+05	1.77E-20	-	5.31E-13	7.01E-18	2.17E-18	1.47E-12	4.74E-11	8.93E-04	2.21E-03	5.23E-04	1.01E-13	1.05E-13	7.67E-21	5.82E-13	1.99E-14	6.46E-16
28	3.09E+05	3.04E-20	-	9.10E-13	1.20E-17	3.72E-18	2.53E-12	8.14E-11	8.47E-04	2.09E-03	4.96E-04	9.55E-14	9.95E-14	7.27E-21	5.52E-13	1.89E-14	6.13E-16
29	3.07E+05	1.44E-14	-	3.98E-14	1.29E-10	1.76E-12	1.11E-13	2.04E-12	1.88E-04	4.64E-04	1.10E-04	2.12E-14	2.21E-14	1.61E-21	1.22E-13	4.18E-15	1.36E-16
30	7.49E+04	5.88E-09	-	1.06E-08	-	7.20E-07	2.94E-08	3.44E-05	4.92E-04	1.21E-03	2.88E-04	5.55E-14	5.78E-14	4.22E-21	3.20E-13	1.10E-14	3.56E-16
31	3.44E+05	1.61E-14	-	4.46E-14	1.44E-10	1.97E-12	1.24E-13	2.28E-12	2.40E-03	5.92E-03	1.40E-03	2.70E-13	2.82E-13	2.06E-20	1.56E-12	5.34E-14	1.73E-15
32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
33	8.81E+04	3.80E-10	-	7.22E-07	2.33E-11	4.65E-08	2.01E-06	5.95E-06	2.19E-04	5.41E-04	1.28E-04	2.47E-14	2.57E-14	1.88E-21	1.43E-13	4.88E-15	1.58E-16
34	5.74E+04	-	-	6.99E-08	-	-	1.94E-07	7.41E-07	1.73E-04	4.29E-04	1.02E-04	1.96E-14	2.04E-14	1.49E-21	1.13E-13	3.87E-15	1.26E-16
35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	3.11E+05	5.37E-08	-	1.05E-07	-	6.57E-06	2.93E-07	1.26E-04	3.98E-03	9.84E-03	2.33E-03	4.49E-13	4.68E-13	3.42E-20	2.60E-12	8.88E-14	2.88E-15
37	3.43E+05	1.61E-14	-	4.45E-14	1.44E-10	1.97E-12	1.24E-13	2.28E-12	2.00E-03	4.95E-03	1.17E-03	2.26E-13	2.36E-13	1.72E-20	1.31E-12	4.47E-14	1.45E-15
38	2.48E+05	1.67E-13	-	2.33E-13	-	2.04E-11	6.48E-13	4.04E-10	4.96E-05	1.23E-04	2.90E-05	5.59E-15	5.83E-15	4.26E-22	3.23E-14	1.11E-15	3.59E-17
39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
41	2.20E+05	2.06E-07	-	2.41E-07	-	2.52E-05	6.69E-07	-	1.43E-04	3.52E-04	8.35E-05	1.61E-14	1.68E-14	1.22E-21	9.29E-14	3.18E-15	1.03E-16
42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44	3.01E+05	2.96E-20	-	8.87E-13	1.17E-17	3.62E-18	2.46E-12	7.93E-11	9.78E-04	2.42E-03	5.73E-04	1.10E-13	1.15E-13	8.40E-21	6.37E-13	2.18E-14	7.08E-16
45	3.31E+05	3.26E-20	-	9.77E-13	1.29E-17	3.99E-18	2.71E-12	8.73E-11	1.02E-03	2.52E-03	5.96E-04	1.15E-13	1.20E-13	8.75E-21	6.64E-13	2.27E-14	7.37E-16
46	2.60E+05	2.55E-20	-	7.65E-13	1.01E-17	3.12E-18	2.12E-12	6.84E-11	1.20E-03	2.96E-03	7.00E-04	1.35E-13	1.41E-13	1.03E-20	7.80E-13	2.67E-14	8.66E-16
47	2.50E+05	-	-	3.96E-07	-	-	1.10E-06	4.43E-05	2.13E-04	5.27E-04	1.25E-04	2.40E-14	2.51E-14	1.83E-21	1.39E-13	4.75E-15	1.54E-16
48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	8.97E+01	4.20E-18	-	1.16E-17	3.76E-14	5.14E-16	3.23E-17	5.95E-16	4.27E-09	1.05E-08	2.50E-09	4.81E-19	5.02E-19	3.67E-26	2.78E-18	9.52E-20	3.09E-21
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phase Totals	4.71E+06	2.67E-07	1.22E-04	1.69E-06	1.16E-05	3.27E-05	4.68E-06	2.13E-04	2.00E-02	4.94E-02	1.17E-02	2.25E-12	2.35E-12	1.72E-19	1.30E-11	4.46E-13	1.45E-14

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Keywords: TPB Degradation
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Catalytic Hydrolysis
Steam Reforming
HLW
Tank 48H

Technical Program Plan for Tank 48H Processing

APPROVED for Release for
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The main goal of the Systems Engineering approach is to deliver solution that meets cost, schedule, and technical requirements while minimizing the environmental, safety, and health risks.

The initial downselection was performed using a disciplined process shown in Figure 1 – Tank 48H Disposition Engineering Process. A 'Best Value' competitively bid contract to disposition the contents of Tank 48H is being developed. The contract will include engineering scale demonstration using simulant to confirm inputs, design, fabrication (off-site), assembly and testing (off-site), disassembly and shipment of modules to SRS, reassembly and start-up support at SRS, and technical oversight support at SRS for a limited time. Vendors will supply flowsheets, risk assessments, costs, and impacts analysis. This methodology allows shared technology risk with the vendor.
The evaluation criteria for the selection process are given in Appendix B- Evaluation Criteria for Tank 48H Disposition Technology Selection. The critical needs, e.g. the 'have to have', are identified as the 'Screening criteria-Go/No Go'. If an alternative cannot successfully satisfy these criteria, it is eliminated from further consideration. The evaluation ensures that Science, Engineering, and Safety attributes are most important. To provide a technical basis for the selection process, flowsheets will be developed for each of the initial list of alternatives. The flowsheet will document the assumed flowrates, chemical characterization, and the product quantities estimates.

The identification and quantification of risk is integral to the Systems Engineering approach. As part of the selection process, a review of each alternative will be performed to identify potential risks associated with implementation of the alternative. This preliminary risk assessment will provide key information to the downselection process.

3.2 Treatment Alternative Descriptions

A brief discussion of each of the selected Tank 48 treatment alternative processes, from the fundamental chemistry perspective, is provided below. This is followed by a discussion of treatment facility configuration options (Section 3.3) and potential product disposition alternatives and associated product requirements (Section 3.4).

3.2.1 Catalytic Oxidation Using Fenton's Reagent

Under moderately acidic conditions (pH 3-5), the combination of hydrogen peroxide and ferrous ion efficiently produces hydroxyl free radicals, which are highly oxidizing. This combination of hydrogen peroxide and iron is known as Fenton's reagent. In the presence of dissolved organic compounds, these free radicals oxidize the organic compounds and convert them into carbon dioxide and water (Taylor, 2002). The TPB salts are sufficiently soluble under these conditions to permit this oxidation reaction to proceed and destoy the organic character of the Tank 48 material. However, at this pH range the risk of corrosion to the mild carbon of Tank 48 is too great and the process would be limited to an out of tank facility.

At higher pH conditions, the effectiveness of the reaction is diminished; however, the correlation between treatment effectiveness and pH has not been well quantified for HLW. This correlation needs to be developed with further research. The advantage of operating a Fenton's reagent process at a higher pH range (mildly alkaline) would be the ability of performing the operation in Tank 48.

3.2.2 Catalytic Hydrolysis Using Metals and Decreased pH

Use of catalytic metals such as copper or palladium can increase the degradation rate of organics in solution, through enhanced hydrolysis. Such reactions were effectively used for increasing the degradation rate of TPB in Tank 49H waste (Martin et al., 2000). The resulting benzene from the degradation in Tank 49 was removed through the existing nitrogen ventilation purge system. Tank 48 has a similar nitrogen ventilation purge system. For highly alkaline solutions such as HLW, this approach is most effective if the pH of the solution is decreased and the temperature is elevated.

The hydrolysis performed in Tank 49 was for sodium tetraphenylborate waste. This material was more soluble and more easily degraded than the potassium and cesium tetraphenylborate salts found in Tank 48. Further research is required to determine if the decomposition rates for Tank 48 waste using catalytic hydrolysis are sufficient to recover Tank 48 by the desired end date. It is expected that the hydrolysis products would include benzene, phenol, terphenyls, water, and non-organic salts. If this process can be performed at mildly alkaline conditions, then the hydrolysis could be done in Tank 48. If research shows the pH range for the hydrolysis needs to be neutral or acidic, then the process must be done out of tank.

3.2.3 Accelerated Degradation Using Elevated Temperatures and Decreased pH

Natural thermal degradation of TPB is a function of temperature and pH. At ambient tank temperatures and high pH conditions, the natural degradation rate is relatively low. At higher temperatures and lower pH conditions, the natural degradation rate is expected to be higher. Further research is required to determine if the decomposition rates for Tank 48 waste using thermal degradation are sufficient to recover Tank 48 by the desired end date. It is expected that the hydrolysis products would include benzene, phenol, terphenyls, water, and non-organic salts. If this process can be performed at mildly alkaline conditions, then the hydrolysis could be done in Tank 48. If research shows the pH range for the hydrolysis needs to be neutral or acidic, then the process must be done out of tank.

3.2.4 Thermal Degradation Using Steam Reforming

Superheated steam and redox reactions are used to evaporate liquids, convert organic compounds into carbon dioxide and water, reduce nitrates and nitrites to elemental nitrogen, and stabilize reactive constituents (Fowler, 2003). This alternative utilizes a fluidized bed to maximize the reactive surface area, maximizing the reaction efficiency. The typical reaction temperature ranges from 600 to 800 C.

Steam reforming facilities are currently being successfully used for treating industrial wastes and commercial reactor ion exchange resin.

3.3 Treatment Configurations:

The research effort to recover Tank 48 can be categorized into two broad categories: in tank and out of tank, as shown in Figure 2. Within each of these broad options there are several options for dispositioning of the Tank 48 material. Each of these approaches will have facility constraints that will impact its implementation if it is the chosen disposition path. Parameters such as Authorization Basis (AB) impacts, environmental permitting, and facility footprint will all have a bearing on the process that is chosen for final disposition.

Processing time for all of the options is impacted by the needed completion. Earlier processing starts support longer processing rates. The in-tank options should require few new components and little modification to existing structures and could likely be implemented relatively quickly. The out of tank options on the other hand require time to site and construct and would be expected to take longer to start processing. The final choice of a processing option will need to account for the differing processing times with the completion date in mind.

All of the options downselected and addressed in this Technology plan have a history in treating organic wastes. Catalytic hydrolysis in the DWPF salt cell was the original chosen method for decomposing the tetraphenylborate precipitate product from the ITP before incorporation in the DWPF vitrification process. This method has been researched at SRTC, but under acidic conditions and at higher temperatures than can be tolerated in Tank 48. Fenton's reagent has been used by AEA Technology to successfully destroy spent radioactive ion exchange resins. Steam reforming is being used commercially to decompose spent radioactive ion exchange resins from nuclear power reactors. Any of these processes can be expected to decompose TPB salts. The research effort of this plan is to determine which process can accomplish this task most efficiently and within the project time constraints.

3.3.1 In-Tank Processing

For the "In-Tank" options, Tank 48 would become the reaction vessel and all processing would take place within the confines of the tank structures and components. This is the approach used successfully for the recovery of Tank 49 (Martin, 2000). All three options would likely require some additional equipment for the addition of reagents, however the space needed for a reagent storage tank and pump would be small. This new equipment could likely be sited on or near Tank 48, or at a minimum could be constructed at the East Hill Cold Feeds area and use the existing lines to transfer material to Tank 48. Minimal new equipment translates into all the in-tank options having a cost and installation time advantage over any of the out of tank options.

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DXSR 45-10W [Rev 4-18-2002]

Procurement Specification Cover Sheet

1. Title SRS Tank 48H Materials Treatment			
2. Specification No. G-SOW-H-00032	3. Revision 0		4. Page 1 of 36
5. Functional Classification SC	6. Requester Department LWDP	7. Requester Division CBU	
8. Cognizant Technical Function			
Name James W. Barber			Date
Title Lead Engineer			
Department Salt Program			
9. Additional Reviewer			
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Department Salt Program			
10. Cognizant Quality Function			
Name William H. Walker			Date
Title Quality Engineer			
Department LW Quality Assurance			
11. Manager			
Name Bernice C. Rogers			Date
Title Project Owner			
Department Salt Program			
12. Other Approver			
Name Willie T. Davis Jr.			Date
Title H Disposition Project Manager			
Department H Tank Farm Disposition Projects			

2.3.4 Other Documents

Document Number	Title
SCDHEC Permit 17,424-IW	F and H Area High Level Radioactive Waste Tank Farms Partial Permit to Operate (Industrial Wastewater Treatment Facility Permit)
M-SPP-G-00243	High Efficiency Particulate Air (HEPA) Filters, Fire Resistant Note: See also Standard 15888
M-MH-G-0109	Sample Vial - Plan and Sections
WSRC-RP-2002-00154	Tank 48H Disposition Alternatives Identification, Phase 1 & 2 Summary Report
S -TSR-G -00001	Technical Safety Requirements, Concentration, Storage, and Transfer Facilities, Rev. 4
WSRC-SA-2002-00007	Concentration, Storage, and Transfer Facilities, Documented Safety Analysis
X-CLC-G-00014	High Level Waste Concentration Storage and Transfer Facilities Safety Analysis Radiological Source Terms (Inhalation Dose Potentials)
Illustration Package	Example SRS Drawings
OSR 45-4	Supplier Deviation Disposition Request (SDDR) Form

3.0 WORK REQUIREMENTS

3.1 Task Requirements

3.1.1 Provide the materials and services required to design, fabricate, inspect, test, document, and deliver a Waste Treatment Unit (WTU) to the Savannah River Site (SRS).

3.1.2 Provide technical support and oversight for WSRC field installation, examination, testing, startup and operation.

3.2 Performance Requirements

3.2.1 The selected process shall be capable of being designed, built, tested and operated to complete disposition of Tank 48H contents and process dilution effluents by June 30, 2005.

3.2.1.1 The detailed chemical and radionuclide composition of Tank 48H is provided in Attachment 5.4.

3.2.1.2 WTU Operational Requirements

1. The WTU shall be capable of operating 24 hours per day, 7 days per week, with a 90 percent Duty Cycle.
2. For the purposes of schedule and equipment sizing, allow 25 percent downtime which includes WSRC process limitations, WTU 10 percent maintenance downtime, and severe weather.

3. The WTU shall be designed to have an operating life of 5 years.
4. The WTU design shall be based on treating 520,000 gallons which includes approximately 160,000 gallons of undiluted slurry feed material (See Attachment 5.4) plus approximately 360,000 gallons of water diluted slurried feed (associated with removal of Tank 48H material. (See Attachment 5.13)
5. Tank 48H material will be transferred to the WTU using the WSRC installed transfer pump which is rated to provide approximately 80-100 gpm at 133 ft Total Dynamic Head (TDH) in a 3 inch schedule 40 pipe. See Attachment 5.11 for details on additional equipment installed on Tank 48H.
6. Transfers to the WTU from Tank 48H will be batch transfers. Transfers to the WTU may be restricted for up to four (4) twelve (12) hour periods during any given week due to WSRC operational limitations. These periods may or may not be consecutive.
7. WTU transfer pump(s) for outputs to be returned to WSRC facilities shall be limited to a maximum of 250 gpm at the WTU interface with the WSRC connection.
8. Output from the WTU will be analyzed by WSRC prior to transfer to confirm compliance with applicable receipt facility Waste Acceptance Criteria (WAC) as listed below in 3.2.2. Samples from the initial outputs shall require a thorough characterization prior to transfer to a WSRC facility. Analysis turn around time will be based on the selected technology.
9. The WTU output streams must have an inhalation dose potential of less than or equal to 2.0E+08 rem/gallon. This shall be calculated following the methodology used in Calculation X-CLC-G-00014, Table 2.

3.2.2 The WTU output streams shall meet the WAC for the SRS facility receiving the treated waste. The acceptance criteria for the SRS facilities are listed below:

1. Tank Farm

- The energy of combustion for the composite flammable components, other than hydrogen, for waste transferred from the WTU shall not exceed the energy produced when combusting 5 percent of the hydrogen LFL volume determined from the output stream vessel vapor space volume at 50 percent capacity. Provide a calculation to validate this condition.

  <u>Assumptions to be used in calculation:</u>

  1. Temperature = 100°C, vapor-liquid equilibrium
  2. No vapor space ventilation other than atmospheric pressure equalization (breathing) is to be used in this calculation. Atmospheric pressure changes average 5mbar/day at a standard pressure of 1,013mbar.
  3. Utilize heat of combustion of hydrogen with water vaporized as a gas.
- Output streams shall be of a temperature less than 70°C.
- Output streams shall have an Organic/Aqueous volume percent less than 0.5 vol %.
- There shall be no organic layer or emulsion.

- Output streams shall not create any flammable species, except hydrogen, from interaction with the waste in the WSRC receiving facility (tank).
- Output streams shall meet the Tank Farm WAC requirements in Attachment 5.7.
- Output streams transferred from the WTU shall have a solid particle size distribution not to exceed 2% retention on an 80 mesh screen and 90% retention on a 200 mesh screen. In addition, the particle density shall be ≤ 2.4 g/ml to prevent the settling of solids during transport.

2. Defense Waste Processing Facility (DWPF)
   - Output streams shall meet the Tank Farm requirements listed above. This assumes that any material sent to DWPF would first be sent to the Tank Farm via Tank 51 shown on Attachment 5.3 Sketch 3.
   - Output streams shall meet the WAC for the DWPF. (See Attachment 5.7)

3. Saltstone Facility
   - Output streams shall meet the Tank Farm requirements listed above; this assumes that material sent to Saltstone would first be sent to the Tank Farm via Tank 50 shown on Attachment 5.3 Sketch 3 for transport to Saltstone.
   - Waste transferred from the WTU to the Saltstone Facility shall meet the WAC for the Saltstone Facility (See Attachment 5.7).
   - The following requirements shall also be met.
     1. Must have inhalation dose potential less than or equal to 1.0E4 rem/gal.
     2. Any hazardous contaminants, volatile contaminants or chelating agents present in the waste that are not specifically listed in the Saltstone WAC require formal review, authorization and a permit modification shall be approved by WSRC.
     3. Known non-hazardous contaminants present in the waste that are not listed in the Saltstone WAC shall be reviewed and authorized prior to transfer if the concentration of the contaminant is greater than or equal to 0.10 g-moles per liter.
     4. Any radioactive contaminant present in the waste and not listed in the Saltstone WAC requires formal review and authorization prior to transfer if the radionuclide is a source of gamma radiation or the radionuclide constitutes greater than 5% of the total Curie concentration in the waste.

4. Effluent Treatment Facility
   - Waste transferred from the WTU to the Effluent Treatment Facility (ETF) shall meet the WAC for the ETF (See Attachment 5.7).
   - Two paths are acceptable for waste directed to ETF: 1) Waste directed to the ETF evaporator shall be transported from the WTU to ETF by a tanker

truck. 2) Waste transferred to the ETF Waste Water Collection Tank (WWCT) will be transferred to the Tank Farm.

- The following requirements shall also be met.
  1. Volatile organic materials at concentrations that can produce, at equilibrium, vapors in the flammable or explosive range during normal storage and treatment are prohibited.
  2. Waste containing toxic gases, vapors, and fumes or it is capable of generating toxic gases, vapor or fumes (excluding tritium) in quantities harmful to people is prohibited.
  3. RCRA Listed waste is prohibited unless prior approval is obtained from WSRC.
  4. Aqueous waste shall be non-organic liquid within limits specified in the ETF WAC.
  5. Any hazardous contaminants, volatile contaminants or chelating agents present in the waste that are not specifically listed in the ETF WAC require formal review, authorization and a permit modification shall be approved by WSRC.
  6. Known non-hazardous contaminants present in the waste that are not listed in the ETF WAC shall be reviewed and authorized prior to transfer if the concentration of the contaminant is greater than or equal to 0.10 g-moles per liter.
  7. Any radioactive contaminant present in the waste and not listed in the ETF WAC requires formal review and authorization prior to transfer if the radionuclide constitutes greater than 1% of the total Curie concentration in the waste.

3.2.3 **WSRC Actual Waste Test:** The selected technology design must successfully demonstrate destruction of organics in actual Tank 48H waste via a WSRC performed Actual Waste Test.

3.2.3.1 WSRC acceptance of the WTU Detailed Design is contingent upon completion of the Actual Waste Test validating the WTU design flowsheet.

3.2.3.2 Subcontractor shall provide inputs to the WSRC test plan that includes the following:

- basic flowsheet conditions (i.e., amounts and addition rates for reagents, temperature, mixing conditions, vapor space controls, etc.) for the demonstration,
- the analytical sample requirements (e.g., timing and volume of sample collections, desired analyses and analytical methods),
- special controls or instrumentation required

3.2.3.3 Subcontractor shall

- concur with the WSRC Actual Waste Test Plan,
- review periodic updates and concur with the Final Test Report provided by WSRC.

3.3 Design Requirements

3.3.1 Safety Basis and Controls

3.3.1.1 The WTU design shall implement safety controls to meet the requirements of 10CFR830 within the safe harbor of DOE STD 3009-94. The WTU design is not considered a "major modification" per 10CFR830. Thus, a Preliminary Documented Safety Analysis is not required.

3.3.1.2 The initial design of the WTU shall meet the following categories per WSRC Procedure 2.25 and SRS Standard 01060 with Attachment 5.9 for supplemental Structural Requirements associated with SRS Standard 01060:

- Primary process and containment SSCs: Safety Class and PC3.(seismic and wind only)
- Ventilation system, if used, supporting the primary process SSCs: Safety Significant and PC2.
- Balance of Plant systems: Production Support and PC2.

3.3.1.3 WSRC will develop a Hazards Analysis (HA) and an Emergency Preparedness Hazard Analysis based on inputs from the Subcontractor. Inputs are based on preliminary design and system flow sheets. Typical inputs may include: Tank capacities, vessel sizes, pump capacities, wall thicknesses, material concentrations, etc.

3.3.1.4 Based on results of the HA, WSRC will determine the accident scenarios requiring detailed analysis. WSRC will provide feedback to the subcontractor and based on the detailed analysis may require revision to the initial Functional Classification of the WTU Structures, Systems and Components (SSCs.) Functional Classification determination by WSRC will be in accordance with methodology used in WSRC Manual E7, Procedure 2.25. The final Functional Classifications shall be used as a basis for the detailed design.

3.3.1.5 Nuclear Criticality

- The WTU design shall incorporate Nuclear Safety Measures to maintain the probability of a nuclear criticality event as incredible. Provide documentation for the basis for determining that nuclear criticality is not credible.
- Provide design inputs to support WSRC in preparing the Nuclear Criticality Safety Evaluation (NCSE). Typical inputs required include:
    - Radionuclide Concentration
    - Total quantity of material
    - Tank geometry
    - Vessel layout

- WSRC will perform the Nuclear Criticality Safety Evaluation on the WTU design per WSRC Manual SCD-3. Applicable sections are as follows:

  Section 1.2 Scope
  Section 1.3 Basis for Criticality Safety Program
  Section 3.0 Nuclear Criticality Safety Control Principles
  Section 3.1 General Criticality Safety Controls, Principles and Practices
  Section 3.3 Means of Control for Criticality Safety
  Section 3.4 Criticality Control Parameters
  Section 6.1 through 6.1.2 Nuclear Criticality Safety Evaluations
  Section 18 Glossary

- Detailed information on Tank 48H content is provided in Attachment 5.4.

3.3.1.6 Instrumentation Uncertainty, Scaling and Setpoint Calculations

- WSRC will perform the instrument uncertainty analysis per ANSI/ISA-67.04.01 and ANSI/ISA-RP- 67.04.02, scaling, and set point calculations on safety system instruments in the WTU design.
- Subcontractor shall provide design inputs to support WSRC in preparing these instrumentation calculations utilizing Attachment 5.14 the Uncertainty Calculation Input Document to transmit instrument uncertainty data.

3.3.1.7 Subcontractor shall provide technical support to WSRC in the development of safety basis documents. An approximate amount of time required to complete each document is shown below, although it is anticipated that some additional minor teleconferences may be needed:

- Hazard Analysis - 2 consecutive weeks of meetings at SRS
- Accident Analysis - 1 week of meetings at SRS
- Nuclear Criticality Safety Evaluation - 2.5 consecutive days of meetings at SRS
- Instrument Uncertainty, Scaling and Set Point Calculations – 20 nonconsecutive hours of meetings via teleconference
- Emergency Preparedness Hazard Analysis - 20 nonconsecutive hours of meetings via teleconference
- Documented Safety Analysis- 80 nonconsecutive hours of meetings via teleconference
- Technical Safety Requirements- 80 nonconsecutive hours of meetings via teleconference

3.3.1.8 WSRC will revise the Documented Safety Analysis and Technical Safety Requirements based on the activities described above.

3.3.2 Environmental Protection

3.3.2.1 National Environmental Policy Act

- Provide support to WSRC in the performance of a National Environmental Policy Act (10CFR1027) evaluation for assessing the environmental impacts of the WTU and its outputs.

3.3.2.2 Air Emissions

- Air emission controls and monitoring shall be in accordance with SRS Engineering Guide 01063-G and ANSI/HPS N13.1-1999.
- Evaluate the impact of WTU processes on the South Carolina Air Pollution Control Regulations, R. 61-62. A Part 70 Air Quality Permit (Title V Air Operating Permit) is in place for the SRS.
- Air emissions rate calculations for both radiological (in Curies per radionuclide) and non-radiological pollutants (in pounds per hour) resulting from the WTU shall be submitted to WSRC for evaluation and determination of environmental permit modifications (by WSRC).

3.3.2.3 Industrial Wastewater

- Evaluate the WTU process for impacts on the Industrial Wastewater Treatment Facility Permit(s) for the F and H Tank Farms. Provide evaluation to WSRC for review and acceptance.

3.3.2.4 Waste Management

Design shall address waste management strategies (both rad and non-rad), waste minimization, and pollution prevention.

- Process Chemical Waste: Provide chemical characterization of waste expected to be generated as a result of WTU testing and operation at SRS including volume estimates. WSRC will use this data to confirm compliance with the SRS site permits. The data to be provided by the subcontractor shall be identified on the SRS Waste Characterization Form (Attachment 5.15).
- Creation of high activity mixed waste is unacceptable due to the lack of adequate preparatory and disposal facilities on or off SRS.

3.3.3 Radiological Protection

3.3.3.1 Comply with SRS Standard 01064. Tank 48H characteristics are described in Attachment 5.4.

3.3.3.2 The design shall be prepared to maintain radiological exposure for personnel As Low As Reasonable Achievable (ALARA). Area outside the WTU modules shall be characterized as a maximum of Radiation Zone 3 per SRS Standard 01064.

3.3.4 Industrial Safety and Hygiene

3.3.4.1 Areas requiring personnel access shall be designed to meet current 29CFR1910 (OSHA) requirements for personnel safety.

3.3.4.2 Subcontractor shall implement the process safety management requirements of 29CFR1910.119, Process Safety Management of Highly Hazardous Chemicals, taking the role of the employer until delivery of the WTU to WSRC.

3.3.4.3 Material Safety Data Sheets shall be provided for chemicals used to support testing, maintenance and operation of the WTU.

3.3.5 Process and Configuration

3.3.5.1 WTU shall be a modular design such that SSCs are skid mounted.

3.3.5.2 Layout shall fit within one of the areas identified in Attachment 5.3, Sketch #3. Final site selection will occur after award.

3.3.5.3 Equipment layout shall address life safety, facility operation, maintenance access, operations monitoring, and decommissioning and decontamination.

3.3.5.4 Support systems shall be self contained and integrated into WTU design. Design shall include features to minimize utilization of WSRC utilities. Utilities supplied by WSRC are listed in 3.11.10.1.

3.3.5.5 Design shall incorporate flushing and rinsing capability to facilitate equipment maintenance and cleaning for disposal.

3.3.5.6 The WTU shall be designed to be located in an outside environment subject to wind, rain, snow, and sunlight. The ambient temperature ranges from 12°F to 110 °F with a relative humidity up to 100%. Design shall consider potential temperature extremes to be experienced by instruments, controls and equipment and provide weather protection as needed.

3.3.5.7 Design shall not use materials which are adversely affected by direct contact with radioactive solutions or exposure to radiation (e.g. Teflon™, fiberglass, or plastics).

3.3.5.8 Output may be in three forms, liquid, slurry or solid. Output streams will be transferred via a pipe or solid material handling process. Interface requirements shall be identified in preliminary and detailed design drawings.

3.3.5.9 Compliance with WAC criteria and organic limits shall be confirmed by sample analysis prior to transfer of an output stream to a WSRC disposal facility. Design shall include provisions for the collection of samples to verify output stream compliance with applicable requirements. The sampling system shall be compatible with the sampling vial shown on Drawing M-MH-G-0109.

3.3.5.10 Use WSRC-TM-95-1, Attachment 4 for SRS standard component identifications. The component identified in the standard shall be utilized in the WTU design if applicable.

3.3.5.11 Provide Master Equipment List datasheets, Attachment 5.16, for each piece of equipment with the preliminary and detailed design. The data shall be provided electronically in Excel or Filemaker Pro.

3.3.5.12 Preliminary design documentation shall utilize a Subcontractor defined numbering system to provide unique component identifiers. Detailed design documents shall replace Subcontractor's component numbering system with the WSRC component numbering system provided to the Subcontractor.

3.3.5.13 Alarm and process control outputs from local alarm and process control station(s) shall be designed to allow WSRC to tie in to remote alarm panel. The remote alarm and process control panel shall be provided as necessary with 10 percent spares. The alarm signal from the alarm panel shall comply with the following:

- Analog signals between instrumentation and the control system shall have a process operating range between 4-20 mA, where 4 mA is the zero value, and 20 mA is the top end of the scale.
- Discrete signals between instrumentation and the control system shall be either 0-24 VDC or 0-120VAC. Discrete signals should be designed such that common types are grouped together to utilize a minimum number of I/O cards.

3.3.5.14 WTU design shall incorporate hard wired interlocks for safety class and safety significant controls, if required.

3.3.5.15 Electrical Requirements

- Electrical equipment shall be U.L. listed or listed by a nationally recognized testing laboratory
- Provide separate equipment grounding conductors for all equipment. Raceways shall not be used for grounding purposes.
- Common neutrals shall not be utilized with branch circuit wiring.

3.3.6 Design Codes and Standards

3.3.6.1 WSRC-TM-95-1, Attachment 1, "National Codes and Standards for Engineering/Design Tasks Matrix," shall be used for the determination of the minimum national codes and standards applicable for each functional classification as the criteria for the design and fabrication of the WTU.

3.3.6.2 Additional codes, standards, orders and regulations not specifically referenced herein but required either by other documents attached to or referenced in this SOW or by U.S. industry practice are also applicable as determined by the Subcontractor.

3.3.6.3 Weld and nondestructive examination (NDE) symbols for weld details shall be in accordance with AWS A2.4.

3.3.6.4 The following SRS Standards shall be applicable to the WTU design

(These standards and guides are expansions / amplifications / elaborations of the national codes and standards. Clarifications required regarding these documents shall be directed to WSRC STR.):

- SRS Structural Design Criteria SRS Standard 01060 (see Attachment 5.9 for supplemental Structural Requirements associated with SRS Standard 01060)
- Radiological Design Requirements SRS Standard 01064
- Application of ISA S84.01 For SRS Non-Reactor Facilities SRS Standard 01703 and Design Guidance For Instrumented Systems That Are Used in Safety Significant And Hazardous Processes SRS Guide 01703-G
- Color Conventions for Process Displays SRS Standard 01709.
- Required Practices to Minimize Chloride Induced Stress Corrosion Cracking of Type 300 Series Austenitic Stainless Steel SRS Standard 05952.

- ASME B31.3 Additional Requirements for SRS Piping Systems SRS Standard 15060
- Mechanical Installation of Safety Class and Safety Significant Instrumentation SRS Standard 15980 and Installation and Calibration of Instruments SRS Guide 15980-G.
- HEPA Filter Requirements SRS Standard 15888 and High Efficiency Particulate Air (HEPA) Filters, Fire Resistant Specification M-SPP-G-00243.
- Confinement Ventilation Systems Design Criteria SRS Standard 15889
- Design Criteria for Airborne Radionuclide Effluent Monitoring Systems SRS Guide 01063-G
- Application of IEEE 384-1992 for SRS Non-Reactor Facilities SRS Guide 16600-G.
- Application of IEEE 308-1980 for SRS Non-Reactor Facilities SRS Guide 16601-G.

3.3.6.5 Pressure Vessels, as defined by ASME B&PVC, Section VIII, Division 1, shall be registered and stamped in accordance with the code. The U-1 Code Data Report for each pressure vessel shall be submitted to WSRC. Pressure Relief Devices shall meet requirements of ASME B&PVC, Section VIII, Division 1. Provide calculations and verification records for WSRC review and acceptance. See Attachment 5.12 for additional requirements.

3.3.6.6 Weld and nondestructive examination (NDE) symbols for weld details shall be in accordance with AWS A2.4.

3.4 Task #1: Preliminary Design Package

3.4.1 A Preliminary Design Package shall be submitted to WSRC and shall contain the following, at a minimum:

1. System Description – Function and Performance Characteristics
2. Identification of codes and standards applicability with edition definition
3. WSRC Engineering Standards applicability
4. Process Flow Sheet for the WTU material balance shall include, at a minimum, the following for each stream:
   - Molar, Mass, Volume
   - Organic constituents
   - Other non-radiological and radiological constituents
   - Maximum, Minimum and Nominal conditions
   - Temperature and pressure
5. Data required for the NEPA evaluation and development of environmental permits including air emissions rate calculations as specified in 3.3.2.
6. Preliminary design documents
   - Piping and Instrumentation Diagrams
   - System Calculations
   - Equipment Sizing Calculations

- Hydraulic Calculations
- Pressure Protection plan
- Electrical Single Line Diagrams
- Electrical Load Requirements
- Area Classification Drawings (if some locations are hazardous)
- Control Logic Diagrams
- Control System Block diagrams
- Physical Arrangement Drawings to include as a minimum:
  - Major Equipment Locations and dimensions
  - Areas for Major Piping and Raceways
  - Access and Egress (Including platforms and ladders)
  - Maintenance and laydown areas
  - Waste Handling Areas
  - Chemical Feed Areas

7. Specific identification of WSRC services and capacities required.
8. Specific identification of process and service requirements including pipe size, connection type, etc.
9. Preliminary Valve List
10. Preliminary Line List
11. Preliminary Master Equipment List (MEL) (Excel or Filemaker Pro) See Attachment 5.16
12. Instrument Index - Input/Output List
13. Material Safety Data Sheets for chemicals used in the process
14. Initial Seismic Analysis
15. Initial Structural Concrete plans and calculations
16. Initial Structural Steel drawings and calculations
17. Initial Radiological Design Summary Report

3.4.2 Provide design inputs in support of WSRC preparation of a revised Documented Safety Analysis and Technical Safety Requirements. Inputs for the following shall be in written format.

1. Hazard Analysis
2. Nuclear Criticality Safety Evaluation
3. Instrumentation Uncertainty and Set Point Calculations
4. Accident Analysis
5. Emergency Preparedness Hazard Analysis

3.5 Task #2: Engineering Scale Test

3.5.1 An Engineering Scale Test shall be performed to demonstrate that the destruction of Tank 48H simulant organic material (TPB) results in an output stream which meets the organic contribution to the hydrogen LFL defined in 3.2.2.

3.5.2 Notify WSRC 14 calendar days in advance of test. WSRC personnel will schedule visits to the Subcontractor's test facility at mutually agreeable intervals.

3.5.3 The Engineering Scale Test shall be of a size that is adequate to demonstrate the Subcontractor's technology. Submit documentation for the scaling methodology used to determine the size of the WTU to WSRC for review and acceptance.

3.5.4 An Engineering Test Performance Plan, including objectives, shall be prepared and submitted to WSRC for review and acceptance. The plan shall include, as a minimum, acceptance criteria, sampling requirements and data collection and monitoring requirements. The test shall be performed covering the range of concentrations expected to be experienced during the Tank 48H Material Removal Program. (See Attachment 5.13)

3.5.5 Feed material for the demonstration shall be prepared in accordance with the recipe defined in Attachment 5.5. To ensure that the simulant used is prepared correctly, a sample of the MST, Sludge and Simulant shall be provided to WSRC for independent analysis. Performance of the Engineering Scale Test is not contingent upon completion of WSRC analysis.

3.5.6 Performance requirements shall be demonstrated. Process streams that exit the Engineering Scale Test unit, e.g. air emissions streams, liquid streams and solid streams shall be analyzed to validate flow sheet. WSRC may elect to collect samples and perform an independent analysis.

3.5.7 A report describing the process and results shall be submitted to WSRC. WSRC will use results as input for the Actual Waste Test.

3.6 Task #3: Detailed Design

3.6.1 A Detailed Design Package shall be submitted to WSRC and shall contain the following, at a minimum:

1. System Description – Function and Performance Characteristics
2. Identification of codes and standards applicability with edition definition
3. WSRC Engineering Standards applicability
4. Process Flow Sheet for the WTU material balance shall include, at a minimum, the following for each stream:
   - Molar, Mass, Volume
   - Organic constituents
   - Other non-radiological and radiological constituents
   - Maximum, Minimum and Nominal conditions
   - Temperature and pressure
5. Data required for the NEPA evaluation and development of environmental permits including air emissions rate calculations
6. Detailed Design Documents including:
   - Finalized Process and Instrumentation Diagrams
   - Finalized System Calculations
   - Finalized Equipment Sizing Calculations
   - Finalized Hydraulic Calculations
   - Finalized Pressure Protection Plan
   - Piping Stress Calculations
   - Area piping drawings
   - Piping Isometrics
   - Finalized Electrical Single Line Diagrams

- Finalized Load Study Calculations
- Finalized Raceway Layouts
- Finalized Grounding drawings (equipment and grid)
- Finalized Area Classification Drawing s(if applicable)
- Cable Schedules
- Conduit Schedules
- Heat Trace drawings (if applicable)
- Lightning protection drawings and calculations
- Panel Schedules
- Schematic Drawings
- Finalized Control Logic Diagrams
- Finalized Control Panel Layouts
- Finalized Control Valve Calculations (if applicable)
- Finalized Flow Meter Sizing Calculation
- Instrument location drawing
- Instrument Installation Details
- Loop Diagrams
- Instrument Rack Drawings (if applicable)
- Level Setting Diagrams
- Set point indexes
- System block diagrams
- Software Logic Diagrams
- Detailed assembly drawings for each modular unit and interconnections
- Finalized Structural and Civil drawings - Concrete slab requirements and structural steel
- Detailed instructions and drawings specific to field handling, assembly and installation, at a minimum, anchorage requirements, tie-in connections, mobilization and startup requirements

7. Physical Arrangement Drawings to include as a minimum:
   - Major Equipment Locations and dimensions
   - Areas for Major Piping and Raceways
   - Access and Egress (Including platforms and ladders)
   - Maintenance and laydown areas
   - Waste Handling Areas
   - Chemical Feed Areas
8. Specific identification of WSRC services and capacities required
9. Specific identification of process and service requirements including pipe size, connection type, etc.
10. Finalized Line List
11. Finalized Valve List
12. Finalized Master Equipment List (MEL) (Excel or Filemaker Pro See Attachment 5.16).
13. Other material specifications for materials not on the MEL
14. Spare Parts identification (Excel or Filemaker Pro)
15. Preventive and Predictive Maintenance Requirements
16. Instrument Index - Input/Output List

17. Material Safety Data Sheets for chemicals used in the process
18. Final Seismic calculations
19. Pipe support drawings and calculations
20. Tray and conduit support drawings and calculations
21. A plan outlining the completion of documents (operations and maintenance manuals) needed to support WSRC implementation of training for operation and maintenance of the WTU
22. Final Radiological Design Summary Report

3.7 Task #4: Fabrication and Shop Assembly

3.7.1 Fabricate, assemble and test in accordance with WSRC accepted Detailed Design documents and this SOW. Testing requirements for the modular parts and assembled WTU are provided in Section 4.0.

3.7.2 Materials of Fabrication

3.7.2.1 A Material Control Procedure shall be developed and submitted to WSRC. Include as a minimum the following:

- Segregation and control of material.
- Provide copies of Certified Material Test Reports (CMTR) for Safety Class components.
- Identification of the materials of piping and structural steel shall be maintained through final assembly. Materials of construction shall bear identification marking to ensure that material can be identified. Subcontractor purchase order numbers, heat numbers, lot numbers, part numbers, material type or grade, and WSRC purchase order number shall be included.
- The exterior surface of major equipment may be used for material control. Fabricator shall restrict exterior markings to electro-etching or vibro-etching. Crayon markings are not to be used, except for temporary markings.

3.7.3 Welding Requirements

3.7.3.1 Welding shall be in accordance with applicable codes, e.g. ASME B&PVC Section VIII and ASME B31.3.

- Only Gas Tungsten-Arc Welding (GTAW) process shall be used on containment or pressure retaining components. Other welding process can be used on structural/supports.
- Submit Welding Procedure Specifications (WPSs) and Procedure Qualification Records (PQRs) to WSRC for review and acceptance before use.
- Prepare and submit a Weld Map at the same time as the welding procedure(s). The Weld Map shall list each weld joint and identify the WPS(s) to be used for the joint. The Weld Map shall also contain as a minimum the following information:
    - Base metal thickness at each joint, whether backgouge and back welding will be performed, base material type and grade at each joint,

type of joint (B-full penetration butt-weld, P-partial penetration weld, O-overlay, C-cladding), if post weld heat treatment is required, if notch toughness testing is required, the WSRC project number, item number and purchase order number, and the supplier's item number and job number.

- Welding Procedure Specifications and Welders Performance Qualifications shall meet the requirements of ASME B&PVC Section IX.

3.7.4 Process Control Software Requirements

3.7.4.1 Process Control software source code, executable code and compilers shall be submitted to WSRC in electronic, target-machine-readable format.

3.7.5 Cleaning Requirements

3.7.5.1 Submit a cleaning procedure that conforms to ASTM A380 to WSRC for review and acceptance before use.

3.7.5.2 Vessels, piping, stainless steel parts and equipment shall be cleaned from dirt, paint, metal chips, filings, slag, flux, scale, rust or other types of contamination. Appropriate measures shall be taken during all aspects of fabrication, testing, and shipments to minimize contamination.

3.7.5.3 Before welding the heads on the vessels, the interior surfaces and nozzle connections shall be clean and free of oil, grease, dust, water, lacquer, paint, welding flux, particulate matter, organic and inorganic (particularly chloride) contamination. Clean and degrease the exterior surfaces in the course of cleaning the interior surfaces.

3.8 Task #5: Field Assembly/Installation and Testing Support to WSRC at SRS

3.8.1 Provide as-built drawings and written instructions specifying, at a minimum, anchorage requirements, tie-in connections, mobilization and startup requirements shall be submitted to WSRC.

3.8.2 Provide technical support and oversight to WSRC for the unloading, assembly and installation of the WTU modules and components. Verify that the assembly and installation are complete and ready for the testing of the WTU. Provide a readiness report to WSRC.

3.8.3 Provide technical support to WSRC for WTU startup and performance of an Integrity Leak Test and Site Acceptance Test discussed in Section 4.0.

3.9 Task #6: Training and Operations Support

3.9.1 Training and Procedures

3.9.1.1 Operations and maintenance manuals shall be provided within one month of after WSRC acceptance of Detailed Design.

3.9.1.2 Identify for WSRC the manpower and skills required operating the WTU for the duration of the treatment process. This information is to be provided to WSRC within 2 months of completion of the preliminary design.

3.9.1.3 Training shall be developed and support shall be provided to WSRC trainers for training of WSRC Operations, Engineering, Industrial Hygiene and Radiological Control personnel.

3.9.1.4 Operations training shall include the following:

- An Operations Manual covering systems, equipment and functions
- Detailed instructions on normal operation of the WTU
- Process simulator training or equivalent using equipment that is equivalent to the designed process control
- Treatment process optimization
- Back flush and purging cycles
- Monitoring, measuring, recording and reporting requirements for system parameters
- Abnormal Operations and alarm response requirements
- Special Material Handling Requirements
- Sampling operations

3.9.1.5 Training shall be developed and support shall be provided to WSRC trainers for training WSRC Maintenance personnel. Maintenance training shall include the following:

- Equipment Maintenance Manuals
- Preventive and predictive maintenance requirements
- Troubleshooting and maintenance of unique equipment

3.9.1.6 Assistance shall be provided to WSRC personnel with the development of:

- Equipment Predictive and Preventive Maintenance Requirements
- Normal and Abnormal Operations Procedures

3.9.2 Technical Field Support

3.9.2.1 Technical field support shall be provided to WSRC during unloading, assembly/installation, testing and operation of the WTU. Support is to be provided 24 hours/7 days per week.

3.10 Quality Requirements

3.10.1 Execute a Quality Assurance Program that meets the requirements of the ANSI NQA-1 and ASME B&PV Code, Section VIII, Division 1, Appendix 10, and this SOW. Prepare and submit a Quality Assurance Program Manual. See Attachment 5.6 for Supplier Quality Assurance Program Requirements.

3.10.2 Develop a Software Quality Assurance Plan for process software systems to be utilized with the WTU for WSRC review and acceptance.

3.10.3 The Subcontractor shall ensure that any sub tier suppliers or subcontractors used for the fulfillment of this procurement have equivalent quality programs (e.g., ASME code certified shop). Provide documentation of compliance.

3.10.4 Maintain required records pertaining to this SOW for a period of not less than 1 year beyond the term of the subcontract. "In-process" quality assurance records and ASME Code Data Reports shall be maintained in accordance with the ASME B&PVC, Section VIII, Division 1. These records shall be accessible to WSRC during the retention period. After the retention period, request instructions from WSRC concerning disposition.

3.11 WSRC Furnished Material, Equipment, Services

3.11.1 SRS and facility specific training as described in OSR Form 1-126.

3.11.2 WSRC will provide unique sequence numbers required for component numbering for the MEL and detailed design.

3.11.3 Actual Waste Test:

- Duration: approximately 4 months to perform testing and issue a Test Report
- WSRC will prepare a Test Plan and provide to the Subcontractor for concurrence
- WSRC will issue periodic reports and a final Test Report to the Subcontractor for concurrence

3.11.4 Documents supporting the development and approval of the Documented Safety Analysis and Technical Safety Requirements for the WTU including:

- Functional Classification
- Hazards Analysis
- Nuclear Criticality Safety Evaluation
- Emergency Preparedness Hazard Analysis
- Accident Analysis
- Safety Related Instrumentation Uncertainty Calculations
- Scaling and Setpoint Calculations

3.11.5 Documents supporting the design, testing, startup and operations of the WTU including:

- Power services and utilities permit for services to the WTU
- Environmental Permits or Modifications to exiting permits approved by SCDHEC
- NEPA Determination

3.11.6 Simulant Materials and chemicals required to perform the Site Acceptance Test for the WTU.

3.11.7 Owner Inspector services to verify ASME B31.3 compliance.

3.11.8 Engineering, materials, installation and testing for WTU concrete slab and associated site work, Tank 48H interface piping and utility services with respective tie-ins to the WTU. Subcontractor shall concur with WSRC preliminary and detailed design.

3.11.9 Unloading and placement into final position of the WTU modules on WSRC provided slab and foundation.

3.11.10 Assembly/Installation and connection of WTU, including tie-ins to services and input and output piping.

3.11.10.1 WSRC will provide the following utilities to the WTU.

- Electricity:
  - 120/208V at the Tank 48H with up to 100 amp service
  - From 241-82H Substation – 480V up to 1000 KVA
- Steam – maximum of 5000 lb/hr of 325 psig steam
- Process Water –100 gpm at 140 psig
- Domestic Water – maximum of 75 gpm at 80 psig. See Attachment 5.10 for water quality data.

3.11.11 Startup and operation of the WTU.

3.11.12 Sampling Analysis for WTU operations

- Analysis of in-stage process samples required to support WTU operations
- Analysis of output streams prior to release to WSRC disposal facilities or free release to the environment.
- Analysis of Tank 48H samples to determine TPB content.

3.12 Period of Performance / Schedule

3.12.1 Award to August 30, 2005, with the completion of the following milestones:

1. Preliminary Design (Task #1)	TBD by Subcontractor
2. Engineering Scale Test (Task #2)	TBD by Subcontractor
3. Detailed Design (Task #3)	No later than 4/6/2004
4. Fabrication, Assembly and FAT (Task #4) -	TBD by Subcontractor
5. Technical Support Field Assembly and Startup (Task #5)	TBD by Subcontractor
6. Training Development (Task #6)	TBD by Subcontractor
7. Technical Support for WTU Hot Operation (Task #6)	TBD by Subcontractor
8. Complete Field Operations	June 30, 2005
9. Project Closeout	August 30, 2005

3.12.1.1 Submit a detailed schedule to WSRC that addresses the milestones above. Identify inputs required from WSRC, identify assumptions, and perform a risk assessment for meeting the milestone requirements.

3.12.1.2 Allow two (2) months for WSRC operations readiness activities between Startup and Commence Operations with Tank 48H Feed.

3.12.1.3 A Preliminary Project Schedule Overview is provided in Attachment 5.8 for use in developing the detailed schedule.

3.12.2 Design development activities.

- Formal design presentations and reviews for Preliminary and Detailed designs shall be shown on the schedule. See 3.14.2.2 and 3.14.2.3 for details.
- Time frames for informal reviews of design development (preliminary and detailed design) shall be allowed in the schedule.

3.12.3 Submittal dates of Engineering Documentation Requirements (Attachment 5.1) will be determined after award based on the schedule agreed upon by WSRC and the Subcontractor.

3.13 Personnel Qualifications/Certifications

3.13.1 Personnel engaged in the fabrication and manufacture of the vessels and associated appurtenances are to be qualified per ASME B&PVC, Section VIII, Division 1, Appendix 10.

3.13.2 The following personnel qualification (or certification) records shall be submitted to WSRC:

- Welder performance qualifications in accordance with ASME B&PVC, Section IX.
- Minimum Level II NDE personnel certifications (NDE and testing personnel requiring certification include those involved in radiographic testing, dye penetrant testing, pneumatic testing, helium leak testing, and vessel rate of rise testing) per SNT-TC-1A.
- These personnel shall also be qualified in accordance with a written procedure to meet the requirements of ASME B&PVC Section V, Subsection A.

3.13.3 Field support personnel shall be qualified by virtue of higher education or experience in operations and maintenance of waste treatment processing facilities similar to the WTU. Provide resume(s) for WSRC information.

3.14 Deliverables (includes Submittals)

3.14.1 Waste Treatment Unit

Ship to:

Westinghouse Savannah River Company
SRS H Area Tank Farms
Purchase Order # _____
Aiken, SC 29808

3.14.2 Submittals - Engineering Documents

3.14.2.1 After WSRC award of Purchase Order, submit engineering documents identified in Attachment 5.1 to WSRC. Documents shall be submitted in accordance with WSRC accepted Subcontractor schedule.

3.14.2.2 **Preliminary Design:** Submit Preliminary Design per date identified on final schedule. Present Preliminary Design in the form of a formal (oral) presentation within ten (10) calendar days after Preliminary Design submittal. Provide two (2) reproducible copies and twenty five (25) copies of preliminary design documents. Anticipate return of comments from WSRC within ten (10) calendar days after the presentation.

3.14.2.3 Engineering documents submitted after Preliminary Design will be reviewed and statused by WSRC within ten (10) calendar days from the date of receipt. Submit to:

Westinghouse Savannah River Company
Building 766-H
Purchase Order # _____
Aiken, SC 29808
Attention: STR (to be determined at time of award)

Also, FAX a copy of the transmittal letter and document inventory transmittal sheet(s) to the WSRC Procurement Representative (PR).

3.14.2.4 **Detailed Design:** Present Detailed Design in the form of an oral presentation (each engineering discipline represented) 14 calendar days before final submittal date. Submit Detailed Design (100 percent complete) five (5) days before oral presentation is scheduled. Provide two (2) reproducible copies and twenty five (25) copies of detailed design documents. Comments generated during this review effort with WSRC shall be resolved prior to final submittal. Submit to address in 3.14.2.3.

3.14.2.5 The engineering documents submitted after Detailed Design will be reviewed for acceptance by WSRC and returned to the Subcontractor with status as follows:

- Status 1- Work may proceed.
  The document required no changes or additions. Matters remaining to be resolved by the Subcontractor will not require document changes and can easily be handled by correspondence.

- Status 2 - Submit final document, work may proceed.
  The document is either not suitable for retention or requires certain non-technical changes to qualify as a final document.

- Status 3 - Revise and resubmit; work may proceed subject to resolution of indicated comments.
  Deviations have been noted, some aspects of the subject matter are

incomplete, or other minor technical changes are required to make the item suitable.

- Status 4 - Revise and resubmit; work may not proceed.
  Information delineated on the document is not to be used by the Subcontractor because it: (1) is of a design that is technically unusable without significant changes, (2) does not meet design requirements or (3) does not conform to the SOW requirements.

- Status 5 - Permission to proceed is not required.
  Information delineated on the document need not be reviewed by WSRC prior to its use by the Subcontractor.

Note: For engineering drawings (e.g. assembly drawings) allow an area of 3 inches by 8 inches, near the drawing title block, for WSRC placement of a "status" stamp.

3.14.2.6 Do not proceed with the procurement of material or fabrication until WSRC permission to proceed is obtained for documents requiring WSRC permission to proceed. The documents that require permission to proceed by WSRC are listed in Attachment 5.1.

3.14.2.7 Incorporate changes as required by WSRC comments and resubmit corrected engineering documents within five (5) calendar days. Identify revisions to the Subcontractor documents by clouding the revised portions of the document and identifying the change with a triangle enclosing the revision number.

3.14.2.8 Do not change Status 1 or Status 5 engineering documents without notifying WSRC and resubmitting them to WSRC.

3.14.2.9 Assignment of a Status 1 or Status 5 to the engineering documents by WSRC does not relieve the Subcontractor of the following:

- Obligation to meet the requirements of this SOW and the applicable national codes and standards.
- Responsibility for the correctness of such engineering documents.
- The adequacy and suitability of materials and equipment represented thereon for the intended function.

3.14.2.10 For each set of documentation submitted after Detailed Design to WSRC, prepare a transmittal letter and document inventory transmittal sheet(s), which lists documents and number of pages submitted. Transmit submittals, transmittal letter and document inventory transmittal sheet via next day delivery to:

Westinghouse Savannah River Company
Document Control
Building 704-1N
Purchase Order # _____
Aiken, SC 29808

Also, FAX a copy of the transmittal letter and document inventory transmittal sheet(s) to the WSRC PR.

3.14.2.11 Submittals shall display the following minimum information:

- Savannah River Site
- Project: Tank 48H Waste Treatment Unit
- Purchase Order Number
- Reference to the applicable document category and SOW Section number as identified in Attachment 5.1.

3.14.2.12 Submit opaque reproducible copies of each drawing as indicated in Attachment 5.1. Use black lines on white background for copies. Provide shop / assembly drawings suitable for microfilming. Minimum drawing size is 8½ inches by 11 inches; maximum size is 36 inches by 48 inches.

3.14.2.13 The use of 100 percent recycled paper for engineering submittals is strictly prohibited. Recycled content up to 25 percent is acceptable.

3.14.3 Deliverables - Quality Verification Documents

3.14.3.1 Quality Verification Documents listed in Attachment 5.2 shall be delivered to WSRC with the delivery of the WTU.

3.14.4 Subcontractor Document Formats

3.14.4.1 Primavera Project Planner shall be used for schedule submittals.

3.14.4.2 All calculations, drawing and specifications shall utilize English units.

3.14.4.3 Drawings

- Provide Drawings Index Sheet with project title and list of drawings.
- Design shall be performed using Intergraph Microstation version SE (or later – version J preferred) or Autocad Version 14 (or later) for drawings. Design drawings shall be E size (30" x 42").
- Drawing and lettering shall be of such size and density that, after reduction to half scale, information is clearly legible.
- Detailed Design shall be submitted with the Subcontractors Professional engineering seal on the drawings and specifications.
- Drawings, including reproducibles, electronic media and prints shall become the property of WSRC.
- The Reference Drawing block on each drawing shall list drawings referenced on that sheet plus the Index Sheet drawing (at a minimum).
- Examples of SRS drawings, such as Single Line Diagrams and P&IDs, are provided for information only to show typical level of detail expected for the detail design documents. See "Illustration Package."

3.14.4.4 Specifications

- Specifications shall be included on design drawings as required, including references to applicable codes and standards that are to be used in the execution of work.

3.14.4.5 Calculations

- Calculations shall be combined in a Design Manual which includes a Table of Contents.

- Submit calculations in sufficient detail to assure that allowable criteria and proper factors of safety have been followed. Each calculation shall provide a statement of its problem, the codes and standards governing its design, and a conclusion. Approved calculations shall be evaluated and revised accordingly to reflect as-built configurations.
- Sufficient detail shall be provided to allow an individual competent in that discipline to understand the methodology, inputs and results.
- For any calculations performed using software, copies of the database and/or calculation shall be provided on electronic media (CD-ROM). This includes Mathcad files, if used.

3.15 Packaging, Handling, Shipping and Storage Requirements

3.15.1 General

3.15.1.1 A Packaging, Handling, Shipping and Storage procedure shall be submitted to WSRC for review and acceptance.

3.15.2 Packaging Requirements

3.15.2.1 Equipment shall be protected from contaminants, exposure to the environment and physical damage. Packaging shall be adequate for up to three months of outside storage.

3.15.3 Handling Requirements

3.15.3.1 Modular unit(s) shall meet the requirements stated in Attachment 5.9 – Structural Requirements, paragraph 9.

3.15.4 Shipping Requirements

3.15.4.1 Notify WSRC at least 72 hours prior to delivery.

3.15.5 Storage Requirements

3.15.5.1 Prior to shipment WTU shall be stored to prevent deterioration due to weather.

3.15.5.2 Subcontractor shall provide interim storage requirements including in-storage maintenance requirements and to prevent deterioration due to weather.

3.16 Marking and Identification Requirements

3.16.1 Marking and Identification of Equipment

3.16.1.1 Components shall be labeled as follows unless specified otherwise by a National Code or Standard or by an SRS Standard or procedure.

- Labels shall be stainless steel.
- Labels shall be permanently affixed to the component by seal welding, permanent adhesive or stainless steel wire.

3.16.1.2 Stamp or engrave component identification nameplates with the following information at a minimum:

- Savannah River Site

- Project: Tank 48H Waste Treatment Unit
- Purchase Order Number (See Purchase Order)
- WSRC Component Number

3.16.1.3 Provide information on the ASME Code nameplates for vessels as required by ASME B&PVC, Section VIII, Division 1 including code stamping.

3.16.1.4 Pressure vessels shall be tagged or labeled as a minimum with:

- Subcontractor identification number
- Maximum Allowable Working Pressure at Temperature

3.16.1.5 Pressure relief devices shall be tagged as a minimum with:

- Subcontractor identification number
- Set / Burst Pressure
- Test Date (mo/day/yr if applicable)
- Test Procedure Number (if tested in place)
- Due Date (mo/day/yr if applicable)
- Late Date (mo/day/yr if applicable)
- The pressure relief device tag shall be stainless steel or aluminum (approximately 1.5" x 4.5") with 1/8" lettering. The Tag shall be attached using stainless wire and a lead seal.

3.16.1.6 Components requiring lifting by mechanical means for field handling and installation shall be labeled with the unit weight and lift points.

3.16.2 Marking and Identification of Shipping Containers

3.16.2.1 Include the following minimum information on the outside of shipping containers on at least 2 sides of the container:

- Destination and Return Address
- Project: Tank 48H Waste Treatment Unit
- SOW # G-SOW-H-00032
- Purchase Order Number_____
- Gross Weight
- Orientation During Shipping, Handling and Storage
- Location of Lifting Lugs/Lifting Points/Rigging Diagram

3.17 Deviations

3.17.1 After award a "Supplier Deviation Disposition Request" (SDDR) form shall be submitted to WSRC for each deviation to the technical or quality requirements of this procurement. Submit SDDR forms to WSRC Document Control as stated in 3.14.2.9.

3.17.2 For each deviation:

3.17.2.1 Identify the SOW and revision number;

3.17.2.2 Identify the criteria that cannot be met by Item and Section number;

3.17.2.3 Present an explanation for the deviation;

3.17.2.4 Present a proposal for resolution, including technical justification; and

3.17.2.5 Present a price adjustment for resolution of the exception.

3.17.3 Do not perform any work or make delivery of any item for which an SDDR is submitted until a written resolution is received from WSRC.

3.18 Subcontract Technical Representative (STR)

3.18.1 The STR for this task will be identified at award of subcontract. The STR is the WSRC representative responsible for all technical communication and direction between WSRC and the Subcontractor.

3.18.2 All technical correspondence shall be directed to the STR with a transmittal copy to the Procurement Representative.

4.0 ACCEPTANCE OF SERVICE

4.1 Inspection/Testing Requirements

NOTE: Notify WSRC at least fourteen (14) calendar days in advance of any required inspections and tests.

4.1.1 Engineering Scale Test – See Section 3.5 Task #2 for details.

4.1.2 Component/Fabrication Testing

4.1.2.1 Perform in process shop inspections during the fabrication and assembly of the system and associated components during their manufacture to ensure that the final product complies with this SOW and the design drawings. Maintain records of in process inspections.

4.1.2.2 Procedures shall be developed in accordance with the applicable National Codes and Standards and submitted to WSRC.

- Visual examination/inspection procedure.
- RT examination procedure.
- PT examination procedure.

4.1.2.3 An Integrity Leak Test procedure shall be developed and submitted to WSRC for review and acceptance.

4.1.2.4 Visual Examination/Inspection

- 100 percent of structural welds shall be visually examined.
- 100 percent of piping welds shall be visually examined.
- Vessels shall be inspected for cleanliness.
- Examination reports shall be submitted to WSRC.

4.1.2.5 Radiographic (RT) Examinations **(Witness Point)**

- RT examination of welds shall be as specified in the National Codes and Standards.
- Examination reports and films shall be submitted to WSRC.

4.1.2.6 Liquid Penetrant (PT) Examinations

- PT examination of welds shall be as specified in the National Codes and Standards.

- Examination reports shall be submitted to WSRC.

4.1.2.7 Integrity Leak Test **(Witness Point)**

- Test shall be conducted in accordance with the Integrity Leak Test procedure.
- Test report shall be submitted to WSRC.

4.1.2.8 Process Control Software Acceptance Test **(Witness Point)**

- Develop a Software Test Plan and a Test Procedure for process software systems for WSRC review and acceptance.
- Perform a software acceptance test with WSRC representatives present.
- A Final Test report shall be submitted to WSRC for review and acceptance.

4.1.2.9 Safety Class wiring: Verify that the separation criteria (Section 5.9.3 in Engineering Guide 16600-G) is met.

4.1.3 Individual System Testing

4.1.3.1 The individual system tests shall demonstrate that the structures, systems, and components operate in accordance with their design in all operating modes. To the extent practical the systems shall be operated throughout their maximum and minimum designed operating ranges. As appropriate, this testing shall include:

- Any local or remote, manual or automatic operation
- Operation in alternate, secondary, or bypass control modes
- The proper and reliable functioning of primary sensors, controls and instrumentation, the individual and integrated effects of a system's sensed variable limits, sensor accuracy, the ranges of their magnitude and rates of change, and the system's command and response times until the proper conclusion of any action
- Demonstration of permissive, prohibiting, or bypass interlocks
- Proper operation in all possible combinations of system logic
- Proper system trip and alarm functions
- Demonstration of the operability, capacity, capability and effectiveness of systems and components functioning within the tested systems such as heaters, dryers, motors, heat tracing, pumps, heat exchangers, filters, etc. within any possible alignment configurations
- The proper operation of any equipment protection device whose random operation or malfunction may prevent or disable the proper operation of systems or components
- Determination by observation and measurement that piping and component movement, vibration, and expansions are acceptable
- Simulation of equipment failures and/or malfunctions that could reasonably be expected to occur during the unit's operational lifetime
- Any expected operation or recovery during or from postulated upset conditions which shall include spills, leaks and/or drops, loss of power, loss of air, loss of cooling water, loss of ventilation, loss of process computer control

4.1.3.2 The individual system testing shall be of sufficient duration to permit the equipment to reach anticipated equilibrium conditions. Individual system alignment, upset

recovery instructions and operation instructions shall be developed and trial tested to the extent practical to determine their adequacy.

4.1.3.3 Provide results of Individual System Testing in a report to WSRC.

4.1.4 Factory Acceptance Test

4.1.4.1 Test shall demonstrate the WTU capability to destroy the organic materials (TPB) in the WSRC defined simulant.

4.1.4.2 A Factory Acceptance Test Procedure shall be developed and submitted to WSRC for review and acceptance. Procedure shall include, as a minimum, the following:

- Integrity Leak Test
- The proper transfer and mixing of solutions
- Chemical reaction rates
- Destruction/Removal of TPB in simulant feed
- Verification that air emission objectives of the design are met
- Validation of design throughput
- Confirm results of Individual Systems Test
- Confirm design Flow Sheet

4.1.4.3 The test duration shall be for a time sufficient to clearly demonstrate design capability over the range of concentrations expected to be experienced during the Tank 48H Material Removal Program. (See Attachment 5.13).

4.1.4.4 Notify WSRC 14 calendar days in advance of test. WSRC personnel will schedule visits to the Subcontractor's test facility at mutually agreeable intervals.

4.1.4.5 Process streams that exit the WTU, e.g. air emissions streams, liquid streams and solid streams shall be analyzed to validate flow sheet. WSRC may elect to collect samples and perform an independent analysis.

4.1.4.6 A record of Factory Acceptance Test activities and results shall be prepared and submitted to WSRC for review and acceptance.

4.1.5 Post Delivery Testing – Integrity Leak Test

4.1.5.1 Subcontractor shall provide technical support for an integrity leak test to demonstrate seal tightness of the WTU unit. Subcontractor shall review and concur with test procedure.

4.1.5.2 Subcontractor shall review and concur with WSRC Integrity Leak Test results.

4.1.6 Post Delivery Testing – Site Acceptance Test

4.1.6.1 The Site Acceptance Test will be performed by WSRC personnel with Subcontractor technical support personnel in attendance.

4.1.6.2 The Site Acceptance Test procedure will be developed by WSRC with inputs from the Factory Acceptance Test and additional inputs deemed necessary for in-situ testing. Subcontractor shall review and concur with test procedure.

RESPONSE TO RAI COMMENT 14
ROADMAP TO REFERENCES

REFERENCED DOCUMENT	*EXCERPT LOCATION	REMARK
Campbell 2004	Excerpt enclosed following response	Assumption 3.4.1: DF >12. Pages from Appendices A, B, and C show a DF of 12 (92% removed) for Cs-137/Ba-137m. DF = Column 1/ Column 10.
d'Entremont, P. D., and M. D. Drumm, 2005, *Radionuclide Concentrations in Saltstone*, CBU-PIT-2005-00013, Revision 3,	Excerpt enclosed following response	CBU-PIT-2005-146 refers to D'Entremont and Drumm (2005) for the salt processing strategy. D'Entremont and Drumm assume no MST strikes.
Performance Objective Demonstration Document (CBU-PIT-2005-00146)	Excerpt enclosed following response	CBU-PIT-2005-00146 does not explicitly state that no MST strikes we performed in the ARP process.
Salt Waste Determination	Excerpt included within response	
Subosits 2004	Excerpt enclosed following response	30 Appendices with the file copy.

*Excerpt Locations:

1. Excerpt included within response: The excerpt is included within the text of the response or is appended to the response.
2. Excerpt enclosed following response: The excerpt is enclosed on a separate sheet or sheets following the response.
3. Representative excerpt(s) enclosed following response: Representative excerpts from a document that is wholly or largely applicable are enclosed following the response.
4. Other

APPROVED for Release for
Unlimited (Release to Public)

CBU-SPT-2004-00059
Revision 1

APPROVED for Release for
Unlimited (Release to Public)
2/25/2005

Preliminary Material Balance For the Modular CSSX Unit

S. G. Campbell
6/22/04

1.0 Introduction

On January 22, 2004, the Department of Energy directed Westinghouse Savannah River Company to initiate pre-conceptual design for a modular Caustic-Side Solvent Extraction (CSSX) process (Ref (1)). The modular CSSX unit (MCU) is to be installed downstream of the Actinide Removal Process (ARP) and be ready for radiological operations in two years. In order to support the conceptual design effort underway, a process flowsheet and material balance have been prepared.

2.0 Open Items

2.1 Reference (11) is in DRAFT form. This source was used as input for two of the three cases (Intermediate and Minimum). When the feed strategy for the MCU is finalized, this material balance may need to be revisited. The Maximum case is not expected to change.

2.2 Decanter design – The decanter design calculation has not been verified. When the design is finalized and performance data is obtained, this material balance may need to be revisited.

3.0 Assumptions

The MCU flowsheet is in the early stages of development, and as such, reasonable assumptions have been made in order to promote the development of the design. These assumptions are summarized here; however, they are only applicable for the purposes of this calculation.

3.1 Conservation of Volume – Volume is conserved in the material balance to support closure of the calculation and to keep the calculation to a reasonable level of complexity. The volumes in the MCU process are small enough that volume discrepancies will be minimal.

3.1.1 When streams are combined, the specific gravity of the resulting solution is calculated by using a weighted average

$$SG_1*(Q_1/(Q_1+Q_2)) + SG_2*(Q_2/(Q_1+Q_2))$$

Where: Q_n = flow rate of a stream (mass or volume)
SG_n = specific gravity or density of a stream

3.2 Solids Formation – High Level Waste (HLW) has been shown to precipitate solids after a pH change, such as during dilution with low hydroxide solutions (Ref (2)). ARP adjusts to a sodium molarity of 5.6 M prior to the filtration step. The adjustment in ARP is to be accomplished using process water or 0.01 M sodium hydroxide flush water, which is unlikely to prevent the formation of solids. By adjusting in advance of filtration, the MCU will be protected from rapid-forming solids. Other relatively slow-forming solids may precipitate after filtration but before CSSX processing; however, solids formation is not addressed in this material balance. The MCU operational strategy/waste acceptance criteria will call for all adjustment to occur prior to filtration in ARP, if required. Temperature changes may also initiate the formation of solid salts.

This calculation assumes that temperature changes in the process are not dramatic enough to cause solid salts to form.

3.3 Clarified Salt Solution (CSS) fed to the contactors from the Salt Solution Feed Tank will be 5.6 M Na^+.

3.4 The extraction contactors will decontaminate 5.6 M Na^+ waste feed down to 0.1 Ci/gal or less.

3.4.1 The extraction contactors will achieve a cesium Decontamination Factor (DF_{Cs}) of at least 12. This DF_{Cs} is required to decontaminate the maximum feed down to 0.1 Ci/gal.

3.5 Chemistry reacts instantaneously and proceeds to completion.

3.5.1 $HNO_3 + NaOH \rightarrow NaNO_3 + H_2O$

3.5.2 $HNO_3 + CsOH \rightarrow CsNO_3 + H_2O$

3.6 The contents of the Caustic Wash Tank will be re-circulated until it is neutralized to the point it is no longer effective. It will then be combined with decontaminated salt solution (DSS). This will be a batch process. The material balance assumes that fresh wash solution is needed every 100 turnovers in the Caustic Wash Tank. The actual number of wash solution turnovers can only be determined during operation.

3.7 Solvent carryover in the aqueous phase from the extraction, strip, and wash contactors is 1 volume % (vol%). The carryover was not calculated in the scrub since the aqueous is an input to the extraction stages. Carryover greater than 1 vol% is indicative of poor hydraulic performance (Ref (6)).

3.8 Solvent entrainment in the aqueous phase from the decanters is 50 ppm. This is likely an under-estimate of the current decanter design capability; however, design has not been finalized (Open Item 2.2)

3.9 Cold feed commodity chemicals can be delivered once per week.

3.10 Soluble cesium is shown as cesium nitrate. Cesium may also exist as a hydroxide in the supernate. Because the concentration of cesium is low, the form (hydroxide vs. nitrate) is insignificant from a waste chemistry perspective. Also, any cesium hydroxide that is extracted will react with the scrub acid (see 3.5.2) to form the nitrate.

4.0 General Bases

The following are the bases for the development of the material balance calculation that apply to all cases. They reflect the current strategy as of the date published. For consistency, all flow rates and flow ratios are on a volumetric basis.

4.1 The MCU will match flow rates with ARP (Ref (1)).

4.1.1 CSS is fed to the MCU from ARP (Ref (1)).

4.1.2 The ARP achieves separation using a 0.1 micron filter (Ref (7)).

4.2 Cs-137 is 22.5% of the total cesium in the waste (Ref (13)).

4.3 Cs-137 is 87 Ci/g (Ref (4)).

4.4 The Strip feed flow is set to achieve a cesium Concentration Factor (CF) of 15 (Ref (8)).

		1	2	3	4	5	6	7	8	9	10
Radiological Summary	Units	Clarified Salt Soln from 512-S	Salt Soln to CSSX	Scrub Feed	Extract Feed	Strip Feed	Caustic Wash Resupply	Caustic Wash Feed	Caustic Wash Recirc	Extract to Decant/ Decay	DSS to Hold Tank
Cs-137	Ci/hr	5.45E+02	5.45E+02		5.46E+02					4.55E+01	4.55E+01
Ba-137m	Ci/hr	5.15E+02	5.15E+02		5.15E+02					4.30E+01	4.30E+01
Sr-90	Ci/hr	6.05E-02	6.05E-02		6.05E-02					6.05E-02	6.05E-02
Y-90	Ci/hr	6.05E-02	6.05E-02		6.05E-02					6.05E-02	6.05E-02
Th-232	Ci/hr	1.47E-09	1.47E-09		1.47E-09					1.47E-09	1.47E-09
U-232	Ci/hr	8.50E-08	8.50E-08		8.50E-08					8.50E-08	8.50E-08
U-233	Ci/hr	5.20E-08	5.20E-08		5.20E-08					5.20E-08	5.20E-08
U-234	Ci/hr	7.13E-09	7.13E-09		7.13E-09					7.13E-09	7.13E-09
U-235	Ci/hr	1.14E-07	1.14E-07		1.14E-07					1.14E-07	1.14E-07
U-236	Ci/hr	6.13E-10	6.13E-10		6.13E-10					6.13E-10	6.13E-10
U-238	Ci/hr	9.42E-06	9.42E-06		9.42E-06					9.42E-06	9.42E-06
Np-237	Ci/hr	4.84E-06	4.84E-06		4.84E-06					4.84E-06	4.84E-06
Pu-238	Ci/hr	2.94E-02	2.94E-02		2.94E-02					2.94E-02	2.94E-02
Pu-239	Ci/hr	4.99E-03	4.99E-03		4.99E-03					4.99E-03	4.99E-03
Pu-240	Ci/hr	1.12E-03	1.12E-03		1.12E-03					1.12E-03	1.12E-03
Pu-241	Ci/hr	2.96E-02	2.96E-02		2.96E-02					2.96E-02	2.96E-02
Pu-242	Ci/hr	2.31E-07	2.31E-07		2.31E-07					2.31E-07	2.31E-07
Am-241	Ci/hr	9.29E-03	9.29E-03		9.29E-03					9.29E-03	9.29E-03
Am-242m	Ci/hr	1.26E-05	1.26E-05		1.26E-05					1.26E-05	1.26E-05
Cm-244	Ci/hr	5.18E-06	5.18E-06		5.18E-06					5.18E-06	5.18E-06
Cm-245	Ci/hr	1.06E-11	1.06E-11		1.06E-11					1.06E-11	1.06E-11

		1	2	3	4	5	6	7	8	9	10
Radiological Summary	Units	Clarified Salt Soln from 512-S	Salt Soln to CSSX	Scrub Feed	Extract Feed	Strip Feed	Caustic Wash Resupply	Caustic Wash Feed	Caustic Wash Recirc	Extract to Decant/ Decay	DSS to Hold Tank
Cs-137	Ci/hr	3.59E+02	3.59E+02		3.60E+02					3.00E+01	3.00E+01
Ba-137m	Ci/hr	3.39E+02	3.39E+02		3.39E+02					2.83E+01	2.83E+01
Sr-90	Ci/hr	6.82E-02	6.82E-02		6.82E-02					6.82E-02	6.82E-02
Y-90	Ci/hr	6.82E-02	6.82E-02		6.82E-02					6.82E-02	6.82E-02
Th-232	Ci/hr	1.66E-09	1.66E-09		1.66E-09					1.66E-09	1.66E-09
U-232	Ci/hr	9.59E-08	9.59E-08		9.59E-08					9.59E-08	9.59E-08
U-233	Ci/hr	5.86E-08	5.86E-08		5.86E-08					5.86E-08	5.86E-08
U-234	Ci/hr	8.05E-09	8.05E-09		8.05E-09					8.05E-09	8.05E-09
U-235	Ci/hr	1.28E-07	1.28E-07		1.28E-07					1.28E-07	1.28E-07
U-236	Ci/hr	6.92E-10	6.92E-10		6.92E-10					6.92E-10	6.92E-10
U-238	Ci/hr	1.06E-05	1.06E-05		1.06E-05					1.06E-05	1.06E-05
Np-237	Ci/hr	5.46E-06	5.46E-06		5.46E-06					5.46E-06	5.46E-06
Pu-238	Ci/hr	3.32E-02	3.32E-02		3.32E-02					3.32E-02	3.32E-02
Pu-239	Ci/hr	5.63E-03	5.63E-03		5.63E-03					5.63E-03	5.63E-03
Pu-240	Ci/hr	1.26E-03	1.26E-03		1.26E-03					1.26E-03	1.26E-03
Pu-241	Ci/hr	3.34E-02	3.34E-02		3.34E-02					3.34E-02	3.34E-02
Pu-242	Ci/hr	2.61E-07	2.61E-07		2.61E-07					2.61E-07	2.61E-07
Am-241	Ci/hr	1.05E-02	1.05E-02		1.05E-02					1.05E-02	1.05E-02
Am-242m	Ci/hr	1.43E-05	1.43E-05		1.43E-05					1.43E-05	1.43E-05
Cm-244	Ci/hr	5.84E-06	5.84E-06		5.84E-06					5.84E-06	5.84E-06
Cm-245	Ci/hr	1.19E-11	1.19E-11		1.19E-11					1.19E-11	1.19E-11

		1	2	3	4	5	6	7	8	9	10
Radiological Summary	Units	Clarified Salt Soln from 512-S	Salt Soln to CSSX	Scrub Feed	Extract Feed	Strip Feed	Caustic Wash Resupply	Caustic Wash Feed	Caustic Wash Recirc	Extract to Decant/ Decay	DSS to Hold Tank
Cs-137	Ci/hr	4.77E-01	4.77E-01		4.78E-01					3.98E-02	3.98E-02
Ba-137m	Ci/hr	4.50E-01	4.50E-01		4.51E-01					3.76E-02	3.76E-02
Sr-90	Ci/hr	6.82E-02	6.82E-02		6.82E-02					6.82E-02	6.82E-02
Y-90	Ci/hr	6.82E-02	6.82E-02		6.82E-02					6.82E-02	6.82E-02
Th-232	Ci/hr	1.66E-09	1.66E-09		1.66E-09					1.66E-09	1.66E-09
U-232	Ci/hr	9.59E-08	9.59E-08		9.59E-08					9.59E-08	9.59E-08
U-233	Ci/hr	5.86E-08	5.86E-08		5.86E-08					5.86E-08	5.86E-08
U-234	Ci/hr	8.05E-09	8.05E-09		8.05E-09					8.05E-09	8.05E-09
U-235	Ci/hr	1.28E-07	1.28E-07		1.28E-07					1.28E-07	1.28E-07
U-236	Ci/hr	6.92E-10	6.92E-10		6.92E-10					6.92E-10	6.92E-10
U-238	Ci/hr	1.06E-05	1.06E-05		1.06E-05					1.06E-05	1.06E-05
Np-237	Ci/hr	5.46E-06	5.46E-06		5.46E-06					5.46E-06	5.46E-06
Pu-238	Ci/hr	3.32E-02	3.32E-02		3.32E-02					3.32E-02	3.32E-02
Pu-239	Ci/hr	5.63E-03	5.63E-03		5.63E-03					5.63E-03	5.63E-03
Pu-240	Ci/hr	1.26E-03	1.26E-03		1.26E-03					1.26E-03	1.26E-03
Pu-241	Ci/hr	3.34E-02	3.34E-02		3.34E-02					3.34E-02	3.34E-02
Pu-242	Ci/hr	2.61E-07	2.61E-07		2.61E-07					2.61E-07	2.61E-07
Am-241	Ci/hr	1.05E-02	1.05E-02		1.05E-02					1.05E-02	1.05E-02
Am-242m	Ci/hr	1.43E-05	1.43E-05		1.43E-05					1.43E-05	1.43E-05
Cm-244	Ci/hr	5.84E-06	5.84E-06		5.84E-06					5.84E-06	5.84E-06
Cm-245	Ci/hr	1.19E-11	1.19E-11		1.19E-11					1.19E-11	1.19E-11

CBU-PIT-2005-00013
REVISION: 3
June 21, 2005

KEYWORDS:
Tank Farm, Salt Program,
Waste Solidification, Class C,
Permit, Saltstone

RETENTION: PERMANENT
CLASSIFICATION: U
Does not contain UCNI
Paul D. d'Entremont
6/21/05 ADC/RO

Radionuclide Concentrations in Saltstone

P. D. d'Entremont, 766-H
M.D. Drumm, 766-H

Approval:

for

~~L. B.~~ Romanowski, Manager,
CBU Salt Disposition Planning

APPROVED for Release for
Unlimited (Release to Public)

Westinghouse Savannah River Company
Closure Business Unit
Planning Integration & Technology Department
Aiken, SC 29808

Prepared for U.S. Department of Energy Under Contract No. DE-AC09-96S

Ci/mg	Tank 41	Tank 25	Tank 28
Sb-126m	6.24E-11	3.09E-11	3.09E-11
Sm-151	2.20E-07	6.05E-08	6.05E-08
Eu-152	1.06E-09	2.92E-10	2.92E-10
Eu-155	1.24E-08	3.42E-09	3.42E-09
Ra-226	1.18E-17	1.21E-24	1.21E-24
Ra-228	No Data	No Data	No Data
Ac-227	1.38E-17	3.63E-17	3.63E-17
Th-229	No Data	4.79E-22	4.79E-22
Th-230	1.44E-15	1.48E-22	1.48E-22
Pa-231	3.84E-17	1.01E-16	1.01E-16
Pu-244	No Data	3.24E-15	3.24E-15
Am-243	3.56E-12	9.77E-13	9.77E-13
Cm-242	3.93E-12	No Data	No Data
Cm-243	2.08E-12	5.72E-13	5.72E-13
Cm-247	4.01E-22	1.10E-22	1.10E-22
Cm-248	4.18E-22	1.15E-22	1.15E-22
Bk-249	3.06E-29	8.39E-30	8.39E-30
Cf-249	2.32E-21	6.37E-22	6.37E-22
Cf-251	7.93E-23	2.18E-23	2.18E-23
Cf-252	2.57E-24	7.07E-25	7.07E-25

Each DDA dissolution batch total activity is the sum of the supernatant contribution, the saltcake contribution and the insoluble solids contribution. The total activity of the salt solution created in each of these batches is then added to the total activity of the DWPF recycle used for aggregation/adjustment to give the total activity sent to Saltstone for each batch. The ARP/MCU batches are calculated in a similar way, with the exception that the insoluble solids are not included because they are filtered out of solution (It was assumed that solids passing through the filter are negligible).. MCU is assumed to achieve a cesium decontamination factor of 12. This is applied to all of the cesium isotopes as well as ^{137m}Ba, the short lived daughter product of ^{137}Cs[15]. Although ARP will have the capability to perform a Monosodium Titanate (MST) strike to lower the soluble strontium and actinide concentrations, none was assumed for this calculation. This methodology was applied to Batches 1, 4, 5, 6, 7 and 9, all of which involve the dissolution of saltcake.

Batch 0, 2, 3 and 8 do not involve salt dissolution. Batch 0 involves the processing of the low-level waste stored in Tank 50. For this batch, the current concentration of Tank 50 supernatant is multiplied by the future volume of supernatant in Tank 50 estimated in the Interim Strategy. Batches 2 and 3 involve the aggregation of waste currently in Tank 48 with DWPF recycle. For Batch 2, a volume of Tank 48 waste and recycle are given so the total activity sent to Saltstone in this batch is the sum of these two streams. Batch 3 involves a heel washing so the total volume of recycle sent into Tank 48 is equal to the total volume of solution transferred from Tank 48 to Saltstone. Conservatively, this stream is assumed to include all of the activity remaining in Tank 48 after Batch 2, as well as all the activity in all of the recycle sent to Tank 48. Batch 8 involves the

ARP batches are filtered only (no MST) per the Interim Strategy. Thus, the only soluble radionuclide that is reduced in processing is ^{137}Cs, which is removed by MCU (e.g., soluble plutonium and strontium are not reduced). ^{137}Cs decontamination factor is 12[15]

Batch 0 concentrations are assumed to be the same as currently in Tank 50[11].

Inventory of radionuclides from SWPF to Saltstone is calculated by summing up soluble inventory from DDA and ARP/MCU going to Saltstone. This sum is subtracted from the total soluble inventory provided and then the SWPF Decontamination Factors are applied. SWPF Decontamination Factors are taken from the Integrated Material Balance[15] for a 12-hour MST strike and are listed below.

Sr	20
Cs	40000
U	1.35
Np	2.4
Pu	5.5
Am	4.6
Cm	1.7

The total volume of salt solution sent to Saltstone from SWPF is 95.8 Mgal[16].

References:

[10] M.J. Mahoney and P.D. d'Entremont, "Interim Salt Processing Strategy Planning Baseline", CBU-PED-2004-00027, Revision 0, August 27, 2004

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[14] J.M. Gillam, "Settling of Insoluble Solids in Supernate from Salt Dissolution", X-CLC-H-00546, Revision 0, March 2005

[15] H.H. Elder, "Integrated Material Balance Input Data Summary", CBU-PED-2004-00033, Revision 0, September 10, 2004

[16] M.A. Rios-Armstrong, "Decontaminated Salt Solution Volume to be Transferred to the Saltstone Disposal Facility from Salt Treatment and Disposition Activities," CBU-PIT-2005-00031, February 13, 2005

CBU-PIT-2005-00146
Revision 0

SALTSTONE
PERFORMANCE OBJECTIVE DEMONSTRATION DOCUMENT
(U)

PREPARED BY:
Kent H. Rosenberger
Bernice C. Rogers
R. Kim Cauthen

JUNE 2005

APPROVED for Release for
Unlimited (Release to Public)

Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

Prepared for the U.S. Department of Energy Under
Contract Number DE-AC09-96SR18500

3.2 Radiological Inventory

3.2.1 Projected Saltstone Inventory

The projected final inventory of the SDF combines the existing inventory of the partially filled vaults 1 and 4 (Crapse et al, 2004) and all projected future inventory additions, based on the present SRS salt processing strategy (d'Entremont and Drumm, 2005). The future inventory additions be added to existing Saltstone vaults as well as other vaults yet to be constructed Table 3-2 presents the projected total SDF inventory as calculated by these references.

Table 3-2. Projected Total Saltstone Disposal Facility Inventory

Nuclide	Current Inventory Vault 1 (Ci)	Current Inventory Vault 4 (Ci)	Future Inventory Additions (Ci)	Total (Ci)
H-3	2.73E+01	2.94E+01	9.37E+03	9.43E+03
C-14	1.28E+00	2.35E-01	5.18E+02	5.20E+02
Na-22	NV	NV	5.05E+03	5.05E+03
Al-26	NV	NV	2.35E+01	2.35E+01
Ni-59	3.46E-02	9.09E-03	2.81E+00	2.85E+00
Co-60	2.77E-03	6.83E-03	1.10E+02	1.10E+02
Ni-63	9.38E-01	6.01E-02	2.50E+02	2.51E+02
Se-79	3.02E-01	2.57E-02	8.91E+01	8.94E+01
Sr-90	1.31E-02	3.17E-01	7.43E+03	7.43E+03
Y-90	NV	NV	7.43E+03	7.43E+03
Nb-94	2.51E-03	9.91E-04	7.23E-04	4.22E-03
Tc-99	1.08E+02	2.35E+01	3.30E+04	3.31E+04
Ru-106	1.14E-02	6.14E-03	2.28E+03	2.28E+03
Rh-106	NV	NV	2.28E+03	2.28E+03
Sb-125	1.29E+00	9.39E-01	9.24E+03	9.24E+03
Te-125m	NV	NV	2.26E+03	2.26E+03
Sn-126	9.97E-01	5.66E-02	4.50E+02	4.51E+02
Sb-126	NV	NV	6.30E+01	6.30E+01
Sb-126m	NV	NV	4.50E+02	4.50E+02
I-129	1.12E-01	8.16E-02	1.78E+01	1.80E+01
Cs-134	NV	1.32E-02	2.71E+03	2.71E+03
Cs-135	NV	NV	4.67E+00	4.67E+00
Cs-137	7.96E+00	1.68E+01	1.35E+06	1.35E+06
Ba-137m	NV	NV	1.28E+06	1.28E+06
Ce-144	NV	NV	6.27E+00	6.27E+00
Pr-144	NV	NV	6.27E+00	6.27E+00
Pm-147	NV	NV	4.14E+03	4.14E+03
Sm-151	NV	9.29E-04	4.55E+03	4.55E+03
Eu-152	6.92E-03	5.14E-03	2.20E+01	2.20E+01

APPROVED for Release for Unlimited (Release to Public) 5/3/2005

OSR 45-244 (Rev 1-10-2000)

ENGINEERING DOC. CONTROL-SRS

00802749

Calculation Cover Sheet

Project Actinide Removal Process (ARP) Facility	Calculation Number X-CLC-S-00113	Project Number W958
Title Actinide Removal Process Material Balance Calculation with Low Curie Salt Feed	Functional Classification PS	Sheet 1 of 15
	Discipline Process	

☒ Preliminary ☐ Confirmed

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

Purpose and Objective

The calculation will capture all the flowsheet bases for the Actinide Removal Process Facility (512-S and 241-96H with 512-S) with Low Curie Salt Feed. This Preliminary Calculation provides information on the chemical process flows. Chemicals and radionuclides in the fresh waste feed are based on the Average Low Curie Salt feed vector (70% interstitial supernate removed with 600 mg/L sludge), High Cesium Case (Tank 36: 70% interstitial supernate removed with 600 mg/L sludge), and the Worst Dose Case (Tank 33: 70% interstitial supernate removed with 1200 mg/L sludge) in the Low Curie Feed Basis document (WSRC-TR-2001-00559).

Summary of Conclusion

The process flows for the ARP Facility with Low Curie Salt Feed are shown herein. Bases, assumptions and the resultant material balances for the 512-S and 241-96H with 512-S ARP Facility options (Reference 7) are presented in the accompanying text and appendices. The flowrates, batch sizes and cycle times presented herein are nominal values and may differ slightly from actual values based on current and future facility configurations for both 512-S and 241-96H. Additional material balance cases for 512-S and 241-96H with 512-S ARP Facility options are presented to show impacts of time-averaged filter flux for the 0.5 micron crossflow filter at 512-S, use of a 0.1 micron crossflowfilter at 512-Sand different MST strike times (0 to 24 hours) at 512-S and 241-96H.

Revisions

Rev No.	Revision Description
D	Updating Material Balance to close open items and incorporate position paper (Reference 16) on material balance inputs (dilution of fresh decontamination factors, etc.)

Sign Off

Rev No.	Originator (Print) Sign/Date	Verification/ Checking Method	Verifier/Checker (Print) Sign/Date	Manager (Print) Sign//Date
D	S.G. Subaits 3/11/2004	Alternative (Hand) Cal.	Mark Hopkins 3/11/04	EWA. M.R. Norton 3/12/04
				S.J. Robertson 3/23/04

Release to Outside Agency – Design Authority (Print)	Signature	Date
NA	NA	NA

Security Classification of the Calculation

Unclassified

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Analytical Methods and Computation	**10**
Results	**11**
Conclusion	**13**
Attachments	**13**
	Through
	Appendix AD

Open Items:

- A provisional DF for Am and Cm of 100 was assumed. SRTC is currently investigating the decontamination of Am and Cm by monosodium titanate (MST). The assumed DF of 100 is conservatively low based on initial testing. This DF was preliminary and accounted for the soluble amount of Am/Cm in an acidic solution going to the insoluble state when neutralized with caustic in addition to the DF from treatment with MST. (**Item Closed** - Testing showed a confirmed DF of 1.7 (Reference 12) for both Am and Cm by contacting with MST for 24 hours. The new DF was included in revision C of this document.)

- The volumes associated with transfer pump priming for Late Wash Precipitate Tank (LWPT) were not incorporated in this revision of the ARP material balance. This will be addressed in subsequent revision to the material balances when such information becomes available. (**Item Closed** - A review of the design documents for the transfer pump priming line indicates a maximum quantity of 400 gallons of water per year from starting the transfer pump. This quantity is negligible in comparison to the total volume of solution processed through the ARP and is not accounted for in the mass balance calculation.)

- To ensure adequate cleaning of residual insoluble solids from the porous tubes of the ARP crossflow filter an optimum filter cleaning protocol is to be recommended by SRTC. The cleaning protocol will have to be tailored to meet both filter performance requirements for restoring filter flux and operational logistics of the 512-S ARP Facility. (**Item Closed -** A filter cleaning protocol has been recommended by SRNL in Reference 15 and implemented in 512-S since the previous revision of this calculation. The protocol was incorporated into revision D of this document.)

- The crossflow filter cleaning protocol incorporated into this revision of the material balance results in a partially neutralized heel in the LWPT, which is transferred forward to the Low Point Pump Pit Precipitate Tank (LPPPPT) and subsequently DWPF. The impact to the actinides sorbed onto the MST in the LWPT heel has not been determined. Impacts from corrosion of the carbon steel transfer line jacket due to the presence of oxalic acid and to criticality analyses from oxalic acid dissolving iron in the DWPF sludge feed appear to be negligible based on current information. (**Item Closed** – A position paper (Reference 17) to resolve this item recommended substitution of a 1.66M NaOH flush for the initial 0.02M NaOH flush of the filter cleaning protocol. The 1.66M NaOH flush has been incorporated into this revision of the calculation)

- Process Vessel Vent (PVV) design data for the 241-96H MST Strike Tanks will be incorporated into a future revision of this calculation when it becomes available following detailed design of the 241-96H Facility. (**Item Closed** – A process vessel vent system exhaust flow calculation (Reference 18) has been performed for the 241-96H MST Strike Tanks and the resulting flows have been incorporated into this revision of the material balance calculation.)

- The current ARP strategy transfers filtrate to the Modular Caustic-Side Solvent Extraction Unit (MCU) for cesium removal as opposed to directly to Tank 50 for Saltstone disposal. Prior revisions of this calculation used 1.66 molar NaOH to dilute salt waste feed to prevent post-filtration precipitation of aluminum. In this revision process water or flush water (0.01M NaOH) are used to dilute feed based on a recommendation from Reference 14. An evaluation of aluminum post-filtration precipitation in feed to the MCU or Tank 50 and related settling and removal issues should be performed prior to implementation in the ARP. (**Item Closed** – Reference 19 closes this open item.)

References:

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6. M-M6-S-0019, Revision 7, "Late Wash Facility Piping and Instrument Diagram – Late Wash Cross-flow Filter".
7. M. A. Nadeau, "Actinide Removal Process Alternative Study and Selection", G-ADS-G-00007, January 2, 2002.
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18. F. D. Somers, "241-96H MST Strike Tanks PVV System Equipment Sizing", M-CLC-H-02601, September 24, 2004.
19. S. G. Subosits, "Engineering Position on the Solids Formation Open Item in the Actinide Removal (ARP) Material Balance Calculation", CBU-SPT-2004-00181, Rev. 0, September 2, 2004.

Input:

512-S Only ARP Bases:

- 0.01M NaOH is used for dilution of the salt waste feed in the LWPT to 5.6 M sodium (Ref 14). This dilution is necessary to increase the rate of alpha and strontium sorption, allowing a reasonable cycle time (Ref 1).
- MST concentration used is 0.4 g of MST per liter of diluted feed in the LWPT (Ref 1).
- The filter cleaning cycle consists of seven steps: 1.66 M caustic (1), 0.02 M caustic (2), 0.02 M caustic (3), oxalic acid (4), 0.02 M caustic (5), 0.02 M caustic (6), 0.02 M caustic (7). Each wash step is 415 gallons (Ref 15 & 17).
- 0.5M oxalic acid used for filter cleaning (Ref 11)
- MST/sludge solids concentrated to approximately $5\%_{wt}$ solids in the LWPT (Ref 1).
- Solids specific gravity = 1.8 (Ref 1)
- The amount of inhibited wash water required to wash the MST/sludge solids to a sodium concentration of 0.5 M (Ref 1) is determined to be ~1.57 gallons of washwater per gallon of salt solution. Using the following equation: Wash water = ln[Na(initial)] – ln[Na(final)]. This constant volume wash follows addition of 2000 gallons of inhibited wash water to raise the LWPT level to run the filter feed pump and dilute the LWPT heel sodium concentration. After the pump has been started, the LWPT will be pumped down to 1,600 gallons before the constant washing procedure begins.
- Based on a 24-hour sorption reaction time, Strontium (Sr) Decontamination Factor (DF) = 129.5 (Ref 2, 3, 14)
- Based on a 24-hour sorption reaction time, Plutonium (Pu) DF = 12.9 (Ref 2, 3, 14)
- Based on a 24-hour sorption reaction time, Uranium (U) DF = 1.2 (Ref 2, 3, 14)
- Based on a 24-hour sorption reaction time, Neptunium (Np) DF = 3.7 (Ref 2, 3, 14)
- Based on a 24-hour sorption reaction time, Americium (Am) DF = 1.7 (Ref 12)
- Based on a 24-hour sorption reaction time Curium (Cm) DF = 1.7 (Ref 12)
- Mixing of Caustic and Oxalic Acid from the spent cleaning solutions results in the following reaction: $H_2C_2O_4 + 2\ NaOH \rightarrow Na_2C_2O_4 + 2H_2O$.
- Nitrogen supply to the LWPT and LWHT is 20 scfm (Ref 5). This is conservatively high because ARP does not have the benzene generation concerns of the Late Wash process. It is likely the nitrogen purge for these vessels will be set to deliver less than 20 scfm when ARP operations commence.
- For vent calculations, the temperature is 35°C and the LWPT and LWHT tank pressure are -5" of w.g. (Ref 10).
- Vessel vent includes 10 scfm in tank leakage (Ref 10).
- The cross-flow filter flux is 0.02 gpm/ft^2 (Ref 1).
- The Cross-flow filter area is 230 ft^2 (Ref 6). The filter media are Mott 0.5 micron sintered metal tubes.
- The 512-S Only ARP Vessel and equipment configuration is based on the Case 2 option with the Option D MST sludge solids disposal path from the Actinide Removal Process Alternative Study and Selection document (Ref 7).

- The Henry's constants for methanol and isopropanol are 338 and 754 mmHg/mole fraction respectively (Ref 9).

512-S Only ARP Assumptions:

- The dilution of the feed from 6.44 M to 5.6 M sodium (Ref 1), MST spiking, and concentrating and washing solids will take place in the Late Wash Precipitate Tank (LWPT) at 512-S.
- Operating volume of the LWPT is 5,400 gallons: 3,800 gallon working volume and a 1,600 gallon heel. The non-transferable amount of the LWPT heel is 650 gallons.
- The filter cleaning is done with the same frequency as the sludge washing, with the two combined taking 36 hours.
- Filtrate is used for backpulsing during LWPT filter concentration and MST/sludge heel washing/filtration operations.
- Spent filter cleaning solution is transferred after the washed MST/sludge solids to the Low Point Pump Pit Precipitate Tank (LPPPPT) to act as a line flush.
- To estimate the impact of ARP on the DWPF processes, the ARP is assumed to feed the Precipitate Reactor Feed Tank (PRFT) in the DWPF Salt Cell 44 times a year to coincide with the 44 DWPF SRAT batches processed per year. Actual transfers to the PRFT, and subsequently the SRAT, may not occur at this frequency, it is only used for impact estimations.
- 1.66 M NaOH is diluted with inhibited water from the shell side of the filter to 0.02M NaOH (Ref 15) for filter cleaning in the Surge Tank. Inhibited water at 512-S is assumed to be flush water (deionized water with 0.01M NaOH added).
- The baseline cycle time for the LWPT is 42 hours (24 hours sorption time, ~14 hours filter time, 2 hours for transfers, and 2 hours for chemical additions) in addition to the average of the filter cleaning/sludge washing time over the filtration cycles. A bar graph with the cycle time layout is included as Appendix AC.

241-96H ARP with 512-S Bases:

- Process water is used for dilution of the waste in the reactor vessels to 5.6 M Na (Ref. 14). This dilution is necessary to increase the rate of alpha and strontium sorption, allowing a reasonable cycle time (Ref 1).
- The MST concentration used is 0.4 g of MST per liter of diluted feed in the reactor vessels (Ref 1).
- The filter cleaning cycle consists of seven steps: 1.66 M caustic (1), 0.02 M caustic (2), 0.02 M caustic (3), oxalic acid (4), 0.02 M caustic (5), 0.02 M caustic (6), 0.02 M caustic (7). Each wash step is 415 gallons (Ref 15, & 19).
- 0.5 M oxalic acid used for filter cleaning (Ref 11).
- MST/sludge solids concentrate to approximately $5\%_{wt}$ solids in the LWPT (Ref 1).
- Solids specific gravity = 1.8 (Ref 1).
- The amount of inhibited washwater required to wash the MST/sludge solids heel to a sodium concentration of 0.5 M (Ref 1) is ~1.57 gallons of washwater per gallon of salt solution using the following equation: Washwater = ln[Na(initial)] – ln[Na(final)]. This constant volume wash follows addition of 2000 gallons of

inhibited wash water to raise the LWPT level to run the filter feed pump and dilute the LWPT heel sodium concentration. After the pump has been started, the LWPT will be pumped back down to 1,600 gallons before the constant washing procedure begins.

- Based on a 24-hour sorption reaction time, Strontium (Sr) Decontamination Factor (DF) = 129.5 (Ref 2, 3, 14)
- Based on a 24-hour sorption reaction time, Plutonium (Pu) DF = 12.9 (Ref 2, 3, 14)
- Based on a 24-hour sorption reaction time, Uranium (U) DF = 1.2 (Ref 2, 3, 14)
- Based on a 24-hour sorption reaction time, Neptunium (Np) DF = 3.7 (Ref 2, 3, 14)
- Based on a 24-hour sorption reaction time, Americium (Am) DF = 1.7 (Ref 12)
- Based on a 24-hour sorption reaction time Curium (Cm) DF = 1.7 (Ref 12)
- Mixing of Caustic and Oxalic Acid from the spent cleaning solutions results in the following reaction: $H_2C_2O_4 + 2\ NaOH \rightarrow Na_2C_2O_4 + 2H_2O$.
- Nitrogen supply to the LWPT and the LWHT is 20 scfm (Ref 5). This is conservatively high because ARP does not have the benzene generation concerns of the Late Wash process. It is likely the nitrogen purge for these vessels will be set to deliver less than 20 scfm when ARP operations commence.
- For vent calculations, the temperature is 35°C and the tank pressure is -5" of wg. (Ref 10).
- Vessel vent includes 10 scfm in tank leakage (Ref 10).
- The cross-flow filter flux is 0.02 gpm/ft^2 (Ref 1).
- The cross-flow filter area is 230 ft^2 (Ref 6). The filter media are Mott 0.5 micron sintered metal tubes.
- Vessel and equipment configuration is based on the Case 6 option in the Actinide Removal Process Alternative Study and Selection document (Ref 7).
- The Henry's constants for methanol and isopropanol are 338 and 754 mmHg/mole fraction respectively (Ref 9).
- Process Vessel Vent System exhaust flow from each MST Strike Tank is 100 SCFM (Ref 18). Total air in-leakage is 100 SCFM for each vessel and the tanks will be maintained at -1" of wg.

<u>241-96H with 512-S ARP Assumptions</u>:

- The incoming fresh waste feed will be diluted from 6.44M to 5.6M sodium in two new reactors in the 241-96H filter cells. MST is subsequently added to the tank(s) to decontaminate by sorption of the soluble strontium and actinides in the waste. The reactors are assumed to each have a 3,800-gallon working volume and will retain a 1,600-gallon vessel heel. The heel is considered to be a homogenous mixture with the working volume for material balance purposes.
- Filtration and MST/sludge solids washing/filtration will occur in the existing LWPT at 512-S. The LWPT is assumed to have a working volume of 3,800 gallons. The LWPT heel volume is 1,600 gallons to yield a total operating volume of 5,400 gallons. The non-transferable amount of the LWPT heel is 650 gallons.
- The filter cleaning is done with the same frequency as the sludge solids washing, with the two combined taking 36 hours.

- Filtrate is used for backpulsing during LWPT filter concentration and MST/sludge heel washing/filtration operations.
- Spent filter cleaning solution is transferred after the washed MST/sludge solids to the Low Point Pump Pit Precipitate Tank (LPPPPT) to act as a line flush.
- To estimate the impact of ARP on the DWPF processes, the ARP is assumed to feed the PRFT 44 times a year to coincide with the 44 DWPF SRAT batches processed per year. Actual transfers to the PRFT, and subsequently the SRAT, may not occur at this frequency, it is only used for impact estimations.
- 1.66 M NaOH is diluted with inhibited water from the shell side of the filter to 0.02 M NaOH (Ref 15) for filter cleaning in the Surge Tank. Inhibited water at 512-S is assumed to be flush water (deionized water with 0.01M NaOH added).
- The baseline cycle time for the LWPT is 32 hours (28 hours for filtration of two 3,800-gallon batches, 4 hours for transfer in of the two filtration batches) in addition to the average time from the filter cleaning/sludge washing operations over the filtration cycles.
- Following the processing of the first batch of reactor slurry through the filter each reactor has a cycle time of 32 hours which includes 24 hours of reaction time, four hours for fresh waste transfers in and chemical additions, 2 hours for sampling & transfers out of vessel to the LWPT, 2 hours holdup time until the LWPT becomes available. Additional cycle time comes from the average time for the filter cleaning/sludge washing operations over the filtration cycles. This additional cycle time is calculated in the material balance. A bar graph with the cycle time layout is included as Appendix AD.

Average Feed Basis:

- The average chemical data is extracted from Reference 4: Table 5, ARP feed adjusted to 6.44M Na+ with Inhibited Water.
- The average radiological data is extracted from Reference 4, Table 5 ARP feed adjusted to 6.44M Na+ with Inhibited Water.

Average Feed Assumptions:

- The sludge concentration is 600 mg/L.
- Material Balance results for the average feed to the 512-S Only ARP are detailed in Appendix A.
- Material Balance results for the average feed to the 241-96H with 512-S ARP are detailed in Appendix D.

Worst Case Inhalation Dose (Tank 33) Feed Basis:

- Tank 33 is used as the worst case feed, it is the ARP feed tank with one of the highest supernate inhalation doses in Table 5 of Reference 4.

Worst Case Inhalation Dose (Tank 33) Feed Assumptions:

- The sludge concentration is 1200 mg/L for the worst case feed.
- Material Balance results for the worst case feed to the 512-S Only ARP are detailed in Appendix B.
- Material Balance results for the worst case feed to the 241-96H with 512-S ARP are detailed in Appendix E.

High Cesium (Tank 36) Feed Basis:

- Tank 36 contains the highest supernate Cesium-137 concentration (10.6 Ci/gal) of the tanks in Reference 4, Table 7. The dissolved salt solution at 6.44 M Na^+ will have an incoming Cs-137 concentration of 0.42 Ci/gal.

High Cesium (Tank 36) Feed Assumptions:

- The sludge concentration is 600 mg/L.
- Material Balance results for the worst case feed to the 512-S Only ARP are detailed in Appendix C.
- Material Balance results for the worst case feed to the 241-96H with 512-S ARP are detailed in Appendix F.

Bases and Assumptions for Additional Cases Presented in Appendices G through AB:

- All cases use the Average Feed Basis extracted from Reference 4 for chemical and radionuclide input data. All other bases and assumptions apply with the exceptions noted below:
- Cases utilizing an 8-hour MST strike time have the following DFs (Ref 14): Sr = 110.1, Pu = 7.6, U = 1.2, Np = 2.6, Am = 1 (No DF) and Cm = 1 (No DF).
- Cases utilizing a 4-hour MST strike time have the following DFs (Ref 14): Sr = 87, Pu = 6.46, U = 1.03, Np = 1.77, Am = 1 (No DF) and Cm = 1 (No DF).
- For cases utilizing a 0.1 micron porous media crossflow filter, the baseline filter flux at 5 wt% solids loading is 0.057 gpm/ft^2 (Reference 14). This permeate flux equates to ~ 5 hours of filtration time for a 3,800 gallon batch in the LWPT at 512-S.
- For cases utilizing the time-averaged flux of 0.036 gpm/ft^2 for the 0.5 micron porous media crossflow filter at 512-S, the permeate flux equates to ~8 hours of filtration time for a 3,800 gallon batch in the LWPT at 512-S. The filter flux is derived from data in Reference 16 where filtration of a salt solution simulant with sludge and MST added was performed as a continuous concentration (no recycle of filtrate) from a starting point of ~0.1 wt% solids to >5 wt%.
- For the 512-S Filter-Only cases which do not require addition of MST, the MST concentration is set to 1.0E-16 g/L, and instead of dilution to 5.6M, salt solution is assumed to be received at 5.6M Na^+ to maximize the throughput of fresh salt waste.
- For Appendices G through AB only detailed flowrates (in lb/hr and gpm) for the major chemical constituents and activity concentrations (in Ci/gal) for the radiological constituents of concern are presented in this calculation. Detailed

radionuclide curie balances and mass balances for minor chemical constituents were calculated for the cases presented in Appendices G through AB, but are not presented for the sake of brevity.

Analytical Methods and Computations:

Steady state material balance calculations around each vessel were set up in a Microsoft Excel© XP Spreadsheet. Due to the 650 gallon residual heel in the LWPT, an actual steady state representation of the ARP cannot be achieved so one must be approximated. The soluble constituents in this heel are negligible and are not considered additive to the fresh feed because they do not affect the number of batches required and will be diluted by each batch added to the LWPT (after four 3,800 gallon batches the 650 gallon heel will be a contribution of <5% of the concentrations of the LWPT). The MST/Sludge solids remaining in this residual heel after the heel transfer to the LPPPPT are diluted with the spent filter cleaning chemicals as they are sent to the LWPT and then on to the LPPPPT. Some remaining solids after these transfers will always be in the LWPT, so therefore they are considered additive to the solids from the fresh transfers, and must be accounted for when determining the number of fresh waste batches necessary to reach 5 wt% solids in the 1,600 gallon LWPT heel. The number of batches required to add to the residual heel insoluble solids to concentrate the heel was rounded to the nearest whole number to make the frequency of performing solids washing and filter cleaning an integer. For material balance purposes the soluble components in the non-transferable heel are treated as an outgoing stream when performing input-output checks of the process material balance. The dilution effect of the residual heel on the LWPT for soluble material is minimal and is ignored to approximate a steady state process.

The material balances for 241-96H with 512-S ARP were performed in a similar manner to 512-S Only ARP utilizing the bases and assumptions for 241-96H with 512-S ARP.

The feed vectors derived from Reference 4 are given in ionic species. The ions were converted to compounds, with the hydroxide concentration adjusted in order to achieve a balanced charge solution. The sludge chemical constituents, extracted from Reference 13, are also tracked in the mass balance separate from the soluble chemical constituents. Each stream lists the mass flow rate (lb/hr) of each compound as well as the activity (Ci/hr) for each isotope that is given in the feed basis. The sludge radionuclide concentrations are extracted from Reference 4, Table 3. The total activity of each stream is further separated into three categories at the top of each column in the material balances for convenience: Cs-137 activity, Sr-90 activity, and Total Alpha activity.

The insoluble component activity for the sludge is calculated using the sludge vector table in Appendix G. To determine Ci/gal of an isotope in the sludge:

- Multiply the Ci Factor by the sludge value in the Radiological Summary Table of Appendix A, B, C, D, E, or F.

$$\text{Sludge (Ci/hr)} * \text{Ci Factor}_{\text{isotope}} = \text{isotope (Ci/hr)}$$

The sludge contribution is then combined with the soluble contribution to give the total activity.

Decontamination Factors (DF) are used to determine the amount of Sr, Pu, U, Np, Am, and Cm that is sorbed by the MST. For example, the feed from the LWPT (stream 8) is separated by filtration into an MST/sludge solids stream (stream 9) and Filtrate to Filtrate Tank stream (stream 11). All adsorbed Sr exits in stream 9. Using a Sr DF of 129.5, there is 129.5 times more soluble Sr in stream 9 than stream 11 on a mass basis. Therefore since all soluble Sr is carried as $Sr(NO_3)_2$, the equation to determine Sr in stream 9 is:

$$Stream9_{Sr(NO3)2} = Stream8_{Sr(NO3)2} - (Stream8_{Sr(NO3)2} \div 129.5)$$

The spreadsheet uses "str#", where # can be any stream number, to mean the value in the same row as the formula of the stream (column) indicated. For example, the formula above would be '=str8-str8/DFsr' as long as this formula is in the $Sr(NO_3)_2$ row, where 'DFsr' is the name of the cell which contains the DF of Sr.

The process vessel vent information is estimated for the two organic constituents, methanol and isopropanol. These two compounds are considered to be in an ideal dilute solution consisting of water, sodium hydroxide, and sodium nitrate, which make up the bulk of salt waste. The partial pressure was determined using Henry's constants for methanol and isopropanol, and vapor pressure for water, sodium hydroxide, and sodium nitrate at the stated temperature and pressure. The mole fraction of each component in the vapor is the mole fraction in the liquid times the partial pressure over the total pressure. The flow rate of each component is then determined from the flow rate of the vent gas. Process vessel vent information for the 241-96H reactor tanks has been incorporated into this revision of the calculation.

Results:

For the case of 512-S Only ARP, using the average feed and high cesium feed, the calculated number of filtration batches processed to reach 5 wt% solids in the heel is 27 batches. For the worst inhalation dose case (Tank 33 with 1200 mg/L sludge) feed the number of filtration batches processed to reach 5 wt% solids in the heel is 17 batches for 512-S Only ARP. For the 512-S Only configuration a filtration batch is defined as one 3,800 gallon LWPT batch, following MST treatment, processed in a 42-hour batch cycle time at 512-S. The cycle time layout for 512-S is included in Appendix AC.

For the case of 241-96H with 512-S ARP, using the average feed and high cesium feed, the calculated number of reactor/filtration batches processed to reach 5 wt% solids in the LWPT heel is 13 batches. For the worst inhalation dose case (Tank 33 with 1200 mg/L sludge) feed the number of filtration batches processed to reach 5 wt% solids in the heel is 9 batches for 241-96H with 512-S ARP. For the 241-96H/512-S configuration a filtration batch is defined as two 3,800 gallon MST Strike Tank batches, following MST treatment, processed in a 32-hour cycle time at 512-S. The cycle time layout for 241-96H with 512-S ARP is included in Appendix AD.

The volumes associated with transfers into and out of the 512-S ARP option are listed in Table 1 for the average feed case with a 24-hour MST strike time:

Table 1: Total Volumes per Batch (gallons)

Stream	Volume per Batch (gal)
Spent Filter Cleaning Solution to LPPPPT	2,905
15 wt% MST Slurry Addition	10
Fresh Waste Addition	3,303
Dilution Water/Caustic Addition	487
Filtrate to LWHT	3,738
Solids Wash Water	4,425
Spent Wash Water from Solids Washing	4,425
Total Transfers to LPPPPT	3,861
Total to SRAT 512-S Only ARP	657

Table 2 presents a summary of the salt waste throughput rates for various 512-S ARP options contained in the appendices of this calculation:

Table 2: Salt Waste Throughput for 512-S ARP Options

512-S Option	Crossflow Filter Media	Salt Waste Throughput (gpm)
24-hr MST Strike Average Feed	0.5 micron	1.27
8-hr MST Strike Average Feed	0.5 micron	2.01
4-hr MST Strike Average Feed	0.5 micron	2.36
Filter Only / No MST Strike Average Feed	0.5 micron	3.78
24-hr MST Strike Average Feed with 0.1 Micron Filter	0.1 micron	1.60
8-hr MST Strike Average Feed with 0.1 Micron Filter	0.1 micron	3.00
4-hr MST Strike Average Feed with 0.1 Micron Filter	0.1 micron	3.84
Filter Only / No MST Strike Average Feed with 0.1 Micron Filter	0.1 micron	8.17
24-hr MST Strike Average Feed with 0.036 gpm/ft2 Filter Flux	0.5 micron	1.48
8-hr MST Strike Average Feed with 0.036 gpm/ft^2 Filter Flux	0.5 micron	2.58
4-hr MST Strike Average Feed with 0.036 gpm/ft^2 Filter Flux	0.5 micron	3.18
Filter Only / No MST Strike Average Feed with 0.036 gpm/ft^2 Filter Flux	0.5 micron	5.89

Table 3 presents a summary of the salt waste throughput rates for various 241-96H with 512-S ARP options contained in the appendices of this calculation:

Table 3: Salt Waste Throughput for 241-96H with 512-S ARP Options

241-96H Option	Crossflow Filter Media	Salt Waste Throughput (gpm)
4-hr, 8-hr and 24-hr MST Strike Average Feed	0.5 micron	3.17
24-hr MST Strike Average Feed with 0.1 Micron Filter	0.1 micron	3.36
8-hr MST Strike Average Feed with 0.1 Micron Filter	0.1 micron	6.57
4-hr MST Strike Average Feed with 0.1 Micron Filter	0.1 micron	6.57
24-hr MST Strike Average Feed with 0.036 gpm/ft^2 Filter Flux	0.5 micron	3.36
4-hr and 8-hr MST Strike Average Feed with 0.036 gpm/ft^2 Filter Flux	0.5 micron	4.84

Conclusion:

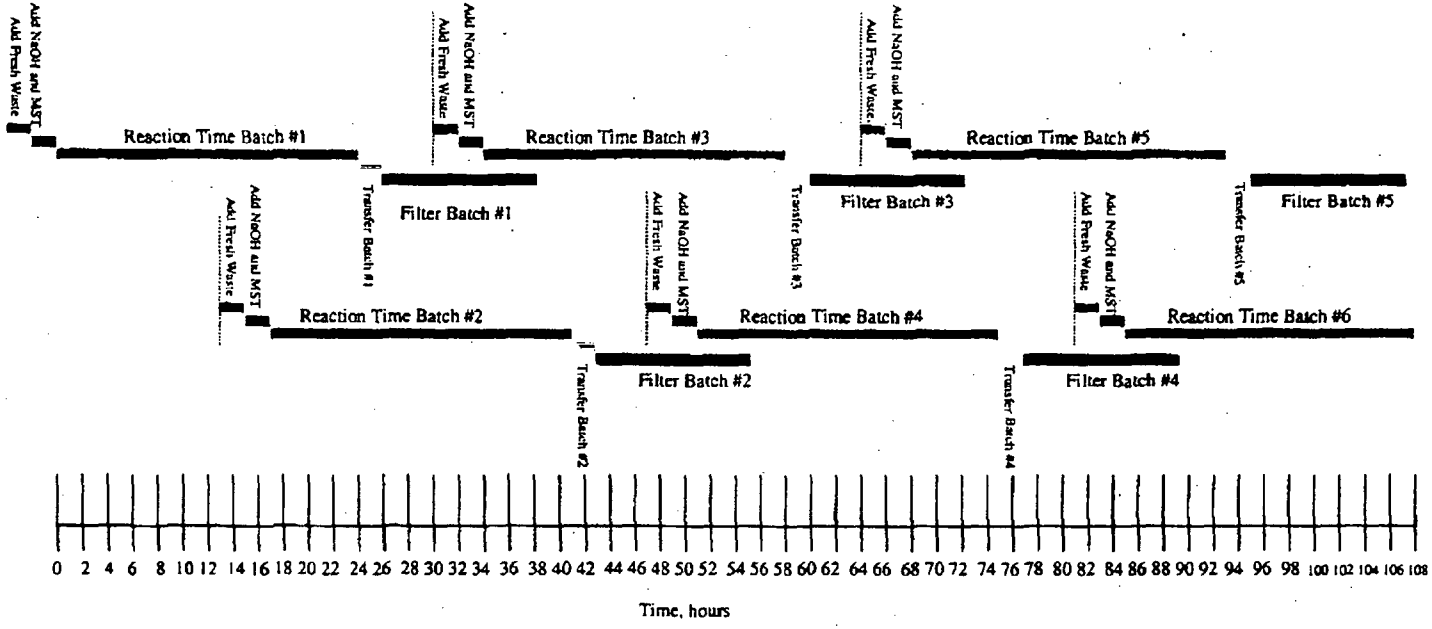
Material balances for ARP Facility Options 512-S Only ARP and 241-96H with 512-S ARP have been calculated for future radioactive operations of the respective plant configurations. The material balance tables in the Appendices A through F may be incorporated into process flow diagrams for the 512-S Only ARP and 241-96H with 512-S ARP options. It should be noted that the flowrates, batch sizes and cycle times calculated herein are nominal values and differ slightly from actual values based on current and future facility configurations for both 512-S and 241-96H. Material Balances are contained in Appendices G through AB for information to show the salt waste flowrates achievable with varying of the MST Strike time (0 to 24 hours), deployment of a 0.1 micron filter at 512-S and use of the time–averaged filter flux (0.036 gpm/ft^2) for the 0.5 micron filter at 512-S.

Attachments:

- **Appendix A** -Detailed Flows for Actinide Removal Process 512-S Only ARP using the Average Case Feed.
- **Appendix B** - Detailed Flows for Actinide Removal Process 512-S Only ARP using the Worst Inhalation Dose Case Feed
- **Appendix C** - Detailed Flows for Actinide Removal Process 512-S Only ARP using the High Cesium Case Feed.
- **Appendix D** - Detailed Flows for Actinide Removal Process 241-96H with 512-S ARP using the Average Case Feed.
- **Appendix E** - Detailed Flows for Actinide Removal Process 241-96H with 512-S ARP using the Worst Inhalation Dose Case Feed.

Appendix AD

241-96H with 512-S ARP - 32 Hour Cycle Time



APPROVED for Release for Unlimited (Release to Public)

RESPONSE TO RAI COMMENT 15
ROADMAP TO REFERENCES

REFERENCED DOCUMENT	*EXCERPT LOCATION	REMARK
Cook et al. 2005	Excerpt enclosed following response	
d'Entremont and Drumm 2005	Excerpt enclosed following response	
d'Entremont and Drumm 2005	Excerpt enclosed following response	Total curie values for Cs-137, alpha emitting TRU, Sr-90, Se-79, Tc-99, Sn-126, I-129, and Np-237 extracted directly from Table A-11 on pages 33 and 34. Insoluble curies sent during DDA were calculated by using the insoluble solids concentrations from Table A-7, multiplying by the post settling insoluble solids concentration of 200 mg/L, multiplying by 3.785 L/gal, and then multiplying each tank by the number of DDA gallons from that tank shown in Table A-1 (Tank 41 = 844 kgal, Tank 25 = 1470 kgal, Tank 28 = 868 kgal)
Drumm et al. 2004	Excerpt included in response	Data from Table 12 of document.
Fowler 1981	Excerpt enclosed following response	Value of <0.1 g/L was converted to <100 mg/L
Georgeton and Hester 1995	Excerpt enclosed following response	
Martino 2005	Excerpt included in response	Figure 1 of document used.
Walker and Hamm 1983	Excerpt enclosed following response	Three Tank 24 sample results from Table I.A (59, 111, and 67 ppm) were averaged (79 ppm) and multiplied by the average density (1.30 g/ml). This value (1.03E-04 g/ml) was converted to 103 mg/L

*Excerpt Locations:

1. Excerpt included in response: The excerpt is included within the text of the response or is appended to the response.
2. Excerpt enclosed following response: The excerpt is enclosed on a separate sheet or sheets following the response.
3. Representative excerpt(s) enclosed following response: Representative excerpts from a document that is wholly or largely applicable are enclosed following the response.
4. Other

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Revision 0

KEY WORDS: Performance Assessment
Low-level Radioactive Waste Disposal

SPECIAL ANALYSIS: REVISION OF SALTSTONE VAULT 4 DISPOSAL LIMITS (U)

PREPARED BY:
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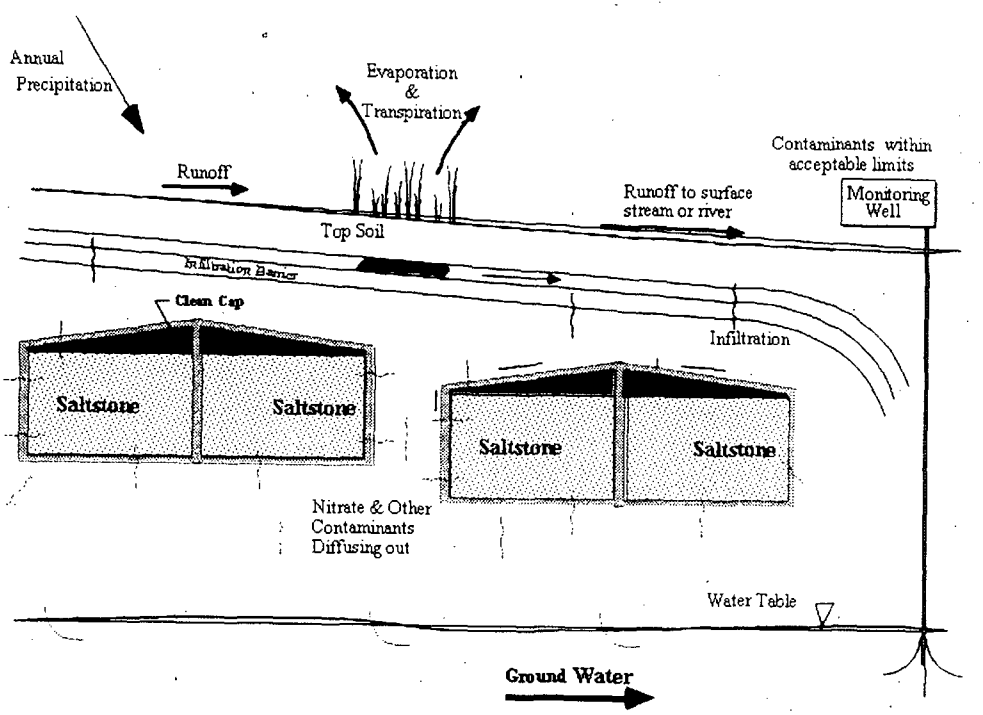
MAY 26, 2005



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Prepared for the U.S. Department of Energy Under Contract Number DE-AC09-96SR18500

SRNL
SAVANNAH RIVER NATIONAL LABORATORY

Table 7-7. Comparison of 10,000-Year Limits from This Analysis and 2002 SA

Radionuclide	New SA Limit, Ci	2002 SA Limit, Ci/Vault[a]	Estimated Inventory, Ci
C-14	4.4E+07	1.2E+04[b]	4.4E+00
Cs-137	6.0E+06	1.0E+09	1.3E+06
I-129	2.2E+02	1.4E+00	8.1E-01
Np-237	6.7E+04	6.9E+03	7.2E-01
Se-79	1.0E+03	2.7E+02	2.0E+00
Sn-126	1.2E+03	1.0E+03	2.7E+00
Sr-90	2.4E+16	No Limit	1.2E+05
Tc-99	3.7E+13	2.8E+04	9.8E+01

[a] From Table 8-1 of Cook et al. 2002. Groundwater limits have been converted from total Ci to Ci/vault by dividing by 14.5.

[b] Cook and Kaplan 2003.

7.4 Projected Vault 4 Impacts Compared to 10 CFR 61 Performance Objectives

Section 3116 of the Ronald W. Reagan NDAA for Fiscal Year 2005 (U.S. Congress 2004) requires, in part, that certain USDOE High Level Wastes that are shown to not need the degree of isolation provided by a geological repository be managed to comply with the performance objectives of 10 CFR 61 (CFR 2004). This section will compare estimated impacts from the disposal of Saltstone in Vault 4 with two of these performance objectives.

There are five performance objectives stated in 10 CFR 61. Only two, protection of the general population from release of radioactivity (i.e., 10 CFR 61.41) and protection of individuals from inadvertent intrusion (i.e., 10 CFR 61.42) are pertinent for comparison with results of a performance assessment calculation such as those presented in this SA.

7.4.1 10 CFR 61 Performance Objectives

Two of the four performance objectives in 10 CFR 61 are pertinent to this discussion. They are 10 CFR 61.41 and 10 CFR 61.42.

10 CFR 61.41 states:

Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.

10 CFR 61.42 states:

Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed.

The dose calculations in this SA use newer dose methodology than that stated in the performance objective for protection of the public. However, the NRC has stated: "The dose methodology used

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Paul D. d'Entremont
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Radionuclide Concentrations in Saltstone

P. D. d'Entremont, 766-H
M.D. Drumm, 766-H

Approval:

for

L. B. Romanowski, Manager,
CBU Salt Disposition Planning

APPROVED for Release for
Unlimited (Release to Public)

Westinghouse Savannah River Company
Closure Business Unit
Planning Integration & Technology Department
Aiken, SC 29808

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Table A- 1: Interim Strategy Batch Summary

Saltstone Batch	Transfers	Salt volume (kgal)	Total Activity (kCi)	Total ^{137}Cs Activity (kCi) [a]
Batch 0	Tank 50	750	[b]	[b]
Batch 1	Tank 41→49→50	422	460	230
	Recycle→50	828	[b]	[b]
	Tank 50→SPF	1250	460	230
Batch 2	Tank 48→50	91	310	155
	Recycle→50	653	[b]	[b]
	NaOH→50	31	[b]	[b]
	Tank 50→SPF	775	310	155
Batch 3	Recycle→48→50	1800	523	262
	Tank 50→SPF	1800	523	262
Batch 6 [c]	Tank 25→41 [c]	619	1747	874
Batch 4	Tank 49	422	460	230
	Tank 25→49	507	377	189
	Tank 49→50	502	438	219
	Recycle→50	638	[b]	[b]
	Tank 50→SPF	1140	438	219
Batch 5	Tank 49→50	494	431	216
	Recycle→50	641	[b]	[b]
	Tank 50→SPF	1135	431	216
Batch 6	Tank 28→48	407	1108	554
	Tank 25→41→48	454	1044	522
	Recycle→48	222	[b]	[b]
	Tank 48→ARP/MCU	1083	2151	1076
	ARP/MCU→50→SPF	1440	180	90
Batch 7	Tank 25→49	958	45	23
	Recycle→49	267	[b]	[b]
	Tank 49→50→SPF	1225	45	23
Batch 8	Tank 24→48	1000	1260	630
	Recycle→48	53	[b]	[b]
	Tank 48→ARP/MCU	1053	1260	630
	ARP/MCU→50→SPF	1400	105	53
Batch 9	Tank 28→49	868	259	130
	Recycle→49	362	[b]	[b]
	Tank 49→50→SPF	1230	259	130

Tank 41

422 + 422 = 844 kgal

Tank 25

507 + 958 = 1470 kg

Tank 28

[a] Assumed half of the total activity

[b] Assumed to have neglible contribution to total activity

[c] Higher activity first dissolution held in Tank 41 until ARP/MCU becomes available for Cs-137 treatment

Table A- 7: Insoluble Solids Composition

Ci/mg	Tank 41	Tank 25	Tank 28	
H-3	No Data	No Data	No Data	
C-14	No Data	3.43E-12	3.43E-12	
Co-60	2.02E-08	5.84E-09	5.84E-09	
Ni-59	8.79E-11	2.01E-10	2.01E-10	
Ni-63	8.35E-09	1.97E-08	1.97E-08	
Se-79	6.82E-11	1.67E-11	1.67E-11	
Sr-90	4.96E-06	1.08E-06	1.08E-06	
Y-90	4.96E-06	1.08E-06	1.08E-06	
Nb-94	1.22E-14	8.84E-15	8.84E-15	
Tc-99	1.15E-09	2.89E-10	2.89E-10	
Ru-106	1.32E-12	4.13E-10	4.13E-10	
Rh-106	1.32E-12	4.13E-10	4.13E-10	
Sb-125	2.88E-09	7.80E-09	7.80E-09	
Sn-126	6.24E-11	3.09E-11	3.09E-11	
I-129	4.00E-15	1.37E-15	1.37E-15	
Cs-134	2.32E-10	6.24E-11	6.24E-11	
Cs-135	7.71E-13	1.93E-13	1.93E-13	
Cs-137	2.68E-07	7.37E-08	7.37E-08	
Ba-137m	2.54E-07	6.97E-08	6.97E-08	
Ce-144	1.80E-13	1.95E-10	1.95E-10	
Pr-144	1.80E-13	1.95E-10	1.95E-10	
Pm-147	7.86E-08	1.41E-07	1.41E-07	
Eu-154	8.12E-08	7.17E-09	7.17E-09	
Th-232	No Data	No Data	No Data	
U-232	No Data	5.53E-14	5.53E-14	
U-233	No Data	1.68E-19	1.68E-19	
U-234	5.23E-12	5.37E-19	5.37E-19	
U-235	6.05E-14	1.59E-13	1.59E-13	
U-236	1.50E-12	2.05E-14	2.05E-14	
U-238	4.14E-15	1.91E-11	1.91E-11	
Np-237	1.56E-11	4.93E-14	4.93E-14	*
Pu-238	8.55E-08	1.02E-07	1.02E-07	*
Pu-239	No Data	1.59E-08	1.59E-08	*
Pu-240	No Data	3.56E-09	3.56E-09	*
Pu-241	No Data	8.38E-08	8.38E-08	
Pu-242	No Data	7.10E-13	7.10E-13	*
Am-241	3.89E-09	3.60E-09	3.60E-09	*
Am-242m	4.74E-12	No Data	No Data	*
Cm-244	4.94E-11	1.03E-12	1.03E-12	*
Cm-245	4.09E-15	4.78E-19	4.78E-19	*
Na-22	5.70E-13	1.57E-13	1.57E-13	
Al-26	3.01E-13	8.28E-14	8.28E-14	
Te-125m	7.04E-10	1.90E-09	1.90E-09	
Sb-126	8.73E-12	4.33E-12	4.33E-12	

* = TRU Alpha

Ci/mg	Tank 41	Tank 25	Tank 28	
Sb-126m	6.24E-11	3.09E-11	3.09E-11	
Sm-151	2.20E-07	6.05E-08	6.05E-08	
Eu-152	1.06E-09	2.92E-10	2.92E-10	
Eu-155	1.24E-08	3.42E-09	3.42E-09	
Ra-226	1.18E-17	1.21E-24	1.21E-24	
Ra-228	No Data	No Data	No Data	
Ac-227	1.38E-17	3.63E-17	3.63E-17	
Th-229	No Data	4.79E-22	4.79E-22	
Th-230	1.44E-15	1.48E-22	1.48E-22	
Pa-231	3.84E-17	1.01E-16	1.01E-16	
Pu-244	No Data	3.24E-15	3.24E-15	*
Am-243	3.56E-12	9.77E-13	9.77E-13	*
Cm-242	3.93E-12	No Data	No Data	*
Cm-243	2.08E-12	5.72E-13	5.72E-13	*
Cm-247	4.01E-22	1.10E-22	1.10E-22	*
Cm-248	4.18E-22	1.15E-22	1.15E-22	*
Bk-249	3.06E-29	8.39E-30	8.39E-30	*
Cf-249	2.32E-21	6.37E-22	6.37E-22	*
Cf-251	7.93E-23	2.18E-23	2.18E-23	*
Cf-252	2.57E-24	7.07E-25	7.07E-25	*

* = TRU Alpha

Each DDA dissolution batch total activity is the sum of the supernatant contribution, the saltcake contribution and the insoluble solids contribution. The total activity of the salt solution created in each of these batches is then added to the total activity of the DWPF recycle used for aggregation/adjustment to give the total activity sent to Saltstone for each batch. The ARP/MCU batches are calculated in a similar way, with the exception that the insoluble solids are not included because they are filtered out of solution (It was assumed that solids passing through the filter are negligible).. MCU is assumed to achieve a cesium decontamination factor of 12. This is applied to all of the cesium isotopes as well as ^{137m}Ba, the short lived daughter product of ^{137}Cs[15]. Although ARP will have the capability to perform a Monosodium Titanate (MST) strike to lower the soluble strontium and actinide concentrations, none was assumed for this calculation. This methodology was applied to Batches 1, 4, 5, 6, 7 and 9, all of which involve the dissolution of saltcake.

Batch 0, 2, 3 and 8 do not involve salt dissolution. Batch 0 involves the processing of the low-level waste stored in Tank 50. For this batch, the current concentration of Tank 50 supernatant is multiplied by the future volume of supernatant in Tank 50 estimated in the Interim Strategy. Batches 2 and 3 involve the aggregation of waste currently in Tank 48 with DWPF recycle. For Batch 2, a volume of Tank 48 waste and recycle are given so the total activity sent to Saltstone in this batch is the sum of these two streams. Batch 3 involves a heel washing so the total volume of recycle sent into Tank 48 is equal to the total volume of solution transferred from Tank 48 to Saltstone. Conservatively, this stream is assumed to include all of the activity remaining in Tank 48 after Batch 2, as well as all the activity in all of the recycle sent to Tank 48. Batch 8 involves the

Table A- 11: Total Activity Sent to Saltstone

Ci	DDA	ARP/MCU	SWPF	Total	
H-3	2.17E+03	5.75E+02	6.62E+03	9.37E+03	
C-14	6.46E+01	1.72E+01	4.37E+02	5.18E+02	
Co-60	4.61E+01	5.92E+00	5.75E+01	1.10E+02	
Ni-59	4.45E-01	3.31E-02	2.34E+00	2.81E+00	
Ni-63	9.48E+01	1.44E+01	1.40E+02	2.50E+02	
Se-79	1.03E+00	1.23E+00	8.68E+01	8.91E+01	
Sr-90	5.72E+03	3.84E+02	1.33E+03	7.43E+03	
Y-90	5.72E+03	3.84E+02	1.33E+03	7.43E+03	
Nb-94	3.15E-05	9.65E-06	6.82E-04	7.23E-04	
Tc-99	3.56E+02	4.55E+02	3.22E+04	3.30E+04	
Ru-106	2.52E+01	3.14E+01	2.22E+03	2.28E+03	
Rh-106	2.52E+01	3.14E+01	2.22E+03	2.28E+03	
Sb-125	1.15E+02	1.27E+02	9.00E+03	9.24E+03	
Sn-126	4.93E+00	6.20E+00	4.39E+02	4.50E+02	
I-129	2.06E-01	1.88E-01	1.74E+01	1.78E+01	
Cs-134	2.44E+03	2.61E+02	5.55E+00	2.71E+03	
Cs-135	4.22E+00	4.44E-01	9.42E-03	4.67E+00	
Cs-137	1.22E+06	1.30E+05	2.76E+03	1.35E+06	
Ba-137m	1.15E+06	1.23E+05	2.61E+03	1.28E+06	
Ce-144	4.13E-01	8.17E-02	5.78E+00	6.27E+00	
Pr-144	4.13E-01	8.17E-02	5.78E+00	6.27E+00	
Pm-147	3.47E+02	5.29E+01	3.74E+03	4.14E+03	
Eu-154	7.64E+01	1.25E+01	8.85E+02	9.74E+02	
Th-232	6.52E-06	2.80E-07	1.04E-01	1.04E-01	
U-232	9.93E-05	5.59E-09	2.13E-02	2.14E-02	
U-233	9.86E-01	8.84E-03	1.22E+00	2.22E+00	
U-234	3.07E+00	9.44E-03	8.34E-01	3.91E+00	
U-235	6.16E-03	1.50E-04	5.75E-02	6.38E-02	
U-236	1.43E-01	1.73E-03	1.58E-01	3.03E-01	
U-238	6.38E-02	8.88E-04	5.00E+00	5.07E+00	
Np-237	5.74E-01	7.83E-03	1.53E+00	2.11E+00	*
Pu-238	3.78E+03	4.71E+01	9.78E+03	1.36E+04	*
Pu-239	4.43E+01	6.93E-01	6.10E+02	6.55E+02	*
Pu-240	1.08E+01	2.36E-01	1.64E+02	1.75E+02	*
Pu-241	2.28E+02	4.14E+00	6.80E+03	7.03E+03	
Pu-242	1.77E-03	2.64E-05	1.71E-01	1.72E-01	*
Am-241	1.29E+01	5.01E+00	7.70E+01	9.49E+01	*
Am-242m	5.39E-03	2.89E-03	4.44E-02	5.27E-02	*
Cm-244	1.60E+00	2.00E+00	8.35E+01	8.71E+01	*
Cm-245	1.57E-04	1.97E-04	8.22E-03	8.58E-03	*
Na-22	2.39E+02	8.55E+01	4.73E+03	5.05E+03	
Al-26	8.98E-01	3.80E-01	2.22E+01	2.35E+01	
Te-125m	2.81E+01	3.10E+01	2.20E+03	2.26E+03	

* = TRU Alpha

Ci	DDA	ARP/MCU	SWPF	Total	
Sb-126	6.91E-01	8.68E-01	6.15E+01	6.30E+01	
Sb-126m	4.93E+00	6.20E+00	4.39E+02	4.50E+02	
Sm-151	3.00E+02	5.93E+01	4.19E+03	4.55E+03	
Eu-152	1.45E+00	2.87E-01	2.03E+01	2.20E+01	
Eu-155	1.70E+01	3.35E+00	2.37E+02	2.57E+02	
Ra-226	2.44E-01	2.13E-08	1.27E+01	1.30E+01	
Ra-228	6.52E-06	2.80E-07	1.04E-01	1.04E-01	
Ac-227	1.40E-06	3.42E-08	1.77E-05	1.91E-05	
Th-229	2.80E-03	2.52E-05	4.70E-03	7.53E-03	
Th-230	1.49E-03	2.60E-06	3.38E-02	3.53E-02	
Pa-231	3.90E-06	9.49E-08	4.92E-05	5.32E-05	
Pu-244	1.16E-05	1.21E-07	7.85E-04	7.96E-04	*
Am-243	4.85E-03	9.58E-04	1.47E-02	2.05E-02	*
Cm-242	4.46E-03	2.37E-03	9.85E-02	1.05E-01	*
Cm-243	2.84E-03	5.61E-04	2.33E-02	2.67E-02	*
Cm-247	5.48E-13	1.08E-13	4.49E-12	5.15E-12	*
Cm-248	5.71E-13	1.13E-13	4.68E-12	5.36E-12	*
Bk-249	4.17E-20	8.23E-21	5.81E-19	6.31E-19	*
Cf-249	3.16E-12	6.24E-13	4.41E-11	4.79E-11	*
Cf-251	1.08E-13	2.14E-14	1.51E-12	1.64E-12	*
Cf-252	3.51E-15	6.93E-16	4.90E-14	5.32E-14	*

* = TRU Alpha

Table A- 12: Concentrations Sent to Saltstone

Ci/gal	DDA	ARP/MCU	SWPF	Total
H-3	2.33E-04	2.03E-04	6.91E-05	8.68E-05
C-14	6.94E-06	6.05E-06	4.56E-06	4.80E-06
Co-60	4.96E-06	2.09E-06	6.00E-07	1.01E-06
Ni-59	4.78E-08	1.17E-08	2.44E-08	2.61E-08
Ni-63	1.02E-05	5.06E-06	1.47E-06	2.31E-06
Se-79	1.11E-07	4.32E-07	9.06E-07	8.25E-07
Sr-90	6.14E-04	1.35E-04	1.39E-05	6.88E-05
Y-90	6.14E-04	1.35E-04	1.39E-05	6.88E-05
Nb-94	3.38E-12	3.40E-12	7.12E-12	6.70E-12
Tc-99	3.82E-05	1.60E-04	3.36E-04	3.06E-04
Ru-106	2.71E-06	1.10E-05	2.32E-05	2.11E-05
Rh-106	2.71E-06	1.10E-05	2.32E-05	2.11E-05
Sb-125	1.24E-05	4.48E-05	9.39E-05	8.56E-05
Sn-126	5.30E-07	2.18E-06	4.58E-06	4.17E-06
I-129	2.21E-08	6.62E-08	1.81E-07	1.65E-07
Cs-134	2.63E-04	9.20E-05	5.79E-08	2.51E-05
Cs-135	4.53E-07	1.56E-07	9.84E-11	4.33E-08
Cs-137	1.31E-01	4.58E-02	2.89E-05	1.25E-02
Ba-137m	1.24E-01	4.34E-02	2.73E-05	1.18E-02
Ce-144	4.44E-08	2.88E-08	6.03E-08	5.81E-08

9. Appendix B—Assumption Summary for Curie Balance

This section describes the assumptions used in the calculations in this report. Most of these assumptions are described elsewhere in the report, so most of the information in this section is redundant. The purpose of the section is to capture all the assumptions in one place to facilitate easier understanding.

The following assumptions made for Tanks 41, 25, and 28 were taken directly from the Interim Strategy[10]:

- ^{137}Cs concentrations and total curies
- Salt levels
- Interstitial liquid is 30% of saltcake volume

For soluble radionuclides, the fraction of the original curies in the tank that is transferred in each batch of DDA is the same as the fraction of ^{137}Cs curies transferred.

Supernatant activities are taken from Tank Radionuclide Inventories[11], For each radionuclide in each tank, the total radionuclide inventory was divided by the total supernatant inventory to calculate the concentration of that radionuclide in the tank..

Due to the dynamic nature of Tank 41, the Tank 41 supernatant concentration was calculated separately. To estimate the Tank 41 supernatant concentration before salt dissolution activities began, the Tank 41 pre-dissolution supernatant activity given in the Interim Strategy (2.5 Ci/gal) was used along with the methodology in Tank Radionuclide Inventories[11], i.e., the majority of radionuclides are calculated on a ratio to ^{137}Cs basis, and some are constant for all supernatant.

The only nuclides of consequence for saltcake are ^{14}C, ^{22}Na and ^{26}Al, which are assumed to be at the same concentration in all tanks. The saltcake activity was taken from the Tank Radionuclide Inventories[11]. The saltcake inventories for all other radionuclides are negligible and were not included in the calculation.

The volume of saltcake dissolved by each batch was determined from the volume of salt solution sent to each batch, 1.0 gal of saltcake makes 2.8 gal of salt solution.[12][13]

Composition of sludge[11] was converted from the given total radionuclide inventory and total mass of dry sludge, to an activity per mass basis. Tank 41 had tank specific sludge, Tanks 25 and 28 are assumed to have the same composition as Tank 26 because Tank 26 was the evaporator feed tank when the salt in Tanks 25 and 28 was deposited.

Salt solution from DDA tanks contains 200 mg/L of sludge (after dissolution, starts out at 600 mg/L[13] but is reduced to 200 after settling[14]).

Volumes of each batch, both salt solution and DWPF recycle are taken from the Interim Strategy. DWPF recycle is assumed to have the same composition as Tank 21[11].

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CLASSIFICATION: U
Does not contain UCNI
Paul D. d'Entremont
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Radionuclide Concentrations in Saltstone

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Approval:

for

L. B. Romanowski, Manager,
CBU Salt Disposition Planning

APPROVED for Release for
Unlimited (Release to Public)

Westinghouse Savannah River Company
Closure Business Unit
Planning Integration & Technology Department
Aiken, SC 29808

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along with the methodology listed in Reference 11 to estimate the baseline Tank 41 supernatant composition listed in Table A- 5. Due to the limited saltcake characterization data available, all Tank Farm saltcake is assumed to have the same composition, therefore the Tank 41 radionuclide concentrations calculated from Reference 11 is used.

Table A- 5: Tank 41 Supernatant Inventory Before Salt Dissolution

Ci			
H-3	1.40E+02	Pu-239	No Data
C-14	2.46E+00	Pu-240	No Data
Co-60	1.44E+00	Pu-241	No Data
Ni-59	1.95E-02	Pu-242	No Data
Ni-63	3.49E+00	Am-241	2.95E+00
Se-79	7.23E-01	Am-242m	1.70E-03
Sr-90	2.40E+02	Cm-244	1.18E+00
Y-90	2.40E+02	Cm-245	1.16E-04
Nb-94	5.69E-06	Na-22	1.64E+01
Tc-99	2.68E+02	Al-26	1.05E-01
Ru-106	1.85E+01	Te-125m	1.83E+01
Rh-106	1.85E+01	Sb-126	5.12E-01
Sb-125	7.50E+01	Sb-126m	3.66E+00
Sn-126	3.66E+00	Sm-151	3.50E+01
I-129	1.38E-01	Eu-152	1.69E-01
Cs-134	1.85E+03	Eu-155	1.98E+00
Cs-135	3.14E+00	Ra-226	4.72E-01
Cs-137	9.21E+05	Ra-228	No Data
Ba-137m	8.72E+05	Ac-227	4.04E-07
Ce-144	4.82E-02	Th-229	No Data
Pr-144	4.82E-02	Th-230	1.29E-03
Pm-147	3.12E+01	Pa-231	1.12E-06
Eu-154	7.39E+00	Pu-244	No Data
Th-232	No Data	Am-243	5.65E-04
U-232	No Data	Cm-242	1.41E-03
U-233	No Data	Cm-243	3.31E-04
U-234	1.53E-01	Cm-247	6.37E-14
U-235	1.77E-03	Cm-248	6.64E-14
U-236	4.39E-02	Bk-249	4.85E-21
U-238	1.21E-04	Cf-249	3.68E-13
Np-237	4.57E-01	Cf-251	1.26E-14
Pu-238	2.50E+03	Cf-252	4.09E-16

The DDA process will include a small amount of entrained insoluble solids that will be sent to Saltstone. The assumed entrainment rate for these insoluble solids in the salt solution is 600 mg/L as it arrives in the receipt tank. This is the entrainment rate that has historically been used a design bases for salt planning[13]. Although this concentration was originally used as a processing upper bound to protect filter performance in the In-Tank

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July 16, 2004

Recommended Waste Characterization System (WCS) Chemical and Radionuclide Attribution to SRS Salt Solids

Prepared by: M. D. Drumm, CBU Flowsheet Development & Optimization — Date 7-22-04

Prepared by: H. Q. Tran, Salt Processing Engineering — Date 7-22-04

Prepared by: J. R. Hester, F&H Process Support Engineering — Date 7/26/04

Radionuclide Portion Reviewed by: Q. L. Nguyen, Salt Processing Eng. — Date 07/22/04

Chemical Portion Reviewed by: J.A. Pike, CBU FD&O — Date 7/22/04

Approved by: S. J. Robertson, Manager, CBU FD&O — Date 8/24/04

Approved by: E. J. Freed, Manager, F&H Process Support Engineering — Date 8/3/04

Additionally, the bulk of the Sr-90 and the actinides in these samples were found to be associated with dry salt, but this finding can be explained by the presence of insoluble solids (2.582E-03 weight fraction[8]), which WCS already attributes to salt. Note that the insoluble solid composition does not account for the C-14, U-235, or U-238. Carbon occurs most dominantly in the crystalline salt solids as carbonates and less so as oxalates. C-14 should be added to the salt composition in WCS. Uranium is known to precipitate when saltcake is formed via evaporation, thus, is present in saltcake as sodium diurinate.[13, 14] This component is generally considered part of the insoluble solids in WCS and, therefore, the composition of insoluble solids should be changed to include U-235 and U-238.

Recommended changes to WCS radionuclide composition are shown in Table 14. Data should be developed to support a similar determination for I-129, which is a constituent of interest to the Integrated Flowsheet Model and the Salt Waste Processing Facility design effort.

Table 12: Major Radionuclide Concentrations in Dry Saltcake

Tank	2F	3F		10H	29H	38H	41H	Average	WCS
pCi/mL	T2F-1-1	T3F-1-1	T3F-1-4	HTF-610	T29H-B6-1	HTF-E-03-114	HTF-E-03-146	pCi/mL	
^{99}Tc	1.13E+04	1.02E+05	5.98E+04	5.38E+04	6.75E+04	8.37E+03	5.04E+03	3.72E+04	0
^{135}Cs	5.87E+02	7.76E+02	8.82E+02	1.29E+02	4.62E+02	5.14E+01	2.35E+02	5.06E+02	0
^{230}Th	1.34E+02	2.03E+03	1.31E+03	6.24E+03	6.49E+02	1.80E+03	1.11E+03	1.28E+03	0
^{232}Th	5.62E-02	1.75E-02	1.07E-02	4.53E+00	1.30E-01	4.79E-01	5.05E-03	1.14E-01	0
^{233}U	6.44E+01	9.75E+02	6.26E+02	1.97E+04	3.75E+03	8.64E+02	1.49E+02	5.36E+02	0
^{234}U	4.16E+01	6.29E+02	4.04E+02	4.07E+03	5.00E+03	1.23E+04		3.35E+03	0
^{235}U	4.97E-01	3.20E-01	1.48E-01	2.91E+01	1.40E+01	1.38E+01		**3.70E+00**	0
^{236}U	3.02E+00	6.52E+00	4.18E+00	2.68E+02	1.88E+02	6.17E+01		1.89E+01	0
^{237}Np	4.69E+00	7.10E+01	4.56E+01	1.12E+03	1.39E+02	6.46E+02	2.29E+01	1.58E+02	0
^{238}U	1.42E+01	1.22E+01	6.73E+00	6.16E+01	9.75E+00	2.99E+02		**8.30E+01**	0
^{239}Pu	1.03E+04	6.26E+03	4.02E+03	2.71E+04	1.86E+04	6.13E+04	3.42E+03	1.71E+04	0
^{240}Pu	1.07E+04	2.30E+04	1.47E+04	7.04E+04	7.33E+03	5.04E+04	1.25E+04	2.23E+04	0
^{241}Pu	8.52E+05	1.04E+07	6.66E+06	3.18E+07	3.31E+06	9.20E+06	5.67E+06	6.55E+06	0
^{242}Pu	2.54E+01	3.85E+02	2.47E+02	1.18E+03	1.23E+02	1.16E+03	2.10E+02	4.06E+02	0
^{14}C	3.57E+03	7.09E+03	8.18E+03	4.79E+04	2.12E+03	1.09E+04	4.66E+02	**6.04E+03**	0
^{90}Sr	2.55E+06	3.59E+06	1.64E+06	1.16E+08	2.79E+07			4.48E+06	9.40E+07
^{137}Cs		3.96E+06	3.91E+07	3.10E+06			1.56E+07	2.15E+07	4.20E+06
^{238}Pu	2.20E+04	1.15E+04	6.17E+03	2.76E+06	2.37E+06	7.02E+06	2.66E+04	1.42E+06	1.20E+06
$^{239/240}Pu$	1.31E+04	4.71E+03	4.14E+03		3.64E+04		1.80E+03	2.97E+04	4.00E+04
^{241}Am	7.28E+03	2.71E+03	2.71E+03	5.07E+04	2.26E+04			4.23E+03	0

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Salt from Tank 1 #1 experiment

V. If the volume of residual solids is ≥ 1 ml, go to step VI. If not add ~10 ml of salt to the solid residue and ~20 ml of H_2O, mix well, centrifuge 30 minutes, discard the solution. Repeat until > 1 ml of insoluble solids is in the cone. Record the total volume of salt required to give ≥ 1 ml solids. (No. of 10 ml portions of salt = 1, total volume salt = 10.0).

Residual Solid > 1 ml

cone broken before weighed!

VI. Wash the residual solid with 15 ml H_2O using mix/centrifuge/decant procedure. Discard wash. Dry solid at 120°C. Reweigh cone + solid. Transfer solid to sample vial. Reweigh empty cone. (Wt cone + solid = 6.7 g, Wt cone = 6.55 g, ~0.1 g) Sample vial No. 14-316

Bulk density: $\frac{13.6\,g}{10.0\,ml} = 1.36$ g/ml wet

$\frac{12.7\,g}{10.0\,ml} = 1.27$ g/ml dry

An additional salt sample will be carried through this procedure because cone was broken before it was weighed after drying. Wt of solid was estimated by weighing sample vial before adding the solid to it, then reweighing the vial. Wt of solid is very approximate.

Wt % H_2O: $\frac{13.6 - 12.7}{13.6} \times 100 = 6.62$ (from I)

The six samples from Step VI will be combined by ACD into a single sample for analysis.

The solid sample will be dissolved by ACD using the Na_2O_2 technique for solid sample dissolution, then analyzed.

Wt % insoluble solid: $\frac{0.1}{13.7} \times 100 = 0.72$ % (from VI).

Vol % insoluble solid: $\frac{1.5}{10.0} = 15$ vol % (from Step III).

ACD obtained ~0.2 g sample ⇒ 1.4 wt % solid wet ~1.6 wt % dry

cont'd on p. 6

EXPERIMENTER [signature] DATE 6/1/81

WITNESS DATE

DATE Fowler 1981

SUBJECT OF EXPT. Analysis of Tank 18 Supernate - Transferred from Tank 19

ACD No. 51-81-75

	Found	(x) Dilution Factor	= Original, molar/l	
NO_3^-	= 1.4 g/l	x 1.95	= 2.91	ρ = 1.20 g/m
NO_2^-	= 0.03 M		= 0.059	
$SO_4^=$	= 0.12 M		= 0.23	
F^-	= 0.04 M		= 0.078	
I^-	= < 0.004 M			
Cl^-	= 0.03 M		= 0.059	
$Al(OH)_4^-$	= 0.101 M		= 0.20	
Free OH^-	= 0.396 M		0.77	
$CO_3^=$	= 0.032 M		0.062	
Pu α	= 2.07E3		4.04E3 d/m/ml	= 0.0018 mCi/l
Tc-99	= 1.4E4		2.7E4 d/m/ml	= ~~1.2E-5 mCi/l~~ 0.012 mCi/l
Sr-90	= 1.63E5		3.18E5 d/m/ml	= 0.14 mCi/l
Se-79	= 1.8E3		3.51E3	= 0.00016 mCi/l 34 mCi/l
Cs	= 2.31E-5 M		4.5E-5	
Mo	< 6x10⁻⁶ M		1.2E-5	
Cr	= 1.32x10⁻⁴ M		2.57E-4	
Na	= 2.15		4.19	
K	= 6.10x10⁻³ M		1.19E-2	
Hg	= 5x10⁻⁵ M		9.8E-8	
Ag	= < 1.6E-6		< 3.1E-6	
Zr	= < 2.7E-3		< 5.27E-3	
Insoluble	~~< 0.1~~		< 0.1 g	

Salt Composition Tank 19

Assumed Species	g/l	Wt. %
$NaNO_3$	247.4	69.9
$NaNO_2$	4.07	1.1
Na_2SO_4	32.66	9.2
NaF	3.28	0.9
NaCl	3.45	0.9
$NaAl(OH)_4$	23.60	6.6
NaOH	30.80	8.7
Na_2CO_3	6.57	1.8
$CaSO_4$	0.0061	0.00
Na_2MoO_4	0.0025	0.00
Na_2CrO_4	0.0412	0.01
KNO_3	1.20	0.3
$NaHgO(OH)$	2.51E-5	0.00
$NaAg(OH)_2$	< 5.1E-4	< 0.00
Na_2ZrO_3	0.641	0.1
Insoluble	< 0.1 g	< 0.0
Total g/l	355.721	

EXPERIMENTER J. R. Fowler DATE 10/20/81

WITNESS DATE

mR

SWM-WCA-94-27

HIGH LEVEL WASTE ENGINEERING
HLW ENGINEERING SUPPORT

WSRC-TR-94-0562

REVISION: 1

KEYWORDS: High Level Waste Engineering, Fission Yield, E-Area Vault, Solid Waste

RETENTION:
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CLASSIFICATION:
UNCLASSIFIED
Does Not Contain UCNI

Paul D. d'Estrem
Authorized Derivative Classifier 1/27/95

CHARACTERIZATION OF RADIONUCLIDES IN HLW SLUDGE BASED ON ISOTOPIC DISTRIBUTION IN IRRADIATED ASSEMBLIES (U)

BY

G. K. GEORGETON

and

J. R. HESTER

ISSUED: January 27, 1995

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dollars and personnel radiation exposure precludes collecting and analyzing a statistically representative number of samples). Only 19 sludge samples have been expressly collected to determine concentration of components in the sludge solids [2]. Any additional sludge sampling, due to the high costs in both funding and personnel exposure, will be limited to more confirmatory application as sludge is removed from tanks and transferred for processing. Thus, a method is required to provide more detailed radioisotope concentration data for HLW sludge.

Method Description

To characterize the radioisotopes in HLW sludge, the concept of a tracer or "key" component will be implemented. All other isotopes can be related to the key component from ratios based on isotopic distribution generated from reactor burnup calculations. The initial distributions are adjusted to account for the effects of Separations processing and for decay. The only data required to use the method is the composition or quantity of the key component in the sludge, and this value can be obtained from estimates, sample analyses, or field dose data converted to quantities of isotopes. An analogous development has previously been used to quantify the amounts of several fission products in solid waste contaminated with HLW supernate [3].

Method Development

Fission Yield Distribution

The basis for the development is the nuclide concentration in fuel and target assemblies following irradiation in SRS reactors. Several different types of assemblies have been irradiated, primarily Mark 16B and Mark 22 as fuel/drivers and Mark 31A and Mark 31B as targets. Over 70% of the waste in the Tank Farms has been generated from processing of these 4 types of assemblies [4]. The remainder is from other targets, scrap product and fuel assemblies from offsite facilities. In Reference [4], the nuclide content of this extraneous material was shown to be similar to that from the 4 main types of assemblies. Further, a review of the nuclide concentration of the various types of assemblies as a function of burnup conditions reflects relatively small differences in the waste stream [5]. Thus, the 4 main types of assemblies are representative of the materials processed and the resultant waste generation. Fuel reprocessed in the HM process (H-Canyon) was represented by the average of the Mark 16B and Mark 22 isotopic distributions. The limited amount of THOREX processing in H-Canyon introduced ^{233}U, which was not included in the average distribution, but was included in the development, as described later. The average radionuclide distribution in the targets processed through the PUREX process (F-Canyon and initial H-Canyon operation) was represented by the average of the Mark 31A and Mark 31B distributions. The distribution of activation products was developed separately, and is discussed below.

In Reference [4], the nuclide content was adjusted to account for processing within the Separations facilities. The actinide content reflects the recovery of particular nuclides within each Canyon. Fission products were assumed to be completely rejected to waste in both canyons, with the exception of ^{129}I, which reflected 60% removal from the waste stream within the canyons. The concentrations of the radionuclides were also decayed to 5 years following discharge of the assemblies from the reactors. The concentration of several nuclides in each of the 4 assemblies (taken directly from Reference [4]) and in the PUREX and HM averages are shown in Table I.

DPST-83-695

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MEMORANDUM

ACC. NO. 105552

July 21, 1983

TO: M. A. EBRA

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FROM: D. D. WALKER, B. A. HAMM DDW BAH

SAMPLE ANALYSES FROM THE FULL SCALE IN-TANK DEMONSTRATION OF THE PRECIPITATION PROCESS

SUMMARY

A full scale demonstration of in-tank salt processing was completed by the Savannah River Plant (SRP) in April 1983. In this test, 427,000 gallons of radioactive salt solution were decontaminated by a combination of precipitation, adsorption, and filtration. At each stage of the demonstration, samples of the salt solution and slurry were processed in the High Level Cells (HLC) and then analyzed by Analytical Development Division (ADD) of the Savannah River Laboratory (SRL). The results of these analyses are reported in this document. It is intended to be a complete listing of analytical information for future interpretive reports.

INTRODUCTION

Between February and April of 1983, a major achievement in high level waste processing was accomplished at the Savannah River Plant. A full scale demonstration of in-tank processing of salt solution was successfully completed. More than 99.9% of the radioactivity in 427,000 gallons of high level waste salt solution was removed by precipitation and adsorption. Salt solution from Tank 24H was transferred to Tank 48H (a new, unused Type IV waste storage tank) for processing. Radioactive cesium was removed by pre-

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TABLE I.A

PHYSICAL PROPERTIES OF THE INITIAL SALT SOLUTION

Property	Sample 1AP[1]	1AD[2]	1BP[3]	1BD[4]	1CV[5]
Density (g/ml)	1.28	1.30	1.31	1.26±.01	1.26±.01
Insoluble Solids (ppm)	59	111	67	--[6]	--[6]
Soluble Solids (wt%)	--	--	--	--	33±1

1 Tank 24H supernate pump sample.

2 Tank 24H dip sample.

3 Tank 24H peristaltic pump sample taken during transfer.

4 Tank 48 dip sample after transfer (cold chemical heel solution included).

5 Tank 48 dip sample after transfer completed.

6 Insoluble solids not measured due to presence of cold chemical heel solution.

RESPONSE TO RAI COMMENT 16
ROADMAP TO REFERENCES

REFERENCED DOCUMENT	*EXCERPT LOCATION	REMARK
Drumm et al. 2004	Excerpt enclosed following response	
Fowler 1982	Excerpt enclosed following response	
Fowler and Cook 1984	Excerpt enclosed following response	
Fowler et al. 1984	Excerpt enclosed following response	
Hester 2004	Excerpt enclosed following response	
Hill 2005	Excerpt enclosed following response	
Rosenberger et al 2005	Other	Provided as a reference in its entirety
Tran 2005	Excerpt enclosed following response	

*Excerpt Locations:

1. Excerpt included in response: The excerpt is included within the text of the response or is appended to the response.
2. Excerpt enclosed following response: The excerpt is enclosed on a separate sheet or sheets following the response.
3. Representative excerpt(s) enclosed following response: Representative excerpts from a document that is wholly or largely applicable are enclosed following the response.
4. Other

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July 16, 2004

Recommended Waste Characterization System (WCS) Chemical and Radionuclide Attribution to SRS Salt Solids

Prepared by: M. D. Drumm, CBU Flowsheet Development & Optimization — Date: 7-22-04

Prepared by: H. Q. Tran, Salt Processing Engineering — Date: 7-22-04

Prepared by: J. R. Hester, F&H Process Support Engineering — Date: 7/26/04

Radionuclide Portion Reviewed by: Q. L. Nguyen, Salt Processing Eng. — Date: 07/22/04

Chemical Portion Reviewed by: J.A. Pike, CBU FD&O — Date: 7/22/04

Approved by: S. J. Robertson, Manager, CBU FD&O — Date: 8/24/04

Approved by: E. J. Freed, Manager, F&H Process Support Engineering — Date: 8/3/04

BACKGROUND

Saltcake in High Level Waste (HLW) tanks consists of crystallized salts with interstitial void space and entrained insoluble solids assumed to be partially sludge solids. In order to determine the composition of the saltcake, the individual parts (saltcake, interstitial supernate, and entrained sludge solids) are first identified and then combined in the appropriate ratios to formulate the final characterization. The interstitial supernate in saltcake is assumed to have the same composition as the free supernate above the saltcake surface. Characterization of free supernate is available for a majority of waste tanks due to routine sampling for corrosion control purposes. Until recent characterization efforts, limited saltcake data existed to characterize the saltcake composition. As a result of this increased saltcake sampling, a discrepancy was found to exist between the current salt crystal composition assumed in the Waste Characterization System (WCS) and that in recent salt core samples.

WCS does not currently attribute radionuclides to the crystal structure of Savannah River Site (SRS) salt. It does ascribe relatively small amounts of Sr-90/Y-90, Cs-137/Ba-137m, Pu-238, and Pu-239 to "insoluble solids", which comprise an estimated two percent of the salt mass. Most of these solids could drop out during salt dissolution without affecting the composition of any liquid phase (supernate) withdrawn for subsequent processing. Recent salt analyses indicate, however, that C-14 and U-235, 238 are integral parts of salt solids. Presumably, therefore, these constituents will dissolve and follow the liquid during supernate removal from a tank.

An enhanced dry saltcake composition is needed to assist with current modeling efforts. This memorandum recommends a chemical composition for dry salt cake and also recommends that C-14, U-235, and U-238 be incorporated into WCS salt solid inventories. The recommended saltcake radionuclide and chemical concentration changes to WCS are shown in the table below.

Isotope	Current WCS (pCi/ml)		New WCS (pCi/ml)	
	Salt	Insolubles	Salt	Insolubles
C-14	0	0	6.04E+03	0
U-235	0	0	0	3.70E+00
U-238	0	0	0	8.30E+01

Chemical Compound	F-Area Saltcake (wt%)	H-Area Saltcake (wt%)	Saltcake (wt%)
$NaNO_3$	66	50	86
$Na_2CO_3 \cdot H_2O$	5.7	3.7	5.7
$NaNO_2$	1.4	11	0.82
$NaAlO_2 \cdot 2H_2O$	7.8	10	2.2
$Na_2C_2O_4$	0.62	0.42	0.45
Na_2SO_4	9.5	5.8	2.9
NaCl	0.51	0.50	0.0068
NaF	0.62	0.34	0.17
NaOH	7.4	16	0.73
Na_3PO_4	0.00040	0.0060	0.59
Total Na	30	32	28

TECHNICAL DIVISION
SAVANNAH RIVER LABORATORY

DPST-82-759

ACC. NO. 149544

MEMORANDUM

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6/27/2005

August 6, 1982

TO: W. V. WRIGHT

FROM: J. R. FOWLER

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UPDATE OF CHEMICAL AND RADIOCHEMICAL COMPOSITION OF DECONTAMINATED SOLUBLE WASTE FROM THE PRECIPITATION PROCESS

Summary

Chemical and radiochemical compositions of decontaminated soluble waste are needed to provide the technical data base for its final disposal. The chemical composition of the soluble waste has been calculated using extensive analytical data that is available for sludge, supernate, salt, and dissolved salt solutions.[1-3] The radiochemical composition in 15-year old soluble waste has been calculated using waste composition data,[1-3] the inventory of actinides,[4] and the curie balance table shown in the Technical Data Summary for the Defense Waste Processing Facility.[5] Experimental data for many of the radionuclides are available for salt and salt solutions.[6-12] In this memorandum, solubility and decontamination factors have been adjusted so that the calculated composition of decontaminated salt is consistent with observed experimental data. This memorandum supersedes DPST-82-547.

Details

I. General Assumptions Used In Calculations

1. In most cases, the basis for radionuclide concentration in aged waste is derived from the radionuclide content of 15-year in-tank waste as shown in Part 3, Item 325 (dated

B. C-14

The level of C-14 in aged waste was calculated from nitrogen impurities in aluminum cladding that goes through F Area (caustic dissolution).[17] A measured value for C-14 in Tank 8F supernate[7] was used to estimate the average level of soluble C-14 in the waste. The concentration of C-14 has been estimated to be $\leq$0.03 nCi/g in decontaminated salt.

C. Cobalt-60, Nickel-59, Nickel-63

The solubility factor for Co-60 was adjusted to yield a concentration in decontaminated salt consistent with experimental data.[12, 13] Neutron activation of naturally occurring Ni-60 is assumed to be the major source of Co-60 in the waste (n, p reaction).[14, 15] The concentration of Co-60 in decontaminated salt has been estimated to be 0.7 nCi/g.

No experimental data is available for the Ni isotopes. Like Co-60, these isotopes are produced from neutron activation of naturally occurring Ni isotopes (n, gamma reactions). Based on activation yields and specific activities relative to Co-60, aged waste was assumed to contain 5.1E-6 Ci/gal of Ni-59 and 5.1E-4 Ci/gal of Ni-63.[14, 15] Because of chemically similar properties, the solubility factor used for Co-60 was also used for these nickel isotopes. In decontaminated salt the concentrations of Ni-59 and Ni-63 have been estimated to be 0.0007 nCi/g and 0.07 nCi/g, respectively.

D. Selenium-79, Technetium-99

Solubility factors for these isotopes were adjusted to yield concentrations in decontaminated salt consistent with experimental data.[6-9, 15] Anion exchange methods to remove Tc-99 are now being investigated. If Tc-99 removal is assumed, a decontamination factor of 10 should be used and the concentration shown for decontaminated salt in the attached tables should be reduced by a factor of 10. The concentrations in decontaminated salt are estimated to be 1 nCi/g for Se-79 and 100 nCi/g for Tc-99.

E. Sr-90/Y-90

The precipitation process effectively reduces Sr-90 (and its Y-90 daughter) to less than 3 nCi/g of salt.[7, 8] Factors were adjusted to yield a concentration consistent with these experimental results and 3 nCi/g of salt was assumed for Sr-90 and Y-90.

DPST-84-343

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SRL Records (4) 773-A
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MEMORANDUM

February 29, 1984

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FROM: J. R. FOWLER/J. R. COOK
mar for JRF JRC

I-129 IN SRP HIGH-LEVEL WASTE AND SALTSTONE

SUMMARY

An earlier tracer study in F-Area showed that a total of 1.3 Ci of I-129 have been sent to the F-Area waste tanks based on the total curies of I-129 that have been processed through F-Area since plant startup.[1] However, only limited data have been available for H-Area.

To improve the data base for H-Area and ultimately for the entire waste inventory, additional soluble waste samples from H-Area waste tanks have been analyzed for I-129. Results from these analyses, earlier analyses of waste samples[2] and the tracer data for F-Area show that the I-129 inventory in high-level waste is significantly less than previously assumed in the DWPF Technical Data Summary.[3,4]

Decontaminated salt to be sent to saltstone will contain an average of 0.14 nCi I-129 per gram of salt. This level is a factor of 5 lower than 0.70 nCi per gram of salt that was calculated from the value shown in the DWPF flowsheet.[4] Based on this source term,

RECORDS ADMINISTRATION
R0962911

DPST-84-343

TECHNICAL DIVISION
SAVANNAH RIVER LABORATORY

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D. D. Walker
~~SRL Records (4)~~ 773-A
PMC File
ACC. NO. ~~460789~~ 141131

MEMORANDUM

February 29, 1984

SRL FILE
RECORD COPY

TO: G. W. WILDS/E. L. ALBENESIUS

FROM: J. R. FOWLER/J. R. COOK
mae for JRF JC

I-129 IN SRP HIGH-LEVEL WASTE AND SALTSTONE

SUMMARY

An earlier tracer study in F-Area showed that a total of 1.3 Ci of I-129 have been sent to the F-Area waste tanks based on the total curies of I-129 that have been processed through F-Area since plant startup.[1] However, only limited data have been available for H-Area.

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DPST-84-334

TECHNETIUM-99 IN SRP HIGH-LEVEL WASTE AND SALTSTONE

by

J.R. Fowler, B.A. Hamm, and J.R. Cook

E. I. du Pont de Nemours & Company
Savannah River Plant
Aiken, South Carolina 29808

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DPST-84-334

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SRL Records (4), 773-A
PMC File, 773-A

ACC. NO. ~~[illegible]~~ 14/122

MEMORANDUM

February 24, 1984b

TO: G. W. WILDS/ E. L. ALBENESIUS

FROM: J. R. FOWLER, B. A. HAMM, J. R. COOK

J R Fowler B.A. Hamm J R Cook

TECHNETIUM-99 IN SRP HIGH-LEVEL WASTE AND SALTSTONE

SUMMARY

Analyses of sludge and soluble waste samples[1-3] and the inventory of sludge[4] and soluble waste[5,6] have been used to estimate the concentration of technetium-99 (Tc-99) in sludge solids and soluble waste. These data were also used to establish if the source term assumptions for Tc-99 in the Defense Waste Processing Facility (DWPF) flowsheet are accurate and determine the fraction of the Tc-99 inventory in the waste that is soluble. This analysis was needed to establish if the present basis for decontaminated salt feed to the saltstone process is correct.[7] These results and the projected leach rate for Tc-99 from saltstone can then be used to establish if Tc-99 must be removed from contaminated supernate.

Results show:

- The inventory of Tc-99 is 31,050 Ci in sludge and soluble waste.

TABLE III

INVENTORY OF SOLUBLE Tc-99 IN THE WASTE TANKS

WASTE COMPONENT	INVENTORY MET. TONS	[Tc-99] nCi/g	TOTAL CURIES Tc-99
H-AREA:			
HM HAW SN	4900	620	3040
HM LAW SN	4400	670	2950
HM CONC. SN	11000	360	3960
HM SALT	19000	80	1520
Al DISS. ADD'N	1800	---	---
H-AREA SOLUBLE WASTE	41100	290 nCi/g	11470
F-AREA:			
PUREX HAW SN	800	680	540
PUREX LAW SN	2500	140	350
COATING WASTE	1100	--	--
PUREX CONC. SN	14000	430	6020
PUREX SALT	21000	60	1260
F-AREA SOLUBLE WASTE	39400	280 nCi/g	8170
TOTAL SOLUBLE WASTE	80500	240 nCi/g	19640

- Tc-99 previously estimated to be 100 nCi/g in soluble waste (DPST-82-759).

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6/27/2005

X-ESR-G-00004
Rev. A

August 30, 2004

TO: E. J. Freed, 703-H

FROM: J. R. Hester, 766H JRH 8/31/04

TECHNICAL RI EW: J. K. Jeffrey, 766-H Jason Jeffrey 8/31/04

APPROVED: D. J. Martin, 766-H D.J. Martin 8/31/04

WCS pernate Radionuclide Concentration Algorithms

INTRODUCTI

Closure Busines Jnit Planning and Execution (P&E) is developing an Integrated Material Balanc id Flowsheet Model to be used for planning and coordination among high level wa process facilities. The model draws data from the Waste Characterization stem (WCS), some of which is not currently included in the system. Therefore, WCS being expanded and upgraded to support the modeling effort. The purpose of this n orandum is to recommend algorithms (rules of thumb) to estimate the concentrations o y radionuclides in supernate, when sample data is unavailable.

SUMMARY

Recent supernat id saltcake liquid analyses from thirteen tanks provide a reasonable, best-estimate b for expanding and improving WCS algorithms for supernate radionuclide con trations.

DISCUSSION

Background

P&E identified t nty key radionuclides important to their model (Attachment A). Of these, WCS sup ate data currently covers all the actinides, except Cm-242, and Cs-137/Ba-137m. I es not cover seven fission/activation products listed in Attachment A.

Recent studies o ee liquid (supernate) from Tanks 13H, 30H, 37H, 39H, 45F, 46F, and 49H [1, 2] and o ltcake liquids from Tanks 3F and 2F [3], 10H [4], 29H [5], 38H [6], and 41H [7] pro an opportunity to expand and improve WCS supernate data.

ENGINEERING DOC. CONTROL - SRS
00811295

X-ESR-G-00004
Rev. A

August 30, 2004

TO:	E. J. Freed, 703-H	
FROM:	J. R. Hester, 766H	JRH 8/31/04
TECHNICAL REVIEW:	J. K. Jeffrey, 766-H	Jason Jeffrey 8/31/04
APPROVED:	D. J. Martin, 766-H	D. J. Martin 8/31/04

WCS Supernate Radionuclide Concentration Algorithms

INTRODUCTION

Closure Business Unit Planning and Execution (P&E) is developing an Integrated Material Balance and Flowsheet Model to be used for planning and coordination among high level waste process facilities. The model draws data from the Waste Characterization System (WCS), some of which is not currently included in the system. Therefore, WCS is being expanded and upgraded to support the modeling effort. The purpose of this memorandum is to recommend algorithms (rules of thumb) to estimate the concentrations of key radionuclides in supernate, when sample data is unavailable.

SUMMARY

Recent supernate and saltcake liquid analyses from thirteen tanks provide a reasonable, best-estimate basis for expanding and improving WCS algorithms for supernate radionuclide concentrations.

DISCUSSION

Background

P&E identified twenty key radionuclides important to their model (Attachment A). Of these, WCS supernate data currently covers all the actinides, except Cm-242, and Cs-137/Ba-137m. It does not cover seven fission/activation products listed in Attachment A.

Recent studies of free liquid (supernate) from Tanks 13H, 30H, 37H, 39H, 45F, 46F, and 49H [1, 2] and of saltcake liquids from Tanks 3F and 2F [3], 10H [4], 29H [5], 38H [6], and 41H [7] provide an opportunity to expand and improve WCS supernate data.

ENGINEERING DOC. CONTROL-SRS
00811295

C-14

C-14 is a minor activation product created in the reactors. It also occurs in nature and is deposited in waste tanks as the liquid takes up CO_2 from the environment. Carbon is mildly soluble (~24 percent) in alkaline media, so C-14 replenishment is expected if fresh liquid is added to a tank. This "buffering" effect should tend to stabilize the C-14 concentration in supernate.

C-14 analyses of free supernate or salt interstitial liquid samples from eight tanks yielded two results (2.69E+02 and 1.71E+03 pCi/mL) above the detection limit (Attachment B, C-14 column). The other analyses indicated "less than" results ranging from 3.43E+02 to 7.11E+03 pCi/mL. Combined, the eight samples averaged 1.76E+03 pCi/mL, with a standard deviation of 2.27E+03 pCi/mL.

A constant value of 1.76E+03 pCi/mL is recommended as a reasonable algorithm for supernate C-14 concentrations.

Co-60

Co-60 is a minor activation product created in the reactors. Cobalt is sparingly soluble (~0.02 percent) in alkaline media; therefore, its concentration in supernate should be low.

Co-60 analyses were performed on free supernate samples from seven tanks, yielding two results (1.90E+03 and 2.74E+03 pCi/mL) above the detection limit (Attachment B, Co-60 column). The other six analyses indicated "less than" concentrations from 3.60E+01 to 1.17E+03 pCi/mL. The average was 1.03E+03 with a standard deviation of 1.02E+03 pCi/mL.

A constant value of 1.03E+03 pCi/mL is recommended as a reasonable algorithm for supernate Co-60 concentrations.

Ni-63

Ni-63 is a minor activation product created in the reactors. Nickel is sparingly soluble (~0.02 percent) in alkaline media; therefore, its concentration in supernate is expected to be low.

Ni-63 analyses were performed on free supernate samples from seven tanks with no results above the detection limit (Attachment B, Ni-63 column). The analyses indicated concentrations of less than 1.14E+02 to 5.72E+03 pCi/mL with an average of 2.50E+03 pCi/mL and a standard deviation of 2.40E+03 pCi/mL.

A constant value of 2.50E+03 pCi/mL is recommended as a reasonable algorithm for supernate Ni-63 concentrations.

CBU-PIT-2005-00127
Rev. 0
May 23, 2005

KEYWORDS:
Waste Characterization Report
Fission Product
Se-79, Tc-99, Sn-126

RETENTION: PERMANENT
CLASSIFICATION: NA
Does not Contain UCNI

Soluble Phase Selenium-79, Technetium-99, and Tin-126 Inventories

P. J. Hill

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Unlimited (Release to Public)
6/23/2005

Westinghouse Savannah River Company
Closure Business Unit
Planning Integration & Technology Department
Aiken, SC 29808

Prepared for U.S. Department of Energy Under Contract No. DE-AC09-96S

1 Summary

Previously, soluble Se-79, Tc-99, and Sn-126 inventories were not tracked in WCS. In 2004, an algorithm for modeling Tc-99 was developed for the Integrated Flowsheet model[6]. This algorithm conservatively overestimates the Tc-99 concentrations. However, a revised estimation method based on analytical data and process history that would project more reliable supernatant inventories is required to support salt solution disposition planning efforts. The purpose of this memorandum is to provide the basis to identify the soluble curie inventory for Se-79, Tc-99, and Sn-126. Using these bases, the projected curie inventories in the supernatant phase for Se-79, Tc-99, and Sn-126 are 8.9E+1 curies, 3.3 E+4 curies, and 4.5E+2 curies respectively.

2 Selenium-79

In 1995, Georgeton and Hester[1] estimated that only 5% of the Se-79 received into the tank farms would be soluble. At the time, only the sludge phase constituents were of concern, and therefore, the soluble portion was not incorporated into WCS. The insoluble portion of the Se-79 (95%) was incorporated into WCS for tracking. As of 5/1/05, the Se-79 sludge phase inventory was 1.6E+3 curies, and the total Se-79 transferred in sludge to DWPF has been 1.1E+2 curies[2]. This is a total WCS tracked sludge inventory of 1.7E+3 curies. Multiplying this by the soluble to insoluble ratio of 0.05 (5% / 95%) yields a supernatant inventory of 8.9E+1 curies. A review of recent supernatant sample results contained in WSRC-TR-2004-00386 indicates that all Se-79 sample analyses reported less than minimum detectable concentrations of Se-79. The lowest detection limit for each tank is shown in Table 1. The average of the lowest detection limit from each tank was 2.3E+3 pCi/ml. If this average concentration is applied to the tank farm inventory of 24M gallons of supernatant (free and interstitial), a total supernatant Se-79 inventory of <2.1E+2 curies is obtained. Since this is in reasonable agreement with the theoretical fission yield total of 8.9E+1 curies, the value of 8.9E+1 curies is recommended for use during salt solution disposal planning.

Table 1 Se-79 Minimum Detection Limits in WSRC-TR-2004-00386, R1

Tank	Lowest Se-79 Detection Limit[3] (pCi/ml)	Dilution Factor[6]	Actual Se-79 (pCi/ml)
13	2.0E+2	2.3	<4.6E+2
30	9.1E+2	2.8	<2.5E+3
37	2.1E+3	2.4	<5.0E+3
39	4.4E+3	1.1	<4.8E+3
45	2.5E+2	3.6	<9.0E+2
46	3.4E+2	2.9	<9.9E+2
49	8.5E+2	1.7	<1.4E+3

CBU-PIT-2005-00050
Rev. 0
February 28, 2005

KEYWORDS:
Waste Characterization Report
Fission Product
I-129

RETENTION: PERMANENT
CLASSIFICATION: NA
Does not Contain UCNI

Supernatant Phase Iodine-129 Inventory

H. Q. Tran

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6/23/2005

Westinghouse Savannah River Company
Closure Business Unit
Planning Integration & Technology Department
Aiken, SC 29808

Prepared for U.S. Department of Energy Under Contract No. DE-AC09-96S

1 Summary

A previous supernatant I-129 inventory was estimated based on a constant I-129 concentration in all waste tanks.[1] However, a revised estimation method based on analytical data and process history would project a more reliable supernatant I-129 inventory. The purpose of this memorandum is to provide the basis to determine the soluble Curie inventory for I-129. Using this basis, the projected I-129 curie inventory in the supernatant phase is 17.4 Ci.

2 Introduction

Projections of the total inventory of I-129 in the SRS Tank Farm were reported in CBU-PIT-2005-00033, Rev. 0.[1] These projections were based on theoretical fission yield data and on the assumption that the I-129 supernatant phase concentration was constant in all waste tanks. Although there were clear uncertainties associated with these bases, the projection approach offered a relatively simple means of estimating total I-129 based on very limited data.

Since the CBU-PIT-2005-00033 document was issued, additional I-129 data were identified and a request for honing in on the supernatant phase I-129 inventory was received. Available analytical supernatant I-129 data are utilized to determine an average I-129 /Cs-137 activity ratio for the supernatant phase. I-129 supernatant inventories are estimated for each waste tank based on the activity ratio and knowledge of the supernatant Cs-137 inventories. Because supernatant Cs-137 concentrations in waste tanks are measured on a regular basis, this projection method is very well suited for estimating I-129.

3 Inputs and Assumptions

Reference date for WCS information: 2/1/2005
Interstitial supernatant volumes accounted for in total supernatant volume, Ref. 2
Volumes of Tanks 26 and 39, the currently H & F Area-Canyon receipt tanks, were updated through 11/2004, Ref. 3
I-129 Half life = 1.57E+07 yr, Ref. 4
I-129 Specific Activity = 1.77E-04 Ci/g, Ref. 4
The interstitial liquid fraction is assumed to be 0.3
Tank 12H is adjusted to be a wet tank

4 Computational Methods

Analytical data listed in Table 1 is utilized to estimate the I-129 inventory in the supernatant phase. The supernatant phase includes the free supernatant liquid, interstitial liquid in saltcake, and interstitial liquid in sludge.

WSRC-RP-92-1360

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RADIOLOGICAL PERFORMANCE ASSESSMENT FOR THE Z-AREA SALTSTONE DISPOSAL FACILITY (U)

Prepared for the

WESTINGHOUSE SAVANNAH RIVER COMPANY
Aiken, South Carolina

by

MARTIN MARIETTA ENERGY SYSTEMS, INC.
EG&G IDAHO, INC.
WESTINGHOUSE HANFORD COMPANY
WESTINGHOUSE SAVANNAH RIVER COMPANY

December 18, 1992

Authorized Derivative Classifier
Date: 10/19/93

Rev. 0

Table C.1-1. Approximate radionuclide content of the waste streams and the Saltstone Disposal Facility

Nuclide	Half-life	Time Units	In-Tank Precipitation Waste Stream[a] Ci/liter	Effluent Treatment Facility Waste Stream[b] Ci/liter	Nominal Blend[c] Ci/liter	Facility Inventory Ci
Tc-99	213000	years	1.0×10^{-4}		8.9×10^{-5}	6.5×10^{4}
Ru-106 + d	368	days	5.0×10^{-5}	5.0×10^{-6}	4.5×10^{-5}	3.3×10^{4}
Cs-137 + d	30.2	years	3.0×10^{-5}	6.0×10^{-6}	2.7×10^{-5}	2.0×10^{4}
H-3	12.3	years	2.0×10^{-5}	7.0×10^{-5}	2.6×10^{-5}	1.9×10^{4}
Sb-125	2.77	years	1.0×10^{-5}	6.0×10^{-8}	8.9×10^{-6}	6.5×10^{3}
Pm-147	2.62	years	6.0×10^{-6}	5.0×10^{-7}	5.4×10^{-6}	3.9×10^{3}
Sm-151	90	years	3.0×10^{-6}		2.7×10^{-6}	2.0×10^{3}
Sr-90 + d	28.6	years	1.0×10^{-6}	4.0×10^{-7}	9.3×10^{-7}	6.8×10^{2}
Eu-154	8.8	years	1.0×10^{-6}		8.9×10^{-7}	6.5×10^{2}
Se-79	65000	years	5.0×10^{-7}		4.4×10^{-7}	3.2×10^{2}
Eu-155	4.96	years	5.0×10^{-7}		4.4×10^{-7}	3.2×10^{2}
Co-60	5.27	years	3.0×10^{-7}	1.0×10^{-7}	2.8×10^{-7}	2.0×10^{2}
Te-125m	58	days	3.0×10^{-7}	6.0×10^{-8}	2.7×10^{-7}	2.0×10^{2}
Sn-126 + d	100000	years	2.0×10^{-7}		1.8×10^{-7}	1.3×10^{2}
Am-241	432	years	2.0×10^{-7}		1.8×10^{-7}	1.3×10^{2}
Cs-134	2.06	years	1.0×10^{-7}		8.9×10^{-8}	6.5×10^{1}
Pu-238	87.8	years	7.0×10^{-8}	4.0×10^{-8}	6.7×10^{-8}	4.9×10^{1}
Pu-241	14.4	years	5.0×10^{-8}		4.4×10^{-8}	3.2×10^{1}

Table C.1-1. (continued)

Nuclide	Half-life	Time Units	In-Tank Precipitation Waste Stream[a] Ci/liter	Effluent Treatment Facility Waste Steam[b] Ci/liter	Nominal Blend[c] Ci/liter	Facility Inventory Ci
Sn-121m	55	years	4.0×10^{-8}		3.6×10^{-8}	2.6×10^{1}
Ni-63	100	years	3.0×10^{-8}		2.7×10^{-8}	2.0×10^{1}
I-129	1.5×10^{7}	years	2.7×10^{-8}	2.7×10^{-8}	2.7×10^{-8}	2.0×10^{1}
Sb-126	12.4	days	2.0×10^{-8}		1.8×10^{-8}	1.3×10^{1}
C-14	5730	years	1.0×10^{-8}		8.9×10^{-9}	6.5
Eu-152	13.6	years	9.0×10^{-9}		8.0×10^{-9}	5.8
Ce-144	284	days	5.0×10^{-9}		$4.4E \times 10^{-9}$	3.2
Pu-239	24100	years	7.0×10^{-10}	1.0×10^{-8}	1.7×10^{-9}	1.2
Cm-244	18.1	years	1.0×10^{-9}		8.9×10^{-10}	6.5×10^{-1}
Ag-110m	250	days	9.0×10^{-10}		8.0×10^{-10}	5.8×10^{-1}
Pu-240	6540	years	5.0×10^{-10}		4.4×10^{-10}	3.2×10^{-1}
Zr-93	1530000	years	4.0×10^{-10}		3.6×10^{-10}	2.6×10^{-1}
U-234	245000	years	4.0×10^{-10}		3.6×10^{-10}	2.6×10^{-1}
Ni-59	75000	years	3.0×10^{-10}		2.7×10^{-10}	2.0×10^{-1}
Ce-142	5×10^{16}	years	3.0×10^{-10}		2.7×10^{-10}	2.0×10^{-1}
Th-231	25.5	hours	2.0×10^{-10}		1.8×10^{-10}	1.3×10^{-1}
Am-242m	152	years	1.0×10^{-10}		8.9×10^{-11}	6.5×10^{-2}
Am-242	16	hours	1.0×10^{-10}		8.9×10^{-11}	6.5×10^{-2}

Table C.1-1. (continued)

Nuclide	Half-life	Time Units	In-Tank Precipitation Waste Stream[a] Ci/liter	Effluent Treatment Facility Waste Steam[b] Ci/liter	Nominal Blend[c] Ci/liter	Facility Inventory Ci
Cm-242	163	days	1.0×10^{-10}		8.9×10^{-11}	6.5×10^{-2}
Np-237 + d	2140000	years	9.0×10^{-11}		8.0×10^{-11}	5.8×10^{-2}
Ra-224 + d	3.62	days	7.0×10^{-11}		6.2×10^{-11}	4.5×10^{-2}
U-232	72	years	7.0×10^{-11}		6.2×10^{-11}	4.5×10^{-2}
Am-243	7380	years	6.0×10^{-11}		5.3×10^{-11}	3.9×10^{-2}
Cs-135	2300000	years	6.0×10^{-11}		5.3×10^{-11}	3.9×10^{-2}
Pr-144m	7.2	minutes	5.0×10^{-11}		4.4×10^{-11}	3.2×10^{-2}
Cm-243	28.5	years	4.0×10^{-11}		3.6×10^{-11}	2.6×10^{-2}
Pd-107	6500000	years	3.0×10^{-11}		2.7×10^{-11}	2.0×10^{-2}
Pa-234	6.7	hours	6.0×10^{-12}		5.3×10^{-12}	3.9×10^{-3}
U-233	159000	years	4.0×10^{-12}		3.6×10^{-12}	2.6×10^{-3}
U-238	4.47×10^{9}	years	3.0×10^{-12}		2.7×10^{-12}	2.0×10^{-3}
Th-234	24.1	days	3.0×10^{-12}		2.7×10^{-12}	2.0×10^{-3}
Th-228	1.91	years	2.0×10^{-12}		1.8×10^{-12}	1.3×10^{-3}
Pu-236	2.85	years	6.0×10^{-13}		5.3×10^{-13}	3.9×10^{-4}
Pu-242	376000	years	6.0×10^{-13}		5.3×10^{-13}	3.9×10^{-4}
U-235	7.04×10^{8}	years	5.0×10^{-13}		4.4×10^{-13}	3.2×10^{-4}
Th-230	77000	years	1.0×10^{-13}		8.9×10^{-14}	6.5×10^{-5}

Table C.1-1. (continued)

Nuclide	Half-life	Time Units	In-Tank Precipitation Waste Stream[a] Ci/liter	Effluent Treatment Facility Waste Steam[b] Ci/liter	Nominal Blend[c] Ci/liter	Facility Inventory Ci
Cm-245	8500	years	7.0×10^{-14}		6.2×10^{-14}	4.5×10^{-5}
Th-232	1.41×10^{10}	years	4.0×10^{-14}		3.6×10^{-14}	2.6×10^{-5}
Sm-147	1.06×10^{11}	years	3.0×10^{-14}		2.7×10^{-14}	2.0×10^{-5}
Nb-94	20300	years	1.0×10^{-14}		9.0×10^{-15}	6.6×10^{-6}
Rb-87	4.73×10^{10}	years	9.0×10^{-15}		8.0×10^{-15}	5.8×10^{-6}
Cm-246	4750	years	5.0×10^{-15}		4.0×10^{-15}	2.9×10^{-6}
Pa-231	32800	years	5.0×10^{-15}		4.0×10^{-15}	2.9×10^{-6}
Ac-227	21.8	years	2.0×10^{-15}		2.0×10^{-15}	1.5×10^{-6}
Ra-223 + d	11.4	days	2.0×10^{-15}		2.0×10^{-15}	1.5×10^{-6}
Other alpha			2.0×10^{-7}		1.8×10^{-7}	1.3×10^{2}
Other beta, gamma			1.0×10^{-5}		8.9×10^{-6}	6.5×10^{3}
Total Activity					2.81×10^{-4}	

[a] *Source:* Fowler 1982a.
[b] *Source:* Heckrotte 1988.
[c] Nominal Blend (NB) refers to blend ration of 8:1 by volume of ITP: ETF feed solution.

Note: Curie values were computed based on an assumed production mix with 15 years of decay.

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ESTIMATED ALL PATHWAYS AND INADVERTENT INTRUDER DOSES FROM SALTSTONE DISPOSAL USING UPDATED SALT WASTE COMPOSITIONS

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SRNL

1.0 EXECUTIVE SUMMARY

All pathways and inadvertent intruder doses from the Saltstone Disposal Facility (SDF) were previously estimated from the results of the Saltstone Special Analysis (SA) [1] using a radionuclide composition for low-curie salt [2]. The radionuclide composition of all salt waste to be disposed in the SDF has been recently estimated [3]. The doses estimated from the SA results have been updated per the revised radionuclide composition in this report. These doses are used for comparison with performance objectives in 10 CFR 61 [4]. The maximum all pathways dose over 10,000 years is 6.3 mrem/year. The maximum dose to the inadvertent intruder over 10,000 years is 0.1 mrem/year, which is 0.02 percent of the NRC performance objective of 500 mrem/year.

2.0 INTRODUCTION

The Saltstone Special Analysis [1] was conducted in 2002 to update the inadvertent intruder analysis conducted in the 1992 Performance Assessment (PA) [5], to extend the groundwater analysis to consider additional radionuclides, and to assess the air and radon emanation pathways. For the groundwater pathway, the analysis used the Maximum Contaminant Levels (MCL) from the Safe Drinking Water Act (SDWA) [6] to calculate limits. Doses from all pathways combined were not calculated.

Now, efforts are underway to provide documentation required by Section 3116 of the Ronald W. Reagan National Defense Authorization Act (NDAA) for Fiscal Year 2005 [7]. One aspect of this is to show compliance with the performance objectives in 10 CFR 61 [4]. One of the performance objectives, 10 CFR 61.41, is that the dose received by a member of the public from all pathways combined should not exceed 25 mrem/year to the whole body, 75 mrem/year to the thyroid and 25 mrem/year to any other organ. Another performance objective, 10 CFR 61.42, is that design, operation and closure of the disposal facility must ensure protection of any individual inadvertently intruding into the disposal facility.

This report provides all pathways doses estimated from the results of the Saltstone SA for use in determining compliance with the performance objectives. It also provides doses to the inadvertent intruder. The doses are estimated using recently updated radionuclide compositions of salt waste to be disposed in the SDF [3].

3.0 UPDATED SALT WASTE COMPOSITIONS

Recently, the radionuclide composition of all salt waste expected to be disposed in the SDF was estimated [3]. Table 3-1 shows the estimated average radionuclide content of salt solution feed to Saltstone for each of the three types of salt solution (i.e., DDA, ARP/MCU, SWPF) [3]. Table 3-2 shows the volumes of each of the three types of salt solution and the total volume of salt solution that is expected to be disposed in the SDF.

4.0 ALL PATHWAYS DOSES

The Saltstone SA [1] computed disposal limits for a number of radionuclides for four pathways (i.e., groundwater, inadvertent intruder, air, and radon emanation). For the groundwater pathway, the performance measure used to derive the limits is the SDWA MCL [6] or the

concentration that would result in an annual dose of 25 mrem, assuming that the receptor consumed 2 liters of water per day for a year, whichever is lower. The point of assessment for the groundwater pathway is a hypothetical groundwater well located at the point of highest groundwater concentration outside a buffer zone of 100 meters surrounding the disposed waste [1].

Tables 4-1, 4-2 and 4-3 show the radionuclide limits derived in the SA for the groundwater pathway and the ratio of the radionuclide concentrations in Table 3-1 to the limits (i.e., the fraction of the limit represented by the salt solution radionuclide concentration) for each of the salt solution types. In the SA, the groundwater pathway considered one exposure pathway, that of drinking the water directly. Other potential exposure pathways, such as use of the groundwater for irrigating a garden and eating the produce from the garden, were not considered.

Since the MCL for beta-gamma emitting radionuclides is based on a dose of 4 mrem/year to the critical organ and the MCL for alpha emitting radionuclides is 15 pCi/L, the fractions of the limits are summed separately for the beta-gamma and alpha emitting radionuclides. The dose to the receptor can be approximated by multiplying the sum-of-fractions of the limits by the performance measure. For the alpha emitting radionuclides, the performance measure used in the SA is either the MCL or a dose of 25 mrem/year TEDE from consuming 2 liters of water per day for a year, whichever is less. For ^{237}Np, the groundwater concentration that results in a dose of 25 mrem/year is 8.9 pCi/L. Therefore, the limiting performance measure for ^{237}Np is the 25 mrem/year dose.

Multiplying the sum-of-fractions of the limits by the performance measure is a very conservative approximation because it assumes that the maximum groundwater concentration of each radionuclide occurs at the same time. The resulting maximum doses for beta-gamma and alpha emitting radionuclides is zero over 1,000 years for all three salt compositions. Over 10,000 years, the maximum beta-gamma doses are 3.3 mrem/year for DDA, 1.49 mrem/year for ARP/MCU, and 6.79 mrem/year for SWPF. Over 10,000 years, the maximum alpha emitter doses are 0.005 mrem/year for DDA, 0.0005 mrem/year for ARP/MCU, and 0.001 mrem/year for SWPF.

For the Air pathway, only tritium and carbon-14 are significant. Tables 4-4, 4-5, and 4-6 show the air pathway limits [1, 9]. The performance measure used to derive the air pathway limit is an annual dose of 10 mrem TEDE to a hypothetical receptor located outside a 100-m buffer zone surrounding the disposed waste. Therefore, the air pathway dose can be estimated by multiplying the sum-of-fractions of the limits by 10. This results in a dose of 0.007 mrem/year for DDA, 0.003 mrem/year for ARP/MCU, and 0.002 mrem/year for SWPF at both the 1,000-year and the 10,000-year compliance times.

To estimate the dose from all pathways, the doses from the groundwater pathway and the air pathway must be summed. Table 4-7 shows the sum of the groundwater and air pathway doses for the 1,000-year and 10,000-year periods. To estimate the dose from all of the salt waste to be disposed in the SDF, the doses from the three waste types must be summed in a volume-weighted manner (i.e., the dose for each waste type is multiplied by the volumetric fraction for that waste type shown in Table 3-2 and the resulting products for all waste types are then summed). Table 4-8 shows the total dose from the groundwater and air pathways for the 1,000-year and 10,000-year periods.

For comparison with the Nuclear Regulatory Commission (NRC) performance objective from all pathways combined, the sum of the groundwater pathway dose for both beta-gamma and alpha emitting radionuclides and the air pathway dose, at the 10,000-year compliance time, is 6.3 mrem/year.

Table 3-1 Estimated Average Radionuclide Concentrations in DDA, ARP/MCU, and SWPF Salt Solution Feed to Saltstone

Nuclide	DDA, Ci/gal[a]	ARP/MCU, Ci/gal[a]	SWPF, Ci/gal[a]
H-3	1.53E-05	1.38E-05	1.02E-05
C-14	5.12E-07	1.52E-07	1.54E-07
Co-60	5.65E-05	3.55E-08	2.31E-08
Ni-59	4.84E-07	1.27E-11	0.00E+00
Ni-63	4.89E-07	1.81E-07	1.81E-07
Se-79	2.85E-07	7.46E-12	0.00E+00
Sr-90	1.79E-02	1.28E-06	1.33E-06
Tc-99	1.07E-05	2.15E-07	2.58E-07
Ru-106	9.39E-07	2.73E-13	0.00E+00
Sb-125	2.69E-05	1.77E-10	0.00E+00
Sn-126	3.77E-07	9.79E-12	0.00E+00
I-129	8.20E-08	3.79E-08	1.73E-07
Cs-134	1.06E-06	4.17E-12	0.00E+00
Cs-135	3.32E-09	8.53E-14	0.00E+00
Cs-137	1.61E-01	5.58E-02	6.47E-05
Ce-144	3.87E-07	2.96E-14	0.00E+00
Pm-147	5.60E-04	3.46E-09	0.00E+00
Eu-154	1.57E-04	2.84E-09	0.00E+00
Th-232	5.25E-10	1.35E-14	2.29E-09
U-232	1.33E-06	5.62E-08	3.91E-08
U-233	1.54E-06	1.09E-07	7.48E-08
U-234	4.24E-07	2.68E-08	1.37E-08
U-235	1.45E-09	2.77E-10	1.16E-09
U-236	1.50E-08	4.12E-09	2.43E-09
U-238	1.23E-08	3.86E-08	1.40E-07
Np-237	9.95E-08	1.00E-08	2.70E-08
Pu-238	4.51E-04	6.47E-05	7.85E-05
Pu-239	5.97E-06	2.11E-07	1.08E-05
Pu-240	1.11E-05	2.90E-07	2.39E-06
Pu-241	1.90E-04	9.98E-05	7.58E-05
Pu-242	2.00E-08	2.95E-09	1.76E-09
iAm-241	9.72E-06	7.51E-06	8.70E-06
Am-241	5.62E-05	2.74E-06	5.39E-05
Am-242m	4.78E-05	2.46E-07	7.51E-08
Cm-244	6.07E-05	3.86E-08	1.91E-05
Cm-245	1.14E-08	5.13E-11	1.44E-09

[a] From Reference 3, Table C-3.

Table 3-2 Volumes of Salt Solution to be Disposed in Saltstone

Type	Volume, gal	Fraction of total volume
DDA	6,897,434	0.06396476
ARP/MCU	5,134,347	0.047614411
SWPF	95,800,000	0.888420828
Total Volume	107,831,781	

[a] From Reference 3, Table C-2

Table 4-1 Estimated Groundwater Dose from DDA

Nuclide	**DDA** Salt Solution Ci/L[a]	limit, Ci/L[b]	10,000-year limit, Ci/L[c]		DDA/1000-yr Limit	DDA/10,000-yr Limit
C-14	1.35E-07	No Limit[d]	2.30E-01			5.88E-07
Se-79	7.53E-08	No Limit[d]	5.30E-06			1.42E-02
Tc-99	2.83E-06	No Limit[d]	5.50E-04			5.14E-03
Sn-126	9.96E-08	No Limit[d]	1.80E-03			5.53E-05
I-129	2.17E-08	No Limit[d]	2.70E-08			8.02E-01
				SOF beta-gamma	0.00E+00	8.22E-01
				Dose beta-gamma[e]	0.00E+00	3.29E+00
Np-237	2.63E-08	No Limit[d]	1.40E-04			1.88E-04
				SOF Alpha	0.00E+00	1.88E-04
				Dose Alpha[e]	0.00E+00	4.69E-03
				Total groundwater dose[e]	0.00E+00	3.29E+00

a From Table 3-1, volume converted to liters by dividing by 3.785412 liters per gallon
b From Reference 1, Table 8-4
c From Reference 1, Table 8-3
d Calculated disposal limit exceeds the specific activity of the isotope or the total number of curies produced at SRS
e Doses are in units of mrem/year

Table 4-2 Estimated Groundwater Dose from ARP/MCU

Nuclide	**ARP/MCU** Salt Solution Ci/L[a]	limit, Ci/L[b]	10,000-year limit, Ci/L[c]		ARP/MCU/1000-yr Limit	0,000-yr Limit
C-14	4.02E-08	No Limit[d]	2.30E-01			1.75E-07
Se-79	1.97E-12	No Limit[d]	5.30E-06			3.72E-07
Tc-99	5.68E-08	No Limit[d]	5.50E-04			1.03E-04
Sn-126	2.59E-12	No Limit[d]	1.80E-03			1.44E-09
I-129	1.00E-08	No Limit[d]	2.70E-08			3.71E-01
				SOF beta-gamma	0.00E+00	3.71E-01
				Dose beta-gamma[e]	0.00E+00	1.49E+00
Np-237	2.65E-09	No Limit[d]	1.40E-04			1.89E-05
				SOF Alpha	0.00E+00	1.89E-05
				Dose Alpha[e]	0.00E+00	4.73E-04
				Total GW dose[e]	0.00E+00	1.49E+00

a From Table 3-1, volume converted to liters by dividing by 3.785412 liters per gallon
b From Reference 1, Table 8-4
c From Reference 1, Table 8-3
d Calculated disposal limit exceeds the specific activity of the isotope or the total number of curies produced at SRS
e Doses are in units of mrem/year

Table 4-3 Estimated Groundwater Dose from SWPF

Nuclide	**SWPF** Salt Solution Ci/L[a]	limit, Ci/L[b]	10,000-year limit, Ci/L[c]		SWPF/1000-yr Limit	SWPF/10,000-yr Limit
C-14	4.08E-08	No Limit[d]	2.30E-01			1.77E-07
Se-79	0.00E+00	No Limit[d]	5.30E-06			0.00E+00
Tc-99	6.81E-08	No Limit[d]	5.50E-04			1.24E-04
Sn-126	0.00E+00	No Limit[d]	1.80E-03			0.00E+00
I-129	4.58E-08	No Limit[d]	2.70E-08			1.70E+00
				SOF beta-gamma	0.00E+00	1.70E+00
				Dose beta-gamma[e]	0.00E+00	6.78E+00
Np-237	7.14E-09	No Limit[d]	1.40E-04			5.10E-05
				SOF Alpha	0.00E+00	5.10E-05
				Dose Alpha[e]	0.00E+00	1.27E-03
				Total groundwater dose[e]	0.00E+00	6.78E+00

a From Table 3-1, volume converted to liters by dividing by 3.785412 liters per gallon
b From Reference 1, Table 8-4
c From Reference 1, Table 8-3
d Calculated disposal limit exceeds the specific activity of the isotope or the total number of curies produced at SRS
e Doses are in units of mrem/year

Table 4-4 Estimated Air Pathway Dose From DDA

Nuclide	**DDA** Salt Solution Ci/L[a]	1,000-year limit, Ci/L[b]	10,000-year limit, Ci/L[b]		DDA/1000-yr limit	DDA/10,000-yr limit
H-3	4.04E-06	4.20E-02	4.20E-02		9.62E-05	9.62E-05
C-14	1.35E-07	2.40E-04	2.40E-04		5.64E-04	5.64E-04
				SOF	6.60E-04	6.60E-04
				Air Dose[c]	6.60E-03	6.60E-03

a From Table 3-1, volume converted to liters by dividing by 3.785412 liters per gallon
b Tritium limits are from Reference 1, Tables 8-3 and 8-4; 14C limits are from Reference 9, Table 6
c Dose is in units of mrem/year

Table 4-5 Estimated Air Pathway Dose From ARP/MCU

Nuclide	ARP/MCU Salt Solution Ci/L[a]	1,000-year limit, Ci/L[b]	10,000-year limit, Ci/L[b]		ARP/MCU/1000-yr limit	ARP/MCU/10,000-yr limit
H-3	3.65E-06	4.20E-02	4.20E-02		8.69E-05	8.69E-05
C-14	4.02E-08	2.40E-04	2.40E-04		1.67E-04	1.67E-04
				SOF	2.54E-04	2.54E-04
				Air Dose[c]	2.54E-03	2.54E-03

a From Table 3-1, volume converted to liters by dividing by 3.785412 liters per gallon
b Tritium limits are from Reference 1, Tables 8-3 and 8-4; 14C limits are from Reference 9, Table 6
c Dose is in units of mrem/year

Table 4-6 Estimated Air Pathway Dose From SWPF

Nuclide	SWPF Salt Solution Ci/L[a]	1,000-year limit, Ci/L[b]	10,000-year limit, Ci/L[b]		SWPF/1000-yr limit	SWPF/10,000-yr limit
H-3	2.68E-06	4.20E-02	4.20E-02		6.39E-05	6.39E-05
C-14	4.08E-08	2.40E-04	2.40E-04		1.70E-04	1.70E-04
				SOF	2.34E-04	2.34E-04
				Air Dose[c]	2.34E-03	2.34E-03

a From Table 3-1, volume converted to liters by dividing by 3.785412 liters per gallon
b Tritium limits are from Reference 1, Tables 8-3 and 8-4; 14C limits are from Reference 9, Table 6
c Dose is in units of mrem/year

Table 4-7 Total Doses From Groundwater and Air Pathways for Each Waste Type

Salt Solution	1000-year Groundwater Dose, mrem/year	10,000-year Groundwater Dose, mrem/year	1000-year Air Dose, mrem/year	10,000-year Air Dose, mrem/year	1000-year Total Dose, mrem/year	10,000-year Total Dose, mrem/year
DDA	0.00E+00	3.29E+00	6.60E-03	6.60E-03	6.60E-03	3.30E+00
ARP/MCU	0.00E+00	1.49E+00	2.54E-03	2.54E-03	2.54E-03	1.49E+00
SWPF	0.00E+00	6.78E+00	2.34E-03	2.34E-03	2.34E-03	6.79E+00

Table 4-8 Total Doses From Groundwater and Air Pathways

Time Period	Dose, mrem/year
1000 years	2.63E-03
10,000 years	6.30E+00

5.0 INADVERTENT INTRUDER DOSES

The Saltstone SA [1] computed disposal limits derived from the inadvertent intruder analysis. The intruder analyses use performance measures for chronic and acute exposure scenarios, respectively, of 100 mrem in a year and 500 mrem total effective dose equivalent (TEDE), excluding radon in air. Relevant chronic exposure scenarios that were considered include agricultural, residential, and post drilling that incorporate ingestion of foodstuffs, ingestion of soil, external exposure, and inhalation of resuspended particles. Relevant acute exposure scenarios that were considered include discovery, construction and drilling that incorporate external exposure, inhalation of resuspended particles, and ingestion of particles [10].

In the Saltstone SA [1], only chronic exposure scenarios were evaluated because they bound exposures from acute scenarios. The design of the concrete vaults and the SDF closure preclude scenarios that involve excavation or drilling into the waste (i.e., the concrete vault cannot be penetrated by equipment typically used to drill wells in the vicinity of the Savannah River Site, SRS, and the erosion barrier ensures that more than three meters of uncontaminated material are always above the saltstone so that the basement excavation in the agriculture scenario will not contact the waste). Thus, only a residential scenario was evaluated. In the residential scenario, the inadvertent intruder is assumed to construct a home above one of the saltstone vaults. Since the excavation for the basement of the home does not contact the waste, the only exposure pathway is direct radiation from the waste while residing in the home [1].

The resident scenario was assumed to be precluded for a period of 100 years following closure of the SDF, based on the assumption that SRS boundaries remain unchanged and the land remains under Federal government ownership and control utilizing the existing site security system (e.g., fences, controlled site access, prohibited residential use of the land or groundwater). This assumption is consistent with the SRS Future Land Use Plan [11], which envisions no unrestricted access of the public to the central portion of the SRS, which encompasses the SDF (i.e., perpetual government control of the SDF).

The residential scenario was evaluated using the 100 mrem in a year DOE performance measure to calculate disposal limits for the SDF (i.e., the radionuclide concentration in the salt solution that, when processed into saltstone and disposed in the SDF, will result in a dose to the intruder of 100 mrem in a year was determined for each radionuclide). These disposal limits are shown in Table 5-1.

Table 5-1 also shows the fractions of the limits for both a 1,000-year and a 10,000-year time frame for each of the salt waste compositions shown in Table 3-1. As in Section 4.0, the dose to the inadvertent intruder can be approximated by multiplying the sum-of-fractions of the limits by the 100 mrem/year performance measure. This is also a very conservative approximation because it assumes that the maximum dose for each radionuclide occurs at the same time.

Table 5-1 Estimated Saltstone Inadvertent Intruder Doses for each Waste Type

Nuclide	1000-yr Limit[a]	10,000-yr Limit[b]	DDA/1000-yr limit	DDA/10,000-yr limit	ARP/MCU/1000-yr limit	ARP/MCU/10,000-yr limit	SWPF/1000-yr limit	SWPF/10,000-yr limit
Co-60	6.00E+03	6.00E+03	2.49E-09	2.49E-09	1.56E-12	1.56E-12	1.02E-12	1.02E-12
Sn-126	2.00E-05	2.00E-05	4.98E-03	4.98E-03	1.29E-07	1.29E-07	0.00E+00	0.00E+00
Cs-137	2.00E+01	2.00E+01	2.13E-03	2.13E-03	7.37E-04	7.37E-04	8.54E-07	8.54E-07
Eu-154	1.50E+02	1.50E+02	1.72E-07	1.72E-07	4.99E-12	4.99E-12	0.00E+00	0.00E+00
Th-232	3.20E-06	3.20E-06	4.33E-05	4.33E-05	1.11E-09	1.11E-09	1.89E-04	1.89E-04
U-232	3.00E-03	3.00E-03	1.17E-04	1.17E-04	4.95E-06	4.95E-06	3.44E-06	3.44E-06
U-233	1.80E-03	2.80E-04	2.26E-04	1.45E-03	1.60E-05	1.03E-04	1.10E-05	7.06E-05
U-234	3.80E-03	9.10E-05	2.95E-05	1.23E-03	1.86E-06	7.78E-05	9.56E-07	3.99E-05
U-235	8.70E-03	1.80E-03	4.40E-08	2.13E-07	8.42E-09	4.07E-08	3.51E-08	1.70E-07
U-238	1.30E-03	1.10E-03	2.50E-06	2.95E-06	7.85E-06	9.28E-06	2.85E-05	3.37E-05
Np-237	1.10E-03	1.10E-03	2.39E-05	2.39E-05	2.41E-06	2.41E-06	6.49E-06	6.49E-06
Pu-238	1.30E+01	2.60E-01	9.16E-06	4.58E-04	1.32E-06	6.58E-05	1.59E-06	7.97E-05
Pu-239	No Limit[c]	3.60E+02		4.38E-09		1.55E-10		7.89E-09
Pu-241	2.20E+02	1.60E+02	2.28E-07	3.14E-07	1.20E-07	1.65E-07	9.10E-08	1.25E-07
Am-241	6.90E+00	5.00E+00	2.52E-06	3.48E-06	3.93E-07	5.42E-07	2.40E-06	3.31E-06
Am-242m	8.30E-01	2.00E-01	1.79E-05	7.42E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cm-245	1.30E-01	1.30E-01	2.32E-08	2.32E-08	1.04E-10	1.04E-10	2.92E-09	2.92E-09
		SOF	7.58E-03	1.05E-02	7.72E-04	1.00E-03	2.44E-04	4.27E-04
	Intruder Dose, mrem/year		7.58E-01	1.05E+00	7.72E-02	1.00E-01	2.44E-02	4.27E-02

a From Reference 1, Table 8-4
b From Reference 1, Table 8-3
c Calculated disposal limit exceeds the specific activity of the isotope or the total number of curies produced at SRS

To estimate the dose from all of the salt waste to be disposed in the SDF, the doses from the three waste types must be summed in a volume-weighted manner (i.e., the dose for each waste type is multiplied by the volumetric fraction for that waste type shown in Table 3-2 and the resulting products for all waste types are summed). Table 5-2 shows the total dose to the inadvertent intruder for the 1,000-year and 10,000-year periods.

The resulting dose for the 1,000-year period is 0.09 mrem/year and that for the 10,000-year period is 0.1 mrem/year, both of which are less than one percent of the NRC inadvertent intruder performance objective of 500 mrem per year [12].

Table 5-2 Estimated Total Saltstone Inadvertent Intruder Doses

Time Period	Dose, mrem/year
1000 years	8.91E-02
10,000 years	1.25E-01

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FOR DOE APPROVAL

KEY WORDS:
Vault
LLW Disposal
Disposal Authorization Statement

SPECIAL ANALYSIS:

REEVALUATION OF THE INADVERTENT INTRUDER, GROUNDWATER, AIR, and RADON ANALYSES FOR THE SALTSTONE DISPOSAL FACILITY

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ground cover which will prevent the growth of pine trees, the most deeply rooted naturally occurring plant type at SRS. Bamboo is a shallow-rooted climax species which evapotranspirates year-round in the SRS climate removing a large amount of moisture from the soil and decreasing the infiltration into the underlying disposal system.

3.3 WASTE CHARACTERISTICS

As presently planned, contaminated wastewater from two sources will be sent to Z Area for treatment and disposal. The wastewater sent to Z Area contains principally soluble solids and very low levels of most radioactive contaminants. Soluble incidental waste from the HLW tanks at the SRS is a major source of wastewater sent to Z Area. A second wastewater stream also containing principally soluble solids and very low levels of radioactive contaminants is generated in the F/H Area ETF where condensate from evaporators in the Separations Facilities and the HLW Tank Farm is sent for treatment. Miscellaneous wastewater streams containing low levels of radioactive contaminants from other sources on the site are also treated in the ETF.

As noted earlier, saltstone is produced from a mixture of salt solution and a dry blend of cementitious materials (slag, fly ash, and cement), and an acceptable waste form can be produced over a range of these individual components. Solid saltstone is a complex mixture of insoluble solids, soluble solids, and water. As the saltstone grout is prepared and cured, several chemical reactions occur between the components of the dry blend and contaminants in the salt solution. Several wastewater contaminants are converted to insoluble species or incorporated into the cement matrix, effectively retarding their release from the saltstone waste form.

Development of this waste form and its physical and chemical properties are described in Sect. 2.4.1 of the original PA (MMES et al., 1992). Briefly, between 1979 and 1987, a formulation for saltstone was developed that rendered the final wasteform product that is resistant to leaching of contaminants present in the porous matrix and is classified as nonhazardous solid waste as defined by USEPA protocol (USEPA, 2002).

The average projected composition of the saltstone that will be sent to the SDF for disposal is 47 wt% salt solution, 25 wt% slag, 25 wt% fly ash, and 3 wt% cement. When first prepared, the saltstone grout is readily pumped from the SPF to a cell in a disposal vault. After setting, the saltstone is self-supporting with a 28-day compressive strength in excess of 1.45×10^6 Pa. The specific gravity of the solidified saltstone ranges from 1.6 to 1.8, and bulk density is estimated at 1.7×10^3 kg/m^3.

The initial incidental wastewater that will be sent to Z Area is called Low Curie Salt (LCS). This wastewater is produced from selected HLW salt tanks that are expected to be low in ^{137}Cs. The supernate in these tanks, which contains the bulk of the cesium, will be drained and pumped to another tank. The resulting salt cake will be dissolved and transferred to HLW tank 50, from which it will be sent to Z Area. The currently estimated radionuclide composition of LCS is presented in Table 3-1. Radionuclide limits derived in this study are compared with this radionuclide composition in Sect. 8.

Table 3-1. Estimated average radionuclide concentrations in low curie salt solution feed to saltstone[a]

Nuclide	Low Curie Salt Solution, Ci/L	Nuclide	Low Curie Salt Solution, Ci/L
H-3	0.00E+00	Sm-151	0.00E+00
C-14	4.46E-10	Eu-154	1.00E-04
Co-60	4.08E-05	Eu-155	0.00E+00
Ni-59	2.57E-07	Th-232	2.88E-10
Ni-63	3.98E-10	U-232	6.23E-11
Se-79	1.51E-07	U-233	1.72E-08
Sr-90	8.94E-03	U-234	6.34E-09
Y-90	8.94E-03	U-235	2.00E-10
Tc-99	2.57E-06	U-236	9.63E-10
Ru-106	9.50E-07	U-238	4.78E-09
Rh-106	9.50E-07	Np-237	8.92E-09
Sn-126[b]	7.50E-07	Pu-238	2.18E-04
Sb-125	2.43E-05	Pu-239	3.32E-06
Sb-126	2.02E-07	Pu-240	1.55E-06
Te-125m	0.00E+00	Pu-241	1.06E-04
I-129	2.37E-11	Pu-242	3.60E-09
Cs-134	1.06E-06	Am-241	2.22E-05
Cs-135	1.81E-09	Am-242m	2.11E-08
Cs-137	2.26E-02	Cm-242	2.20E-05
Ba-137m	2.14E-02	Cm-243	0.00E+00
Ce-144	4.90E-07	Cm-244	2.20E-05
Pr-144	4.90E-07	Cm-245	1.64E-09
Pm-147	5.13E-04		

[a] Values from Drumm (2002), Appendix D, Average Feed, 30% Interstitial, 300 mg/L sludge.
[b] Value from Reboul (2002).

APPROVED for Release for
Unlimited (Release to Public)

RESPONSE TO RAI COMMENT 17
ROADMAP TO REFERENCES

REFERENCED DOCUMENT	*EXCERPT LOCATION	REMARK
1Q Quality Assurance Manual	Excerpt included within response.	.
1Q Quality Assurance Manual, Procedure 20, page 5	Representative excerpt enclosed following response.	This reference is included in its entirety for information.
1Q Quality Assurance Manual, Procedure 20-1	Excerpt enclosed following the response.	Pages from WSRC 2003, Procedure 20-1
10 CFR 830 Subpart A-Quality Assurance Requirements	Excerpts from the document are enclosed following the response.	Sections 830.120, 121, and 122
ACRi, Inc. 1994	Excerpt enclosed following the response.	Pages from Acri, Inc. 1994, Porflow Validation
ACRi, Inc. 2005	Excerpt enclosed following the response.	Section on Supporting Qualitative Evidence for Quality Assurance
Collard 2002	Excerpt enclosed following the response.	Appendix, pg. 26
DOE Order 414.1C, Quality Assurance	Representative excerpts from the document are enclosed following the response.	Attachment 2
DOE O 414.1B	Excerpt enclosed following the response.	Pages from DOE Order 414b.
DOE O 435.1	Excerpt enclosed following the response.	Pages from DOE Order 435.1
DOE M 435.1-1	Excerpt enclosed following the response.	Pages from DOE Order 435.1-1
SRM414.1.1C, 2005, *Quality Assurance Program Manual*, U. S. Department of Energy (DOE), Savannah River Operations Office (SR), Aiken, South Carolina.	The excerpt from the document is enclosed following the response.	Section 1.1
Saltstone PA (reference 1 in the NRC RAI)	Other	This reference in its entirety has been provided separately for information.
2002 Special Analysis (reference 3) in the NRC RAI)	Other	This reference in its entirety has been provided separately for information.
Vault 4 Special Analysis (Cook et al.	Other	This reference in its entirety has been

2005)		provided separately for information.
USEPA 1994a	Other	This reference in its entirety has been provided separately for information.
USEPA 1994b	Other	This reference in its entirety has been provided separately for information.
USEPA 1987a	Other	This reference in its entirety has been provided separately for information.
USEPA 1987b	Other	This reference in its entirety has been provided separately for information.

*Excerpt Locations:

1. Excerpt included within response: The excerpt is included within the text of the response or is appended to the response.
2. Excerpt enclosed following response: The excerpt is enclosed on a separate sheet or sheets following the response.
3. Representative excerpt(s) enclosed following response: Representative excerpts from a document that is wholly or largely applicable are enclosed following the response.
4. Other

safety structures, systems, and components and their support systems required for safe operations are maintained, that facility operation is within safety limits, and that limiting control settings and limiting conditions for operation are met.

Technical safety requirements (TSRs) means the limits, controls, and related actions that establish the specific parameters and requisite actions for the safe operation of a nuclear facility and include, as appropriate for the work and the hazards identified in the documented safety analysis for the facility: Safety limits, operating limits, surveillance requirements, administrative and management controls, use and application provisions, and design features, as well as a bases appendix.

Unreviewed Safety Question (USQ) means a situation where

(1) The probability of the occurrence or the consequences of an accident or the malfunction of equipment important to safety previously evaluated in the documented safety analysis could be increased;

(2) The possibility of an accident or malfunction of a different type than any evaluated previously in the documented safety analysis could be created;

(3) A margin of safety could be reduced; or

(4) The documented safety analysis may not be bounding or may be otherwise inadequate.

Unreviewed Safety Question process means the mechanism for keeping a safety basis current by reviewing potential unreviewed safety questions, reporting unreviewed safety questions to DOE, and obtaining approval from DOE prior to taking any action that involves an unreviewed safety question.

Use and application provisions means the basic instructions for applying technical safety requirements.

(b) Terms defined in the Act or in 10 CFR Part 820 and not defined in this section of the rule are to be used consistent with the meanings given in the Act or in 10 CFR Part 820.

§ 830.4 General requirements.

(a) No person may take or cause to be taken any action inconsistent with the requirements of this part.

(b) A contractor responsible for a nuclear facility must ensure implementation of, and compliance with, the requirements of this part.

(c) The requirements of this part must be implemented in a manner that provides reasonable assurance of adequate protection of workers, the public, and the environment from adverse consequences, taking into account the work to be performed and the associated hazards.

(d) If there is no contractor for a DOE nuclear facility, DOE must ensure implementation of, and compliance with, the requirements of this part.

§ 830.5 Enforcement.

The requirements in this part are DOE Nuclear Safety Requirements and are subject to enforcement by all appropriate means, including the imposition of civil and criminal penalties in accordance with the provisions of 10 CFR Part 820.

§ 830.6 Recordkeeping.

A contractor must maintain complete and accurate records as necessary to substantiate compliance with the requirements of this part.

§ 830.7 Graded approach.

Where appropriate, a contractor must use a graded approach to implement the requirements of this part, document the basis of the graded approach used, and submit that documentation to DOE. The graded approach may not be used in implementing the unreviewed safety question (USQ) process or in implementing technical safety requirements.

Subpart A—Quality Assurance Requirements

§ 830.120 Scope.

This subpart establishes quality assurance requirements for contractors conducting activities, including providing items or services, that affect, or may affect, nuclear safety of DOE nuclear facilities.

§ 830.121 Quality Assurance Program (QAP).

(a) Contractors conducting activities, including providing items or services, that affect, or may affect, the nuclear safety of DOE nuclear facilities must conduct work in accordance with the Quality Assurance criteria in § 830.122.

(b) The contractor responsible for a DOE nuclear facility must:

(1) Submit a QAP to DOE for approval and regard the QAP as approved 90 days after submittal, unless it is approved or rejected by DOE at an earlier date.

(2) Modify the QAP as directed by DOE.

(3) Annually submit any changes to the DOE-approved QAP to DOE for approval. Justify in the submittal why the changes continue to satisfy the quality assurance requirements.

(4) Conduct work in accordance with the QAP.

(c) The QAP must:

(1) Describe how the quality assurance criteria of § 830.122 are satisfied.

(2) Integrate the quality assurance criteria with the Safety Management System, or describe how the quality assurance criteria apply to the Safety Management System.

(3) Use voluntary consensus standards in its development and implementation, where practicable and consistent with contractual and regulatory requirements, and identify the standards used.

(4) Describe how the contractor responsible for the nuclear facility ensures that subcontractors and suppliers satisfy the criteria of § 830.122.

§ 830.122 Quality assurance criteria.

The QAP must address the following management, performance, and assessment criteria:

(a) Criterion 1—Management/Program.

(1) Establish an organizational structure, functional responsibilities, levels of authority, and interfaces for those managing, performing, and assessing the work.

(2) Establish management processes, including planning, scheduling, and providing resources for the work.

(b) Criterion 2—Management/Personnel Training and Qualification.

(1) Train and qualify personnel to be capable of performing their assigned work.

(2) Provide continuing training to personnel to maintain their job proficiency.

(c) Criterion 3—Management/Quality Improvement.

(1) Establish and implement processes to detect and prevent quality problems.

(2) Identify, control, and correct items, services, and processes that do not meet established requirements.

(3) Identify the causes of problems and work to prevent recurrence as a part of correcting the problem.

(4) Review item characteristics, process implementation, and other quality-related information to identify items, services, and processes needing improvement.

(d) Criterion 4—Management/Documents and Records.

(1) Prepare, review, approve, issue, use, and revise documents to prescribe processes, specify requirements, or establish design.

(2) Specify, prepare, review, approve, and maintain records.

(e) Criterion 5—Performance/Work Processes.

(1) Perform work consistent with technical standards, administrative controls, and other hazard controls adopted to meet regulatory or contract requirements, using approved instructions, procedures, or other appropriate means.

(2) Identify and control items to ensure their proper use.

(3) Maintain items to prevent their damage, loss, or deterioration.

(4) Calibrate and maintain equipment used for process monitoring or data collection.

(f) Criterion 6—Performance/Design.

(1) Design items and processes using sound engineering/scientific principles and appropriate standards.

(2) Incorporate applicable requirements and design bases in design work and design changes.

(3) Identify and control design interfaces.

(4) Verify or validate the adequacy of design products using individuals or groups other than those who performed the work.

(5) Verify or validate work before approval and implementation of the design.

(g) Criterion 7—Performance/Procurement.

(1) Procure items and services that meet established requirements and perform as specified.

(2) Evaluate and select prospective suppliers on the basis of specified criteria.

(3) Establish and implement processes to ensure that approved suppliers continue to provide acceptable items and services.

(h) Criterion 8—Performance/Inspection and Acceptance Testing.

(1) Inspect and test specified items, services, and processes using established acceptance and performance criteria.

(2) Calibrate and maintain equipment used for inspections and tests.

(i) Criterion 9—Assessment/Management Assessment. Ensure managers assess their management processes and identify and correct problems that hinder the organization from achieving its objectives.

(j) Criterion 10—Assessment/Independent Assessment.

(1) Plan and conduct independent assessments to measure item and service quality, to measure the adequacy of work performance, and to promote improvement.

(2) Establish sufficient authority, and freedom from line management, for the group performing independent assessments.

(3) Ensure persons who perform independent assessments are technically qualified and knowledgeable in the areas to be assessed.

Subpart B—Safety Basis Requirements

§ 830.200 Scope.

This Subpart establishes safety basis requirements for hazard category 1, 2, and 3 DOE nuclear facilities.

§ 830.201 Performance of work.

A contractor must perform work in accordance with the safety basis for a hazard category 1, 2, or 3 DOE nuclear facility and, in particular, with the hazard controls that ensure adequate protection of workers, the public, and the environment.

§ 830.202 Safety basis.

(a) The contractor responsible for a hazard category 1, 2, or 3 DOE nuclear facility must establish and maintain the safety basis for the facility.

(b) In establishing the safety basis for a hazard category 1, 2, or 3 DOE nuclear facility, the contractor responsible for the facility must:

(1) Define the scope of the work to be performed;

(2) Identify and analyze the hazards associated with the work;

(3) Categorize the facility consistent with DOE-STD-1027-92 ("Hazard Categorization and Accident Analysis Techniques for compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports," Change Notice 1, September 1997);

(4) Prepare a documented safety analysis for the facility; and (5) Establish the hazard controls upon which the contractor will rely to ensure adequate protection of workers, the public, and the environment.

(c) In maintaining the safety basis for a hazard category 1, 2, or 3 DOE nuclear facility, the contractor responsible for the facility must:

(1) Update the safety basis to keep it current and to reflect changes in the facility, the work and the hazards as they are analyzed in the documented safety analysis;

(2) Annually submit to DOE either the updated documented safety analysis for approval or a letter stating that there have been no changes in the documented safety analysis since the prior submission; and

(3) Incorporate in the safety basis any changes, conditions, or hazard controls directed by DOE.

§ 830.203 Unreviewed safety question process.

(a) The contractor responsible for a hazard category 1, 2, or 3 DOE nuclear facility must establish, implement, and take actions consistent with a USQ process that meets the requirements of this section.

(b) The contractor responsible for a hazard category 1, 2, or 3 DOE existing nuclear facility must submit for DOE

CONTRACTOR REQUIREMENTS DOCUMENT
DOE O 414.1C, *QUALITY ASSURANCE*

Regardless of the performer of the work, the contractor is responsible for complying with the requirements of this Contractor Requirements Document (CRD). The contractor is responsible for flowing down the requirements of this CRD to subcontractors at any tier to the extent necessary to ensure the contractor's compliance with the requirements and the safe performance of work. When the contractor conducts activities or provides items or services that affect or may affect the safety of Department of Energy (DOE), including National Nuclear Security Administration (NNSA), nuclear facilities, it must conduct work in accordance with the quality assurance (QA) requirements of 10 CFR 830 Subpart A.

This CRD includes a requirement to integrate multiple QA program (QAP) drivers imposed by QA regulations [see Title 10 Code of Federal Regulations (CFR) 830], the Nuclear Regulatory Commission, and other Federal agencies. The CRD includes activity-specific requirements for work that also may need to comply with QA regulations. This integration requirement supplements but does not supersede or alter compliance with QA regulations. Where a work activity, process, or item is specifically identified as within the scope of a QA regulation (e.g., 10 CFR 830 or 10 CFR 63), that regulation prevails. In the event of a conflict between this CRD and any QA regulation, the regulation prevails. [See QAP integration requirement, paragraph 2a(4) below.]

OBJECTIVES.

a. To ensure that DOE, including NNSA, products and services meet or exceed customers' expectations.

b. To achieve QA for all work based upon the following principles.

(1) That quality is assured and maintained through a single, integrated, effective QA program (i.e., management system).

(2) That management support for planning, organization, resources, direction, and control is essential to QA.

(3) That performance and quality improvement require thorough rigorous assessment and corrective action.

(4) That workers are responsible for achieving and maintaining quality.

(5) That environmental, safety, and health risks and impacts associated with work processes are minimized while maximizing reliability and performance of work products.

c To establish quality process requirements to be implemented under a QAP for the control of suspect/counterfeit items (S/CIs) and control of safety software.

2 GENERAL QUALITY REQUIREMENTS.

a Quality Assurance Program Development and Implementation. A contractor must assign and identify a senior management position responsible for the development, implementation, assessment, and improvement of a QAP that does the following.

(1) Implements QA criteria as defined in paragraph 3 of this CRD, S/CI prevention requirements as defined in paragraph 4, and safety software as defined in paragraph 5, using a graded approach and describing how the QA criteria and graded approach are applied. See paragraph 2 of this CRD for guidance on compliance.

(2) Uses the appropriate national or international consensus standard where practicable and consistent with contractual or regulatory requirements, and identifies the standard used. Appropriate standards include the following.

(a) ASME NQA-1-2000, *Quality Assurance Requirements for Nuclear Facility Applications* (for nuclear-related activities).

(b) ANSI/ISO/ASQ Q 9001-2000, *Quality Management System Requirements* (for nonnuclear activities).

(c) ANSI/ASQ Z 1.13, 1999, *Quality Guidelines for Research,* (for nonnuclear research activities).

(3) Applies additional standards, where practicable and consistent with contractual or regulatory requirements and as necessary to address unique/specific work activities (e.g., development and use of safety software or establishing the competence of a testing and calibration laboratory). [Note: These standards are sometimes referred to as "voluntary standards." However, once the practicable standard(s) is adopted through regulation, code, contract, QAP, or procedure, compliance with the standard is required and is not voluntary.]

(4) Integrates, where practicable and consistent with contract or regulatory requirements, quality management system requirements as defined in this CRD, the S/CI prevention process (Paragraph 4) and Safety Software Quality Requirements (Paragraph 5) with other quality or management system requirements in DOE directives and external requirements, including as applicable -

(a) DOE P 450.4, *Safety Management System Policy,* dated 10-15-96

(b) DOE P 450.5, *Line Environment, Safety and Health Oversight,* dated 06-26-97.

(c) NNSA *Quality Management Policy*, QC-1, (quality management system for the nuclear weapons complex and weapons-related activities).

DOE/RW-0333P, DOE Office of Civilian Radioactive Waste Management, *Quality Assurance Requirements and Description*.

DOE/CBFO-94-1012, DOE Carlsbad Field Office, *Quality Assurance Program Description*, (for the Waste Isolation Pilot Plant and related activities).

NOTE: This integration requirement does not establish or imply a hierarchy of quality requirements or programs.

b. Quality Assurance Program Approvals and Changes. The contractor must—

(1) Submit a QAP to DOE for approval before beginning work under a DOE contract.

(2) Implement the QAP as approved and modified by DOE.

(3) Indicate in the submittal any third-party certification affecting the QAP

(4) Revise an existing QAP that was approved in accordance with previous versions of this CRD (e.g., CRD to DOE O 414.1B, *Quality Assurance*, dated 04-29-04) to address enhancements required by this CRD.

(5) Regard a QAP as approved by DOE 90 calendar days after DOE receipt, unless approved or rejected by DOE at an earlier date, and include any modification made or directed by DOE.

(6) Submit QAP changes made the previous year annually to DOE for review and approval. In the submittal, identify the changes, the reason for the changes, and the basis for concluding that the revised QAP continues to satisfy the requirements of this CRD.

(a) The contractor may make changes to an approved QAP at any time.

Editorial changes made to correct spelling, punctuation, grammar, etc., do not require explanation.

c. Quality Guidance Usage. The contractor must consider QA guidance in developing and implementing a QAP. The following guidance documents (most recent revisions) are available at http://www.directives.doe.gov/.

(1) DOE G 414.1-1A, *Management Assessment and Independent Assessment Guide for Use with 10 CFR, Part 830, Subpart A, and DOE O 414.1A,*

Quality Assurance; DOE P 450.4, Safety Management System Policy; and DOE P 450.5, Line ES&H Oversight Policy, dated 5-31-01.

(2) *DOE G 414.1-2A, Quality Assurance Management System Guide for Use with 10 CFR 830 Subpart A Quality Assurance Requirements and DOE O 414.1C, Quality Assurance,* dated 6-17-05.

(3) *DOE G 414.1-3, Suspect/Counterfeit Items Guide for Use with 10 CFR 830 Subpart A, Quality Assurance Requirements, and DOE O 414.1B, Quality Assurance,* dated 11-03-04.

(4) *DOE G 414.1-4, Safety Software Guide for use with 10 CFR 830 Subpart A, Quality Assurance Requirements, and DOE O 414.1C, Quality Assurance,* dated 6-17-05.

3. QUALITY ASSURANCE CRITERIA. The QAP must address the following management, performance, and assessment criteria.

a. Management/Criterion 1—Program.

Establish an organizational structure, functional responsibilities, levels of authority, and interfaces for those managing, performing, and assessing work.

Establish management processes, including planning, scheduling, and providing resources for work.

b. Management/Criterion 2—Personnel Training and Qualification.

(1) Train and qualify personnel to be capable of performing assigned work.

(2) Provide continuing training to personnel to maintain job proficiency.

c. Management/Criterion 3—Quality Improvement.

(1) Establish and implement processes to detect and prevent quality problems.

(2) Identify, control and correct items, services, and processes that do not meet established requirements.

(3) Identify the causes of problems, and include prevention of recurrence as a part of corrective action planning.

(4) Review item characteristics, process implementation, and other quality-related information to identify items, services, and processes needing improvement.

d. Management/Criterion 4—Documents and Records.

(1) Prepare, review, approve, issue, use, and revise documents to prescribe processes, specify requirements, or establish design.

(2) Specify, prepare, review, approve, and maintain records.

e. Performance/Criterion 5—Work Processes.

(1) Perform work consistent with technical standards, administrative controls, and hazard controls adopted to meet regulatory or contract requirements using approved instructions, procedures, etc.

(2) Identify and control items to ensure proper use.

(3) Maintain items to prevent damage, loss, or deterioration.

(4) Calibrate and maintain equipment used for process monitoring or data collection.

f. Performance/Criterion 6—Design.

(1) Design items and processes using sound engineering/scientific principles and appropriate standards.

Incorporate applicable requirements and design bases in design work and design changes.

Identify and control design interfaces.

Verify/validate the adequacy of design products using individuals or groups other than those who performed the work.

Verify/validate work before approval and implementation of the design.

g. Performance/Criterion 7—Procurement.

(1) Procure items and services that meet established requirements and perform as specified.

(2) Evaluate and select prospective suppliers on the basis of specified criteria.

(3) Establish and implement processes to ensure that approved suppliers continue to provide acceptable items and services.

h. Performance/Criterion 8—Inspection and Acceptance Testing.

(1) Inspect and test specified items, services, and processes using established acceptance and performance criteria.

(2) Calibrate and maintain equipment used for inspections and tests.

i. Assessment/Criterion 9—Management Assessment. Ensure that managers assess their management processes and identify and correct problems that hinder the organization from achieving its objectives.

j. Assessment/Criterion 10—Independent Assessment.

(1) Plan and conduct independent assessments to measure item and service quality, to measure the adequacy of work performance and to promote improvement.

(2) Establish sufficient authority and freedom from line management for independent assessment teams.

(3) Ensure that persons conducting independent assessments are technically qualified and knowledgeable in the areas to be assessed.

4. DOE-WIDE SUSPECT/COUNTERFEIT ITEM PREVENTION PROCESS. The process is operated by the DOE Office of Environment, Safety and Health as a service to DOE and its contractors and provides for collecting, analyzing, and disseminating S/CI information; notifying Secretarial Officers (SOs) when specific actions must be taken to investigate and resolve S/CI quality and safety issues; and tracking and reporting the status of corrective actions.

NOTE: This service does not relieve the contractor from complying with the requirements defined in this CRD.

a. Supplemental Quality Management System Requirements for Suspect/Counterfeit Items. An S/CI prevention process must be developed and implemented as a part of the contractor's QAP and must be commensurate with the facility/activity hazards and mission impact. The QAP must be applied to identifying, analyzing, and removing S/CIs and preventing them from being supplied to DOE/NNSA and its contractors. The QAP must address the following elements for S/CI prevention.

(1) Preventing the introduction and use of S/CIs through engineering involvement, design, procurement, testing, inspection, maintenance, evaluation, disposition, reporting, trend analysis, and lessons learned work process controls.

(2) Training and informing managers, supervisors, and workers on S/CI processes and controls (including prevention, detection, and disposition of S/CIs).

(3) Identifying and disposing of S/CIs onsite

(4) Restricting S/CI use to only those items that have been found acceptable through engineering analysis and formal disposition process.

(5) Collecting, maintaining, disseminating, and using the most accurate, up-to-date information on S/CIs and associated suppliers using all available sources. S/CI information sources include the following.

Government-Industry Data Exchange Program (www.gidep.org).

(b) Institute of Nuclear Power Operations (www.inpo.org).

(c) DOE Occurrence Reporting and Processing System (http://www.eh.doe.gov/paa/orps.html).

(d) DOE S/CI Web site (http://www.eh.doe.gov/sci/).

(6) Identifying the management point of contact responsible for these activities to ensure that the DOE Office of Environment, Safety and Health has a viable recipient for S/CI information notices.

b. Work Process Controls. Work processes must be developed and implemented using available S/CI information and must include the following elements.

(1) Engineering involvement in the development of procurement specifications; during inspection and testing; and when replacing, maintaining, or modifying equipment.

(2) Procurement processes that prevent introduction of S/CIs by

(a) identifying technical and QA requirements in procurement specifications;

accepting only those items that comply with the procurement specifications consensus standards, and commonly accepted industry practices; and

inspecting inventory and storage areas to identify, control, and disposition S/CIs.

(3) Inspection, identification, evaluation, and disposition of S/CIs installed in all safety applications[1] and other applications that create potential hazards.

(4) Engineering evaluations and disposition of S/CIs installed in safety applications/systems or in applications that create potential hazards. The evaluations must consider potential risks to the public and worker and cost/benefit impact, and include a schedule for replacement (if required).

(5) Ensuring that S/CIs identified in nonsafety applications during routine maintenance and/or inspection are reported, evaluated, and dispositioned to prevent future use in safety applications.

(6) Contacting the DOE Inspector General (IG) before destroying or disposing of S/CIs and their documentation to determine whether to retain them for criminal investigation or litigation.

Testing procured or installed S/CIs as necessary using approved engineering test methods.

Reporting S/CIs as per DOE O 231.1A Change 1, *Environment, Safety, and Health Reporting,* dated 06-03-04, and DOE O 221.1, *Reporting Fraud, Waste, and Abuse,* dated 03-22-01, to—

(a) the responsible DOE/NNSA line management offices;

(b) the Office of Environment, Safety and Health; and

(c) the Office of the Inspector General.

(9) Conducting trend analysis and issuing lessons learned reports for use in improving the S/CI prevention.

5. SAFETY SOFTWARE QUALITY REQUIREMENTS. These requirements are necessary to ensure that DOE/NNSA safety software in nuclear facilities performs its intended specific functions in relation to structures, systems, or components (SSCs) and that the classification, design, and analysis associated with nuclear facility operations is correct. These requirements complement those of 10 CFR 830 and provide detail for work associated with safety software that is conducted under the nuclear facility QAP compliant with 10 CFR 830.

Work processes involving safety software must be developed and implemented using national or international consensus standards and must include the following elements.

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[1]Safety applications are those whose failure could adversely affect the environment, safety, or health of the public or workers. This term includes safety systems in nuclear facilities (see 10 CFR 830.2).

a. Facility design authority involvement in identifying software specification, acquisition, design, development, verification and validation (including inspection and test), configuration management, maintenance, and retirement.

b Identify, document, and maintain safety software inventory

c. Establish grading levels for safety software. Document those grading levels in the QAP.

d . Using the grading levels established and approved above, select and implement the applicable software QA work activities from the following list to ensure that safety software performs its intended functions. ASME NQA-1-2000, *Quality Assurance Requirements for Nuclear Facility Applications,* or other national or international consensus standards that provide an equivalent level of quality assurance requirements as NQA-1-2000, must be used to implement these work activities. The standards used must be specified by the user and approved by DOE. DOE G 414.1-4 provides acceptable implementation strategies and appropriate standards for these work activities.

(1) Software project management and quality planning

(2) Software risk management

(3) Software configuration management

(4) Procurement and supplier management

(5) Software requirements identification and management

(6) Software design and implementation

(7) Software safety

(8) Verification and validation

Problem reporting and corrective action

Training of personnel in the design, development, use, and evaluation of safety software

1.0 PURPOSE AND SCOPE

1.1 PURPOSE

1.1.1 Quality Assurance Program (QAP)

A. This Quality Assurance Program Manual (QAPM) describes the QAP for the Department of Energy Savannah River Operations Office (DOE-SR) as required by DOE O 414.1B, "Quality Assurance." It describes the overall program (management system) established to assign responsibilities and authorities, define policies and requirements, and provide for the performance and assessment of work.

B. The DOE-SR QAP is a management system that ensures DOE-SR's mission, policies, and objectives are integrated into standard business practices and work processes. Functions and activities performed to satisfy or implement DOE-SR's mission, policies, and objectives are based on the requirements of various source documents (e.g., DOE Orders, Federal Regulations, commercial standards). The commercial consensus standard upon which the DOE-SR QAP is primarily based is the American Society of Mechanical Engineers (ASME) NQA-1-2000, "Quality Assurance Requirements for Nuclear Facility Applications." The requirements of this standard are tailored using a graded approach to meet the needs of an organization whose primary functions involve contractor oversight.

C. The QAP involves all DOE-SR organizational components and is not the sole ownership of any single group. It is based on the criteria applicable to DOE as stated in paragraphs 4 and 5 of DOE O 414.1B, "Quality Assurance." The QAP applies to the management and oversight of basic and applied research, scientific investigation, engineering design, operations, maintenance, repair and decommissioning of facilities, and eventual environmental restoration and reflects DOE-SR's comprehensive way of doing business throughout the life cycle of DOE programs and projects.

D. The goal of the QAP is to achieve continuous improvement while satisfying the appropriate requirements in a cost-effective manner. To achieve that goal, a culture that encourages all employees to establish and maintain high standards, identify and resolve problems, accept recommendations for improvement, and foster mutual respect and effective communication has to be established and maintained. Employees are responsible for continuous pursuit of enhancements to safety and quality -- not just complying with a minimal set of requirements.

E. The flow down to contractors of quality requirements, as well as other environment, safety and health requirements, is performed using a process that generates a Standards/Requirements Identification Document (S/RID). An S/RID is considered a part of the official contract between DOE-SR and a contractor and is approved by DOE. The S/RID process is defined and controlled by the requirements in SRIP 251.2, "Oversight of Contractor S/RID Activities." Validation and verification of contractor compliance with an S/RID is accomplished primarily through independent assessments, oversight of contractor self-assessments, and the facility representative oversight process.

Quality Assurance Program Manual (QAPM)

A. This QAPM is written to reflect the tone and format of DOE O 414.1B, "Quality Assurance," in that it contains a section corresponding to each of the ten criteria of DOE O 414.1B. Within each criterion section, the basic requirement of DOE O 414.1B has been quoted, followed by a description of how DOE-SR satisfies the applicable portions of the requirement. Following the description, DOE-SR responsibilities are assigned and defined at the level where requirement implementation is most effective. At the end of each criterion section, there is a statement of implementation.

B. In addition to the ten criteria of DOE O 414.1B, the QAPM contains a section covering the DOE-SR Suspect/Counterfeit Item Program (section 14); Corrective Action Management Program (section 15); and Safety Software Quality Requirements (section 16).

C. The transmission of Quality Assurance requirements to contractors is accomplished in the formal contracting process. For example, Federal Acquisition Requirements (FAR) and DOE Acquisition Requirements (DEAR) are passed on to the Savannah River Site (SRS) management and operating (M&O) contractor, Westinghouse Savannah River Company (WSRC), and safeguards and security contractor, Wackenhut Services, Incorporated (WSI), through their respective contracts. These contracts require them to subsequently flow down the requirements to any subcontractors or vendors doing work or providing products and services for SRS.

Project-Specific QAPs

A. While the requirements of DOE O 414.1B involve all DOE-SR functions and activities, specific DOE-SR projects may impose other quality assurance program requirements. When this occurs, DOE-SR evaluates the project-specific requirements to determine their impact on this QAPM. If there are significant differences, DOE-SR addresses those requirements in project-specific QAPs. These requirements originate in ASME NQA-1-2000, "Quality Assurance Requirements for Nuclear Facility Applications," or other national or international standards and are documented in the appropriate contracts utilizing the S/RID process.

B. The Office of Civilian Radioactive Waste Management (OCRWM) establishes requirements governing the waste acceptance process activities for the high-level waste form production to ensure its acceptance in the repository at Yucca Mountain. The Office of Environmental Management (EM) conducts audits, typically annually, with the support of OCRWM to establish and maintain a high degree of confidence that the quality assurance requirements for high-level waste form production are being met.

1.1.4 Integrated Safety Management System (ISMS)

A. The objective of ISMS is to ensure that DOE-SR and its contractors systematically integrate safety into management and work practices at all levels so that missions are accomplished while protecting the worker, the public, and the environment. The bottom-line objective is to "DO WORK SAFELY." The DOE-SR QAP is consistent with and identified as an integral part of the DOE-SR safety management system. The mechanisms used in the implementation of the DOE-SR QAP are linked to the implementation of the ISMS core functions and guiding principles. These commonly referenced DOE-SR mechanisms are found throughout both SRM 400.1.1B, "DOE-SR Safety Management System Description Manual" and the QAP.

B. Savannah River Policies (SRP), Notices (SRN), Manuals (SRM), and Implementing Procedures (SRIP) define the principal mechanisms for implementing the DOE-SR ISMS. These directives provide the detail necessary to ensure the proper implementation of QAP and ISMS requirements. Maintenance and control of implementing directives is described in Section 7 of this QAPM.

Environmental Management System (EMS)

A. The SRS has implemented an EMS in accordance with the requirements of the International Standards Organization (ISO) 14001, "Environmental Management System;" Executive Order 13148, "Greening of Government Through Leadership in Environmental Management;" and DOE Order 450.1, "Environmental Protection Program." In addition to DOE-SR, it encompasses the primary site contractors and other government agencies located at SRS. The EMS is not a standalone system, but is an integral part of the ISMS as required by DOE Order 450.1.

B. Verification of implementation and maintenance of the SRS EMS is accomplished by a SRS EMS Task Committee and through assessments by DOE-SR (particularly the Environmental Quality Management Division) and site contractors.

C. The SRS EMS is described in SRP 04-03, "Savannah River Site Environmental Management System Policy."

1.2 SCOPE

This manual applies to all DOE-SR Federal employees. The National Nuclear Security Administration – Savannah River Site, consisting of the Savannah River Site Office (SV) and the Fissile Materials Disposition Office (NA-266), may elect to adopt this directive for the conduct of their business.

This QAPM is NOT applicable to contractors or subcontractors who have in place a QAP that has been approved by the DOE-SR Manager in accordance with DOE O 414.1.1B, "Quality Assurance." For example, the M&O contractor, WSRC, and the safeguards and security contractor, WSI, both have approved QAPs in place. The requirements of this QAPM flow down to all contractors and subcontractors performing work for DOE-SR who do not have a DOE-SR approved QAP.

U.S. Department of Energy

Washington, D.C.

ORDER

DOE O 435.1

Approved: 7-09-99
Review: 7-09-01
Change 1: 08-28-01

SUBJECT: RADIOACTIVE WASTE MANAGEMENT

1. OBJECTIVE. The objective of this Order is to ensure that all Department of Energy (DOE) radioactive waste is managed in a manner that is protective of worker and public health and safety, and the environment.

2. CANCELLATION. This Order cancels DOE 5820.2A, RADIOACTIVE WASTE MANAGEMENT, dated 9-26-88. Cancellation of that Order does not, by itself, modify or otherwise affect any contractual obligation to comply with the Order. The provisions of this canceled Order which have been incorporated by reference in a contract shall remain in effect until the contract is modified.

3. APPLICABILITY.

   a. DOE Elements. This Order applies to all DOE elements, including the National Nuclear Security Administration (NNSA), except as stated in item "d."

   b. Radioactive Waste. Except as stated in item "d," this Order applies to the management of:

      (1) All high-level waste, transuranic waste, and low-level waste, including the radioactive component of mixed waste, for which DOE is responsible;

      (2) DOE accelerator-produced radioactive waste; and

      (3) If managed at DOE low-level waste facilities, byproduct materials as defined by section 11e.(2) of the *Atomic Energy Act of 1954*, as amended, or naturally occurring radioactive materials.

   c. Contractors. The Contractor Requirements Document, Attachment 1, sets forth requirements to be applied to contractors performing work that involves management of DOE radioactive waste at DOE-owned or leased facilities. Contractor compliance with the Contractor Requirements Document will be required to the extent set forth in a contract.

Vertical line denotes change

Distribution:
All Departmental Elements

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Office of Environmental Management

VALIDATION

VERSION 2.50

APPROVED for Release for
Unlimited (Release to Public)

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1.2 OVERVIEW OF TEST PROBLEMS

1.2.1 *Verification Test Problems*

Problem V1: Transient One-Dimensional Diffusion: This problem simulates the diffusive transport of a contaminant in a homogeneous, semi-infinite slab. The contaminant concentration at the right edge of the slab is maintained at a constant value. The left edge is insulated so that no contaminant enters or leaves the boundary. An analytic solution for this problem is given by Carslaw and Jaeger (1959). This problem tests the diffusive transport component of the PORFLOW algorithm.

Problem V2: Heat Transfer in Unidirectional Flow: In this test, advective, diffusive and dispersive heat transfer in a saturated porous medium is simulated. The computational domain consists of a horizontal slab with unidirectional flow from left to right. Initially, the temperature is uniform throughout the domain. At time t=0, water with a higher temperature begins entering the computational domain from the left boundary. The analytic solution for this problem is given by Carslaw and Jaeger (1959). The problem, as formulated, is attributed to Avdonin (1964) and has been used previously for verification of computer codes by several authors. The primary objective of this problem is to test the ablility of PORFLOW to correctly simulate coupled advective and dispersive transport.

Problem V3: Theis Solution for Transient Drawdown: This classic problem (Theis, 1935) simulates the transient drawdown of pressure head due to pumping in a homogeneous, confined aquifer of constant thickness that is fully penetrated by a well. The problem was originally posed and solved by Theis with the assumption that the flow is radial. It tests the ability of PORFLOW to correctly propagate a pressure transient in a radial geometry.

Problem V4: Finite Cylinder with Heat Source: This problem involves a finite cylinder in which heat is generated at a constant rate while the surface of the cylinder is maintained at zero temperature. The purpose of this test is to determine the ability of PORFLOW to simulate heat sources. The analytic solution for this problem is described by Carslaw and Jaeger (1959).

Problem V5: Convective Heat Transfer in Regional Flow: This problem concerns a homogenous, isotropic, vertical cross-section of a region with a geothermal gradient. The geothermal heat flux enters the region from the bottom and leaves through a constant-temperature surface at the top. The region is bounded on its two vertical faces with topological divides such that there is no major lateral flow. A recirculating flow pattern is induced due to lateral variations in the water table. This problem was formulated and solved by Domenico and Palciauskas (1973). The objective of the problem is to test the capability of the PORFLOW algorithm to predict convective heat transfer in the presence of a non-uniform flow field.

Problem V6: Three-Dimensional Contaminant Transport: This problem simulates the transport of a contaminant in a three-dimensional domain. A finite source near the upper surface of the computational domain continuously releases a contaminant into an aquifer that initially is free of the contaminant. The flow within the aquifer is unidirectional. Advective transport moves the contaminant in the downstream direction, while dispersive movement causes spreading of the contaminant in all directions. An analytic solution for this problem was obtained by Codell et al. (1982). This problem tests the ability of PORFLOW to simulate three-dimensional advective and dispersive transport of a contaminant from a finite source.

Problem V7: Philip's Horizontal Unsaturated Flow: The physical setting for this problem is a horizontal slab of homogeneous, isotropic soil. The vertical extent of the slab is infinite. Initially, the soil is partially saturated with ground water. At time t=0, the saturation at the left boundary is increased to unity. This saturation front then migrates downstream. The objective of this problem is to test the ability of PORFLOW to correctly compute a propagating saturation front in the absence of gravitational effects. An analogous problem was first formulated and analytically solved by Philip (1957a).

Problem V8: Philip's Vertical Unsaturated Column: The physical setting for this problem is a vertical column of homogeneous, isotropic soil. The horizontal extent of the column is considered to be infinite. The soil is initially partially saturated. At time t=0, the saturation at the top boundary is increased to unity. Transient infiltration of moisture in the vertical direction results from capillary forces and gravity. An analytic solution for an analogous problem with a propagating front was obtained by Philip (1957b). This problem tests the ability of PORFLOW to correctly simulate a migrating saturation front in the presence of gravitational effects.

Problem V9: Infiltration from a Line Source: This problem describes the flow from a single subsurface irrigation pipe that is located in an unsaturated zone above a shallow water table. Due to the infinite extent of the problem along the direction of the porous pipe, this three-dimensional problem with a line source is mathematically equivalent to a two-dimensional problem with a point source. An approximate analytic solution for this problem is given by Warrick and Lomen (1977). The objective of this problem is to evaluate the ability of PORFLOW to correctly simulate flow and saturation distribution in a variably-saturated, two-dimensional domain.

Problem V10: Free-Surface Boussinesq Flow with Recharge: This problem concerns a semi-infinite, unconfined aquifer. Initially, the phreatic surface is horizontal everywhere. At time t=0, the water level at the left boundary is suddenly raised. A compression wave, consisting of an elevated phreatic surface, then propagates from left to right in a transient manner. This problem is often referred to as the Boussinesq problem. It is described in detail by Polubarinova-Kochina (1954). The objective of this test is to determine the ability of PORFLOW to correctly model a compression wave in an unconfined aquifer.

Problem V11: Free-Surface Boussinesq Flow with Seepage: This test problem is a variation of the previous Boussinesq problem. In this test case also, the initial phreatic surface is horizontal everywhere. At time t=0, the water level at the left boundary is suddenly lowered. An expansion wave, consisting of a lowered phreatic surface, then propagates from right to left in a transient manner. The objective of this test is to determine the ability of PORFLOW to correctly simulate an expansion wave in an unconfined aquifer.

1.2.2 *Benchmark Test Problems*

Problem B1: Two-Dimensional Transient Infiltration: This problem considers flow through a two dimensional, rectangular column of partially saturated soil. The right vertical face of the column is held at its initial pressure head, while the pressure in the upper part of the left vertical face is increased. The lower part of the left face is impermeable. This causes a two-dimensional saturation front to propagate from left to right. This problem was proposed by Ross et al. (1982) for benchmark testing of computer codes. Pruess (1987) has solved this problem numerically with the TOUGH computer code. It tests the ability of PORFLOW to correctly simulate saturation fronts propagating in two dimensions.

Problem B2: Two-Dimensional Steady-State Infiltration: This problem concerns the steady-state movement of moisture under variably saturated flow conditions. The physical setting for the problem is a vertical cross-section of an aquifer with a regional hydrologic gradient. The lateral extent of the aquifer is assumed to be infinite and only a unit width is considered. Recharge occurs at the left boundary and the flow discharges at the right boundary. Additional recharge occurs through infiltration at the surface. The problem is described by Magnuson et al. (1990) and has been used as a benchmark problem for several codes. The FEMWATER computer code by Yeh and Ward (1979) was used as a benchmark for comparing the PORFLOW results. This problem tests the ability of PORFLOW to compute two-dimensional, variably saturated flow with infiltration.

Problem B3: Jornada Test Trench Simulation: This problem is based on the field tests conducted at the Jornada Test Site near Las Cruces, New Mexico. The test involves transient, two-dimensional infiltration of water into an extremely dry heterogeneous soil. The physical setting and hydraulic properties of the soil are described by Smyth et al. (1989). The test area comprises three layers of soil which vary in material and hydrologic properties. Additionally, a small zone of high conductivity soil is contained within the lowermost soil layer. The experiment was conducted under the direction of Dr. Peter Wierenga of the University of Arizona. Smyth et al. (1989) numerically solved four problems of increasing complexity using the TRACER3D computer code. The problem considered here is the fourth and most complex of these problems. It was also numerically solved by Magnuson et al. (1990) using the TRACER3D, FLASH and PORFLOW (Version 1.00) computer codes. This problem tests the

POR FLOW

a software tool for multiphase fluid flow, heat and mass transport in fractured porous media

USER'S MANUAL

VERSION 5.0

Rev:5

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PREFACE

During the past 25 years, **PORFLOW™** has evolved from a simple mathematical model for flow and heat transfer into a comprehensive **software tool for analysis of a wide range of environmental applications in flow, heat and mass transport in geologic media**. It provides for coupled transport of flow, heat and multiple chemical species in complex three-dimensional geometry, transient or steady-state flow, confined or unconfined aquifers, fully or partially saturated media, single or multiple phase systems, and phase change between liquid and solid and liquid and gaseous phases. It has grown from a simple computer code with few modules and fewer options to a software package with well over 300 modules and a versatile set of options that can accommodate almost any user requirements

PORFLOW™ has been used to analyze problems as diverse as salinity intrusion into fresh water aquifers and remediation of hazardous waste sites. It has been used to evaluate pumping of an aquifer over a period of days, remediation of waste sites over a period of years, corrosion of waste canisters over tens of years, and transport of contaminants from nuclear waste over a time span of hundreds of thousands of years.

In the process, **PORFLOW™** has evolved with the user's needs. At every stage, the flexibility and generality of the software were maintained while options were added to address user requirements. As a result, today **PORFLOW™** provides a flexible format that is bound neither to a specific algorithm, nor to a particular methodology. Rather, it provides a framework that facilitates experimentation. The user can change numerical schemes, solution method, matrix inversion algorithms, or any of the physical or mathematical features.

Of all features of **PORFLOW™**, two deserve special mention: generality of applications over a diverse range of problems, and ease of use provided by the conversational **FREEFORM™** command language. These have enabled **PORFLOW™** to emerge as leading software in its field of application.

PORFLOW™ is also distinguished from other computer models by the diversity of its users. Commercial, research and educational organizations in 15 countries are using the software. Among its users are: U.S. DOE, USGS, U.S.NRC, U.S.Army, Southwest Research Institute, Idaho National Engineering Laboratory, Oak Ridge National Laboratory, Savannah River Laboratory, Battelle Pacific Northwest Laboratory, ANDRA (France), SCK-CEN (Belgium), AECL (Canada), Westinghouse, Lockheed Martin, Fluor Daniel, Rockwell, and a large number of other commercial organizations. Over 100 publications and project reports on the benchmarking, verification and application of **PORFLOW™** are currently available.

PORFLOW™ has been extensively peer-reviewed. Idaho National Engineering Laboratory, Battelle Pacific Northwest, and Prof. Allan Freeze of the University of British Columbia have formmaly reviewd **PORFLOW™** or its derivatives. Additionally, it has been reviewed by ANDRA (France), BAe-SEMA (UK), British Petroleum (UK), Exxon Production Research, Failure Analysis Associates Inc., Fluor Daniel Inc., Gaz de France (France), SAIC, Shell Oil, SOHIO, and Westinghouse Hanford Company.

PORFLOW™ relies on the numerical solution of complex mathematical equations. Some familiarity with the strengths and weaknesses of such mathematical and numerical algorithms is highly recommended. Every attempt has been made to provide the necessary information for satisfactory use of **PORFLOW™** in this manual. As is the case for any software of this type, it is not possible to anticipate all questions and users' requirements. In addition to this manual, Analytic & Computational Research, Inc. also provides training and support in the use of the software. For additional questions and enquiries, please contact:

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Akshai Runchal
Bel Air, California
March 25, 2002

U.S. Department of Energy
Washington, D.C.

ORDER

DOE O 414.1B

Approved: 04-29-04
Review: 04-29-06

SUBJECT: QUALITY ASSURANCE

1. OBJECTIVES.

   a. To ensure that the quality of Department of Energy (DOE), including National Nuclear Security Administration (NNSA), products and services meet or exceed customers' expectations.

   b. To achieve quality assurance (QA) for all work based upon the following principles:

      (1) That quality is assured and maintained through a single, integrated, effective quality assurance program (i.e., management system).

      (2) That management support for planning, organization, resources, direction, and control is essential to QA.

      (3) That performance and quality improvement require thorough, rigorous assessment and corrective action.

      (4) That workers are responsible for achieving and maintaining quality.

      (5) That environmental, safety, and health risks and impacts associated with work processes can be minimized while maximizing reliability and performance of work products.

   c. To establish quality process requirements to be implemented under a QA Program (QAP) for the control of suspect/counterfeit items and safety issue corrective actions.

2. CANCELLATIONS. This Order cancels the following.

   a. DOE O 414.1A, *Quality Assurance*, dated 9-29-99.

   b. Portions of DOE O 440.1A, *Worker Protection Management for DOE Federal and Contractor Employees*, dated 3-27-98, as follows:

      (1) Attachment 1, paragraph 8, Suspect and Counterfeit Item (S/CI) Controls, and

      (2) Attachment 2, paragraph 22, Suspect and Counterfeit Item (S/CI) Controls.

DOE M 435.1-1

Approved: 7-09-99
Change 1: 6-19-01

R

RADIOACTIVE WASTE MANAGEMENT MANUAL

U.S. DEPARTMENT OF ENERGY

Distribution:
All Departmental Elements

Initiated By:
Office of Environmental Management

RADIOACTIVE WASTE MANAGEMENT MANUAL

1. PURPOSE. This Manual further describes the requirements and establishes specific responsibilities for implementing DOE O 435.1, *Radioactive Waste Management*, for the management of DOE high-level waste, transuranic waste, low-level waste, and the radioactive component of mixed waste. The purpose of the Manual is to catalog those procedural requirements and existing practices that ensure that all DOE elements and contractors continue to manage DOE's radioactive waste in a manner that is protective of worker and public health and safety, and the environment.

2. APPLICABILITY. The requirements set forth in this Manual apply to DOE elements and contractors as set forth in DOE O 435.1, *Radioactive Waste Management*.

3. SUMMARY. This Manual is organized into four (4) chapters. Chapter I, *General Requirements and Responsibilities*, contains requirements and responsibilities which are applicable to all radioactive waste types and delineates responsibilities for radioactive waste management decision-making at the complex-wide and Field Element levels. Chapters II through IV contain those requirements that are applicable to high-level waste, transuranic waste, and low-level waste including the radioactive component of mixed low-level waste, respectively.

4. IMPLEMENTATION. The requirements of this Manual apply to all new and existing DOE radioactive waste management facilities, operations, and activities. Implementation of the requirements shall begin at the earliest possible date, and all DOE entities shall be in compliance with this directive within one year of its issuance. Compliance with this directive includes implementing the requirements or an approved implementation or corrective action plan. If compliance with this Order cannot be achieved within one year of its issuance, the Field Element Manager must request approval to extend the compliance date to no later than October 1, 2001, from the cognizant Program Secretarial Officer (PSO). Failure to implement the requirements of this directive shall, through the appropriate lines of management, result in corrective actions including, if necessary, shutdown of radioactive waste management facilities, operations, or activities until the appropriate requirements are implemented. Any of the requirements in this Manual may be waived or modified through application of a DOE-approved requirements tailoring process, such as the "Necessary and Sufficient Closure Process" in DOE P 450.3 and DOE M 450.3-1 and DOE P 450.4, *Safety Management System Policy*, the applicable or relevant and appropriate requirements identification process for actions taken pursuant to the Department's CERCLA authorities, or by an exemption processed in accordance with the requirements of DOE M 251.1-1A, *Directives System Manual*.

Manual Number: 1Q

Manual Title: *Quality Assurance Manual*

Revision Summary

1.	**Document and Revision Numbers:** 20-1, Revision 8
2.	**Document Title:** Software Quality Assurance
3.	**Effective Date:** 10/16/03
4.	**Document Changes** (can be in paragraph or list): ***Editorial Only__X___ Title Change_____ Forms Revised_____ Cancellation_____*** **<u>Attachments:</u>** Attachment 2, Typo: Change G to R for Level B Software Development and Level B Purchased Software. Changed G= Graded/Safe Mission Essential applicability to G= Graded Approach Attachment 3: Changed G= Graded/Safe Mission Essential applicability to G= Graded Approach
5.	**Training Requirements:** (As with any procedure revision, those employees affected by the procedure need to familiarize themselves with the changes. No additional training is required.)

Software Quality Assurance

APPROVED
COMPANY-LEVEL
PROCEDURE

Purpose

This procedure defines the requirements and responsibilities for a standard systematic approach for the quality control of computer software.

This procedure also establishes a mechanism for WSRC to meet the applicable requirements in support of WSRC contractual obligations. For a current list of Source Document references, go to the Standards/Requirements Identification Document (S/RID) webpage accessible through ShRINE.

Scope

The provisions of this procedure apply to Westinghouse Savannah River Company (WSRC) and other members of the Performing Entity (i.e., WSRC, Bechtel Savannah River, Inc. {BSRI}, BWX Technologies {BWXT}, Inc., Savannah River Company, and BNFL Savannah River Corporation) for management and operations at Savannah River Site (SRS), and to subcontractors performing work for any member of the Performing Entity when required by contract or applicable law that develop, procure, maintain, operate, use, or retire software. It defines the extent and level of software life cycle controls and software design verification activities related to software based on the software classification of the software application. The software classification is based on the intended use of the software.

This procedure applies to all software and firmware except:

- Software which is part of measuring and test equipment (M&TE) or measuring systems and equipment (MS&E) where the equipment is verified periodically as part of a calibration program compliant with Procedure Manual 1Q, *Quality Assurance Manual*, Procedure 12-1, "Control of Measuring and Test Equipment" or Procedure Manual 1Q, Procedure 2-7, "QA Program Requirements for Analytical Measurement Systems" respectively
- Engineering Calculations under control of Procedure Manual E7, *Conduct of Engineering and Technical Support*, Procedure 2.31, "Engineering Calculations"
- Software used exclusively for scoping activities as defined by Procedure Manual 1Q, Procedure 2-3, "Control of Research and Development Activities"

Terms and Definitions

See Procedure Manual 1Q, Appendix A, "Glossary of Terms" for Terms and Definitions http://www.srs.gov/msd/1q/appendixa.html

Responsibilities

Managers

- ensure a software quality assurance program is established, documented, and implemented in accordance with this procedure,
- designate individuals or organizations responsible for implementing this procedure and define the interfaces with external organizations.

Cognizant Technical Functions (CTFs)

- ensure software classification is determined for the intended use of software,
- ensure Software Quality Assurance (QA) procedures/plans are reviewed and approved by the CTF's manager and the CTF's Cognizant Quality Function (CQF).

Cognizant Quality Functions (CQFs)

- review and approve Software QA procedures/plans
- accepts or rejects Level E software classifications
- verify Software Classifications are established

Procedure

This procedure comprises the following Sections:

A. General
B. Software Classification Requirements
C. Software Quality Assurance Procedures/Plans
D. Software Life Cycle
E. Software Configuration Control
F. Existing and Acquired Software
G. Software Procurement
H. Problem Reporting and Corrective Action
I. Access Control

A. General

1. Management ensures that a software quality assurance program is established, documented, and implemented. They designate individuals or organizations responsible for implementation and define the interfaces with external organizations.

2. Software shall be controlled throughout its life cycle, using a graded approach, based on its software classification. It is not the intent of this procedure to restrict the software life cycle methodology defined in implementing procedures, provided that the chosen methodology encompasses the activities, documentation, reviews, and approvals required by this procedure.

3. The WSRC approach to Software Quality Assurance is based on a classification scheme used for managing the software through out the life cycle based on its intended function. The two types of classification are:

   - software designated with an A through E classification, or

   - software designated as part of a Structure, System, or Component (SSC) with an assigned functional classification

B. Software Classification Requirements

1. The CTF shall determine which classification process applies (A through E or Functional Classification).

2. Classification of software using the A through E designation is based on: its direct effect on nuclear safety protection systems; indirect effect on nuclear safety protection systems or toxic material hazard systems; unacceptable programmatic, schedule, or cost effects; or, importance to daily business operations. The detailed definition for the A through E designation is outlined in Attachment 1, "A through E Graded Approach to Software Classification". The Life Cycle Documentation associated with these software classifications is provided in Attachment 2, "A through E Life Cycle Documentation Requirements Matrix".

3. Software that is part of an SSC which has a Component Location Identifier (CLI) Number (as defined in Procedure Manual E7, Procedure 1.30 "Component Numbering System") is classified using the associated Functional Classification. SSC designated software is classified using the Functional Classification approach (reference Procedure Manual E7, Procedure 2.25, "Functional Classifications"). The Life Cycle Documentation associated with these software classifications is provided in Attachment 3, "SSC Software Life Cycle Documentation Requirements Matrix".

4. Detailed implementation requirements for the application of the software classification process is provided in organizational specific manuals (for example, E7, 12B, L1, etc.) or software project management plans.

5. The CTF will assure that the software quality assurance implementation process meets the requirements throughout the entire software life cycle.

6. The CQF will verify that the software classification has been established and approves the use of software classified Level E.

C. Software Quality Assurance Procedures/Plans

1. Based on the nature, complexity, and intended use of the software, the CTF shall ensure that procedures/plans for software quality assurance are prepared which identify the following:

   a. the software products to which it applies

   b. the organizations responsible for performing the work and achieving software quality, and their tasks and responsibilities

   c. the software engineering methods

   d. required documentation

   e. standards, conventions, techniques, or methodologies which shall be used to guide the software development, as well as methods to assure compliance to the same

   f. the required software reviews

   g. the methods for error reporting and corrective action

2. These procedures/plans may be prepared individually for each software project, or may exist as a generic document to be applied to software prepared within, procured, or used by each organization. Software QA procedures/plans shall be reviewed and approved by the CTF's manager and the CTF's CQF. Optionally, these requirements may be distributed within the software life cycle documentation specified in Section D. If such requirements are distributed in life cycle documentation, the CQF shall review and approve these documents to ensure that such requirements are addressed prior to the implementation phase.

D. Software Life Cycle

1. Introduction

   Software shall be controlled in a traceable, planned, and orderly manner. The software life cycle defined in this section provides the basis for planning and implementing a software development, maintenance, or application project. This section identifies the specific software activities, documentation, and reviews associated with each life cycle phase. The identified life cycle phase requirements shall be applied using the graded approach appropriate for the software. However, no strict chronological constraints exist between the requirements identified. The number of phases and relative emphasis placed on each phase of software development or maintenance shall be defined in the software QA procedure/plan and will be dependent on the nature and complexity of the software. As each life cycle document is approved, it shall be placed under configuration control in accordance with Section E.

2. Requirements Phase

   a. During this phase the requirements that the software must satisfy shall be specified, documented, reviewed, and approved. These requirements shall define the functions to be performed by the software and shall provide the detail and information necessary to design the software.

   b. Software requirements shall be verifiable and traceable throughout all stages of the software development cycle.

   c. Documentation

      Software requirements documentation shall define requirements for, functionality, performance, design inputs, design constraints, installation considerations, operating systems (if applicable), and external interfaces necessary to design the software. Acceptance criteria shall be established in the software requirements documentation for each of the identified requirements. Such criteria shall be used for verification/validation planning and performance as defined in each related life cycle phase.

   d. Review and Approval

      The CTF shall assure that the software requirement documentation is reviewed and approved by the responsible organization at the completion of this phase. This review shall assure that the requirements are complete, verifiable, consistent, and technically feasible. The review shall also assure that the requirements will result in a feasible and usable final product.

3. Design Phase

   a. During this phase a software design shall be developed, documented, and reviewed and controlled. The responsible design organization shall prescribe and document the design activities to the level of detail necessary to permit the design process to be carried out and to permit verification that the design meets requirements.

   b. Design Elements

      (1) The design shall specify the interfaces, overall structure (control and data flow) and the reduction of the overall structure into physical solutions (algorithms, equations, control logic, and data structures).

      (2) Computer programs are designed as an integral part of an overall system. Therefore, software design shall consider the computer program's operating environment.

(3) Measures to mitigate the consequences of problems shall be an integral part of software design. These potential problems include external and internal abnormal conditions and events that can affect the computer program

c. Documentation

Software design documentation shall contain:

(1) a description of the major components of the software design as they relate to the software requirements;

(2) a technical description of the software with respect to the theoretical basis, mathematical model, control flow, data flow, control logic, data structure, numerical methods, physical models, process flow, process structures, and applicable relationship between data structure and process standards;

(3) a description of the allowable or prescribed ranges for inputs and outputs;

(4) the design described in a manner that can be translated into code; and

(5) a description of the approach to be taken for intended test activities based on the requirements and design that specify the hardware and software configuration to be used during test execution.

d. Review and Approval

(1) The organization responsible for the design shall identify and document particular verification methods to be used and assure that an Independent Review (IR) is performed and documented. This review shall evaluate the technical adequacy of the design approach; assure internal completeness, consistency, clarity, and correctness of the software design; and verify the software design is traceable to the requirements.

(2) The organization responsible for the design shall also assure that the test results adequately demonstrate the requirements have been met (See Section D. 5. "Test Phase").

(3) The IR shall be performed by competent individual(s) other than those who developed and documented the original design, but who may be from the same organization. The results of the IR shall be documented with the identification of the verifier indicated. When review alone is not adequate to determine if requirements are met, alternate calculations shall be used, or tests shall be developed and integrated into the appropriate activities of the software development cycle. Software design documentation shall be completed prior to finalizing the IR.

(4) The extent of the IR and the methods chosen are a function of:

(a) the importance to safety,

(b) the complexity of the software,

(c) the degree of standardization, and

(d) the similarity with previously proven software.

4. Implementation Phase

a. Implementation Phase

During this phase the implementation process shall result in software products such as computer program listings and instructions for computer program use. The implemented software shall be analyzed to identify and correct errors. The source code for development of software classified

A/B or SC/SS shall be placed under configuration control in accordance with Section E (Software Configuration Control) prior to commencement of the Test Phase.

b. Documentation

Implementation documentation shall include a copy of the software, test cases and associated criteria that are traceable to the software requirements, and design documentation.

c. Review and Approval

The CTF shall assure that specified design constraints, standards, and conventions are implemented. In addition, the CTF shall assure that reviews of the test cases are performed and the test cases are approved by the responsible organization at the completion of this phase.

5. Test Phase

a. During this phase the software shall be validated by executing the test cases. Failure to successfully execute the test cases shall be reviewed to determine if modification of the requirements, the design, the implementation, or the test plans and test cases are required. Testing shall demonstrate the capability of the software to produce valid results for test cases encompassing the range of permitted usage defined by the program documentation. Such activities shall ensure that the software adequately and correctly performs all intended functions.

b. Testing shall demonstrate, as appropriate, that the computer program:

(1) properly handles abnormal conditions and events as well as credible failures

(2) does not perform adverse unintended functions; and

(3) does not degrade the system either by itself, or in combination with other functions or configuration items.

c. Test Phase activities shall consist of the testing of the software to assure adherence to requirements, and to assure that the software produces correct results for the test cases specified. Acceptable methods for evaluating the adequacy of the software test case results include:

(1) analysis without computer assistance

(2) other validated computer program(s),

(3) experiments and tests,

(4) standard problems with known solutions,

(5) confirmed published data and correlation's

d. Documentation

Test Phase documentation shall include test procedures or plans and the results of the execution of test cases. The test results documentation shall demonstrate successful completion of all test cases or the resolution of unsuccessful test cases and provide direct traceability between the test results and specified software requirements.

e. Test procedures or plans shall specify the following, as applicable:

(1) required tests and test sequence,

(2) required range of input parameters,

(3) identification of the stages at which testing is required,

(4) requirements for testing logic branches,

(5) requirements for hardware integration,

(6) anticipated output values,

(7) acceptance criteria,

(8) reports, records, standard formatting, and conventions,

(9) identification of operating environment, support software, software tools or system software,

(10) Hardware Operating System(s) and/or limitation

f. Review and Approval

The CTF shall ensure that a technical review of the test procedures/plans and test results are performed. The technical review of the test results shall ensure that the test requirements have been satisfied. When software design is required, ITR of the test results is required in accordance with the design phase section of this procedure.

6. Installation and Acceptance Phase

a. During this phase the software becomes part of a system incorporating applicable software components, hardware, and data and is accepted for use. For the installation and acceptance phase:

(1) The CTF shall determine the acceptance testing to be performed.

(2) Acceptance testing shall include a comprehensive test in the operating environment.

(3) Acceptance testing shall be performed prior to approval of the computer program for use.

(4) Software validation shall be performed to ensure that the installed software product satisfies the specified software requirements. The engineering function shall determine the acceptance testing to be performed prior to approval of the computer program for use.

b. Documentation

Installation and acceptance phase documentation shall include results of the execution of test cases for system installation and integration, user instructions, and documentation of the acceptance of the software for operational use.

c. User instructions shall include:

(1) approved operating systems

(2) a description of the user's interaction with the software,

(3) a description of any required training necessary to use the software,

(4) input and output specifications,

(5) input and output formats,

(6) a description of software and hardware limitations,

(7) a description of user messages initiated as a result of improper input and how the user can respond,

(8) information for obtaining user and maintenance support.

d. Review and Approval

The CTF shall assure that design verification activities and a technical review of the acceptance testing, installation results, and user instructions is performed and completed prior to computer program use. Installation testing shall ensure the integrity of the software and its interfaces (for example, associated system and memory resident software, associated run-time libraries, and the hardware configuration). If any of these dependent features are changed in any way, installation testing shall be re-performed. The documentation of the acceptance of the software for operational use shall ensure that configuration baselines, documentation, and reviews have been completed.

7. Operations and Maintenance Phase

a. During this phase, software shall be controlled to remove latent errors (corrective maintenance), to respond to new or revised requirements (preventive maintenance), or to adapt the software to changes in the operating environment (adaptive maintenance). Software modifications shall be approved, documented, verified and validated, and controlled in accordance with the related life cycle phases.

b. The validation of modifications shall be subject to selective regression testing to detect errors introduced during the modification of software or operating system components to verify that the modifications have not caused unintended adverse effects and to verify that the modified software still meets its specified requirements.

c. Test cases shall be developed and documented to permit confirmation of acceptable performance of the software in the environment in which the software is used. Test cases shall be run whenever the software is installed on a different computer, or when significant hardware or operating system configuration changes are made.

d. Periodic in-use manual or automatic self-check in-use tests shall be prescribed and performed for those computer programs where computer program errors, data errors, computer hardware failures, or instrument drift can affect required performance.

8. Retirement Phase

During the retirement phase, the support for a software product shall be terminated and the routine use of the software prevented.

E. Software Configuration Control

1. Introduction

The methods to be used to control, uniquely identify, describe, and document the configuration of each version or update of a computer program (for example, source, object, back-up files) and its related documentation (for example, software design requirements, instructions for computer program use, test plans, and results) shall be described in implementing procedures. Such procedures shall meet the following criteria for configuration identification, change control and configuration status accounting.

2. Configuration Identification

a. A configuration baseline shall be defined at the completion of each major phase of the software life cycle. Approved changes created subsequent to a baseline shall be added to the baseline. A baseline shall define the most recently approved software configuration.

b. A baseline labeling system shall be implemented that:

(1) uniquely identifies each configuration item,

(2) identifies changes to configuration items by revision,

(3) provides the ability to uniquely identify each configuration of the revised software available for use.

3. Configuration Change Control

a. Proposed changes to software shall be formally documented. This documentation shall contain a description of the change, the rationale for the change, requirements for re-testing and acceptance of the test results, and the identification of other life cycle documentation that will require modification to address the proposed change. For example, a change in the design documentation may require a change in the requirements, implementation, and user documentation.

b. The change shall be evaluated and approved for release by the organization responsible for the original design, unless an alternative organization has been given the authority to approve the changes. Modification to the life cycle documentation will require the same level of review and approval as the original. Only approved changes shall be made to software baselines. Software verification activities shall be performed for the change as necessary to ensure the change is appropriately reflected in software documentation, and to ensure that document traceability is maintained. Software validation shall be performed as necessary to ensure that the change does not adversely affect the performance of the software.

4. Configuration Status Accounting and Control

The information that is needed to manage a configuration baseline shall be documented. This information shall identify the approved configuration baseline, the status of proposed changes to the configuration baseline, the status of approved changes, and information to support the functions of configuration identification and configuration control. Configuration control is to include configuration status notification of organizations affected by configuration changes.

F. Existing and Acquired Software

1. Software, which was not developed in accordance with this procedure, shall be classified, evaluated, validated, placed under configuration control, and controlled in accordance with the life cycle requirements specified in the applicable attachment. Management shall ensure that an implementation schedule for affected software is developed. The CTF shall perform and document an evaluation of existing software which:

a. determines the adequacy of software documentation to support testing, operation, and maintenance.

b. identifies activities to be performed throughout the applicable life cycle of the software including preparation of required documentation and performance of required reviews and/or tests,

c. determines the software's capabilities and limitations for intended use,

d. specifies test plans and test cases required to validate the capabilities within the stated limitations,

e. identifies instructions for software use within the limits of its capabilities,

f. identifies any exceptions to the life cycle documentation and its justification.

2. This evaluation may be documented in a work request, plan, procedure, project level instruction, or other method, as appropriate. Exceptions to the life cycle documentation shall be approved by the CQF.

3. As an alternative, the user organization shall obtain the above documentation from the supplier or perform a documented review of the documentation at the supplier facility to determine acceptability.

4. Revisions to previously baseline software received from organizations not required to follow WSRC Computer Software QA Requirements shall be evaluated in accordance with the WSRC requirements.

5. The results of the above documentation and the performance of the actions necessary to accept the software shall be reviewed and approved. The documentation and associated computer program(s) shall establish the current baseline.

G. Software Procurement

1. Procurement

   a. Software and software services shall be procured in accordance with WSRC procurement procedures. Procurement documents shall identify requirements for Supplier's reporting of software errors to the Purchaser and, as appropriate, the Purchaser's reporting of software errors to the Supplier.

   b. Procurement of software, including development of specifications, shall be in accordance with the requirements of Procedure Manual 3E, Procurement Specification Procedure Manual, and the following matrix.

A through E Classified Software	SSC Classified Software	Procurement Level
A	SC	1
B	SS	2
C	PS	3
D or E	GS	3

   c. Software intended for commercial dedication may be procured as a standard commercial grade item. Procured software shall be classified, placed under configuration control, and controlled in accordance with the life cycle requirements prior to installation.

2. Dedication of Commercial Grade Software

   Organizations planning to use off-the-shelf software in applications classified as A/B or SC/SS shall review the intended application sufficiently to determine the critical functions that provide evidence of the software's suitability for use. Once the critical functions have been established, the user or support organization's CTF shall define the methods to verify their adequacy and provide verifiable acceptance criteria. Acceptable dedication methods and required dedication documentation shall be prepared in an appropriate manner similar to Procedure Manual 1Q, Procedure 7-3, "Commercial Grade Item Dedication".

H. Problem Reporting and Corrective Action

1. The problem reporting and corrective action process shall address the appropriate requirements of the WSRC QA program corrective action system and the following elements:

   a. Method(s) for documenting, evaluating, and correcting software problems shall:

      (1) describe the evaluation process for determining whether a reported problem is an error; and

      (2) define the responsibilities for disposition of the problem reports, including notification to the originator of the results of the evaluation.

   b. When the problem is determined to be an error, the method shall provide, as appropriate, for:

(1) how the error relates to appropriate software engineering elements;

(2) how the error impacts past and present use of the computer program;

(3) how the corrective action impacts previous development activities;

(4) how the users are notified of the identified error, its impact; and how to avoid the error, pending implementation of corrective actions.

2. The methods to be used for reporting operational software problems and taking appropriate action shall be described in implementing procedures which comply with paragraphs above and the requirements of Procedure Manual 1Q, Procedure 15-1, "Control of Nonconforming Items" and Procedure Manual 1B, Management Requirements and Procedures, Procedure 4.21, "Problem Identification and Resolution Process".

I. Access Control

The methods to be used to permit authorized and prevent unauthorized access to a computer system shall be described in implementing procedures. The CTF shall ensure that access control complies with applicable site automated data processing system security requirements specified in Procedure Manual 10Q, *Computer Security Manual*. The CTF shall ensure that software generated by WSRC organizations receive reviews for classified or sensitive information in accordance with the requirements of Procedure Manual 7Q, *Security Manual*.

Records

Records shall be controlled in accordance with the requirements of Procedure Manual 1Q, Procedure 17-1, "Quality Assurance Records Management". The following shall be retained as Quality Assurance records based on software classification:

- software quality assurance plan(s) or procedure(s)
- software design requirements documentation
- software design documentation
- implementation documentation
- user documentation
- test procedures/plans, test cases, and test results
- evidence of required reviews, review comments and their disposition, and approvals

References

- For a current list of Source Document references, go to the Standards/Requirements Identification Document (S/RID) webpage accessible through ShRINE
- Department of Energy (DOE) Radioactive Waste (RW) DOE/RW-0333P, "Quality Assurance Requirements and Description for the Civilian Radioactive Waste Management Program"
- Procedure Manual 1B, Management Requirements and Procedures, Procedure 4.21, "Problem Identification and Resolution Process"
- Procedure Manual 7B, *Procurement Management Manual*
- Procedure Manual 12B, *Information Management*, Procedure 1.05, "Software Management"
- Procedure Manual 3E, Procurement Specification Procedure Manual

- Procedure Manual 1Q, Quality Assurance Manual
  - Procedure 2-3, "Control of Research and Development Activities"
  - Procedure 2-7, "QA Program Requirements for Analytical measurement Systems"
  - Procedure 7-3, "Commercial Grade Item Dedication"
  - Procedure 12-1, "Control of Measuring and Test Equipment"
  - Procedure 15-1, Control of Nonconforming Items"
  - "Glossary of Terms"

- Procedure Manual 7Q, *Security Manual*
- Procedure Manual 10Q, *Computer Security Manual*
- Procedure Manual E7, Conduct of Engineering and Technical Support
  - Procedure 1.30, "Component Numbering System"
  - Procedure 2.25, "Functional Classifications"
  - Procedure 2.31, "Engineering Calculations"

Forms

None

Attachments

Attachment 1. A through E Graded Approach to Software Classification
Attachment 2. A through E Life Cycle Documentation Requirements Matrix
Attachment 3. SSC Life Cycle Documentation Requirements Matrix

Attachment 1. A through E Graded Approach to Software Classification

Level "A"

- Software applications that have a direct effect on nuclear safety protection systems that keep exposure to the general public below the off-site regulatory or evaluation guidelines.

Level "B"

- Software applications whose failure to properly function may have an indirect effect on nuclear safety protection systems or toxic materials hazard systems that are used to keep nuclear or toxic material hazard exposure to the general public and workers below regulatory or evaluation guidelines
- Software applications whose results are used to make decisions that could result in death or serious injury or are part of the evaluation in accident analyses.

Level "C"

- Software applications whose failure to perform as expected would not affect nuclear safety but would have an unacceptable impact by causing loss of:
  - greater than $2 Million Dollars production investment value and/or recovery cost
  - primary program capabilities in excess of six months.
- Software applications important to continued operations of the business and that which is used to support decisions regarding operating activities.
- Software applications used to comply with regulatory laws, environmental permits or regulations and/or commitments to compliance.
- Software applications required by the SRS Emergency Plan for environmental monitoring or for communications with Local, State and Federal Government agencies.

Level "D"

- Software applications important to the day-to-day administration of the business but whose failure to perform as intended will not adversely affect the safety or reliability of operations or will not result in losses exceeding $2 Million Dollars or result in a six month loss of program capabilities.

Level "E"

- Software that is within scope of this procedure but does not meet the criteria specified in the above classification levels.

Attachment 2. A through E Life Cycle Documentation Requirements Matrix

This attachment is for reference only. Please verify and use the current version of the required implementing procedure, per the CTF / process for latest guidance.	Level A Software Development	Level A Existing Software	Level A Purchased Software	Level B Software Development	Level B Existing Software	Level B Purchased Software	Level C Software Development	Level C Existing Software	Level C Purchased Software	Level D Software	Level E Software
Software Classification	R	R	R	R	R	R	R	R	R	R	R
SQA Procedures / Plans	R	R	R	R	R	R	R	R	R	R	N
Dedication	G	G	R	G	G	R	G	G	G	G	N
Evaluation	G	R	G	G	R	G	G	R	G	G	N
Requirements	R	R	R	R	R	R	R	G	G	G	N
Design	R	G	G	R	G	G	G	G	G	G	N
Implementation	R	G	G	R	G	G	G	G	G	G	N
Testing	R	G	R	R	G	R	G	G	G	G	N
User Instructions	R	R	R	R	R	R	G	G	G	G	N
Acceptance Test	R	R	R	R	R	R	R	G	R	G	N
Operation & Maintenance	R	R	R	R	R	R	G	G	G	G	N
Configuration control	R	R	R	R	R	R	R	R	R	G	N
Error Impact	R	R	R	G	G	G	G	G	G	G	N
Access Control	R	R	R	R	R	R	G	G	G	G	N
General Note											
R= Required											
G = Graded Approach											
N = no applicability											

Attachment 3. SSC Software Life Cycle Documentation Requirements Matrix

Guidance for Structure, System, Competent Class software. This attachment is for reference only. Please verify and use the current version of the required implementing procedure / process for latest guidance.	SC/SS Software Development	SC/SS Existing Software	SC/SS Purchased Software	PS Software Development	PS Existing Software	PS Purchased Software	GS Software
Software Classification	R	R	R	R	R	R	R
SQA Procedures / Plans	R	R	R	R	R	R	R
Dedication	G	G	R	G	G	G	N
Evaluation	G	R	G	G	R	G	N
Requirements	R	R	R	R	G	G	N
Design	R	G	G	G	G	G	N
Implementation	R	G	G	G	G	G	N
Testing	R	G	R	G	G	G	N
User Instructions	R	R	R	G	G	G	N
Acceptance Test	R	R	R	R	G	R	N
Operation & Maintenance	R	R	R	G	G	G	N
Configuration control	R	R	R	R	R	R	N
Error Impact	G	R	R	G	G	G	N
Access Control	R	R	R	G	G	G	N
General Note							
R= Required							
G = Graded Approach							
N = no applicability							

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Manual Number: 1Q

Manual Title: *Quality Assurance Manual*

Revision Summary

1.	**Document and Revision Numbers:** 20-1, Revision 8
2.	**Document Title:** Software Quality Assurance
3.	**Effective Date:** 10/16/03
4.	**Document Changes** (can be in paragraph or list): ***Editorial Only__X___ Title Change_____ Forms Revised_____ Cancellation_____*** **Attachments:** Attachment 2, Typo: Change G to R for Level B Software Development and Level B Purchased Software. Changed G= Graded/Safe Mission Essential applicability to G= Graded Approach Attachment 3: Changed G= Graded/Safe Mission Essential applicability to G= Graded Approach
5.	**Training Requirements:** (As with any procedure revision, those employees affected by the procedure need to familiarize themselves with the changes. No additional training is required.)

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Responsibilities

Managers

- ensure a software quality assurance program is established, documented, and implemented in accordance with this procedure,
- designate individuals or organizations responsible for implementing this procedure and define the interfaces with external organizations.

Cognizant Technical Functions (CTFs)

- ensure software classification is determined for the intended use of software,
- ensure Software Quality Assurance (QA) procedures/plans are reviewed and approved by the CTF's manager and the CTF's Cognizant Quality Function (CQF).

Cognizant Quality Functions (CQFs)

- review and approve Software QA procedures/plans
- accepts or rejects Level E software classifications
- verify Software Classifications are established

Procedure

This procedure comprises the following Sections:

A. General
B. Software Classification Requirements
C. Software Quality Assurance Procedures/Plans
D. Software Life Cycle
E. Software Configuration Control
F. Existing and Acquired Software
G. Software Procurement
H. Problem Reporting and Corrective Action
I. Access Control

A. General

1. Management ensures that a software quality assurance program is established, documented, and implemented. They designate individuals or organizations responsible for implementation and define the interfaces with external organizations.

2. Software shall be controlled throughout its life cycle, using a graded approach, based on its software classification. It is not the intent of this procedure to restrict the software life cycle methodology defined in implementing procedures, provided that the chosen methodology encompasses the activities, documentation, reviews, and approvals required by this procedure.

3. The WSRC approach to Software Quality Assurance is based on a classification scheme used for managing the software through out the life cycle based on its intended function. The two types of classification are:

   - software designated with an A through E classification, or

   - software designated as part of a Structure, System, or Component (SSC) with an assigned functional classification

B. Software Classification Requirements

1. The CTF shall determine which classification process applies (A through E or Functional Classification).

2. Classification of software using the A through E designation is based on: its direct effect on nuclear safety protection systems; indirect effect on nuclear safety protection systems or toxic material hazard systems; unacceptable programmatic, schedule, or cost effects; or, importance to daily business operations. The detailed definition for the A through E designation is outlined in Attachment 1, "A through E Graded Approach to Software Classification". The Life Cycle Documentation associated with these software classifications is provided in Attachment 2, "A through E Life Cycle Documentation Requirements Matrix".

3. Software that is part of an SSC which has a Component Location Identifier (CLI) Number (as defined in Procedure Manual E7, Procedure 1.30 "Component Numbering System") is classified using the associated Functional Classification. SSC designated software is classified using the Functional Classification approach (reference Procedure Manual E7, Procedure 2.25, "Functional Classifications"). The Life Cycle Documentation associated with these software classifications is provided in Attachment 3, "SSC Software Life Cycle Documentation Requirements Matrix".

4. Detailed implementation requirements for the application of the software classification process is provided in organizational specific manuals (for example, E7, 12B, L1, etc.) or software project management plans.

5. The CTF will assure that the software quality assurance implementation process meets the requirements throughout the entire software life cycle.

6. The CQF will verify that the software classification has been established and approves the use of software classified Level E.

C. Software Quality Assurance Procedures/Plans

1. Based on the nature, complexity, and intended use of the software, the CTF shall ensure that procedures/plans for software quality assurance are prepared which identify the following:

   a. the software products to which it applies

   b. the organizations responsible for performing the work and achieving software quality, and their tasks and responsibilities

   c. the software engineering methods

   d. required documentation

   e. standards, conventions, techniques, or methodologies which shall be used to guide the software development, as well as methods to assure compliance to the same

   f. the required software reviews

   g. the methods for error reporting and corrective action

2. These procedures/plans may be prepared individually for each software project, or may exist as a generic document to be applied to software prepared within, procured, or used by each organization. Software QA procedures/plans shall be reviewed and approved by the CTF's manager and the CTF's CQF. Optionally, these requirements may be distributed within the software life cycle documentation specified in Section D. If such requirements are distributed in life cycle documentation, the CQF shall review and approve these documents to ensure that such requirements are addressed prior to the implementation phase.

D. Software Life Cycle

1. Introduction

   Software shall be controlled in a traceable, planned, and orderly manner. The software life cycle defined in this section provides the basis for planning and implementing a software development, maintenance, or application project. This section identifies the specific software activities, documentation, and reviews associated with each life cycle phase. The identified life cycle phase requirements shall be applied using the graded approach appropriate for the software. However, no strict chronological constraints exist between the requirements identified. The number of phases and relative emphasis placed on each phase of software development or maintenance shall be defined in the software QA procedure/plan and will be dependent on the nature and complexity of the software. As each life cycle document is approved, it shall be placed under configuration control in accordance with Section E.

2. Requirements Phase

   a. During this phase the requirements that the software must satisfy shall be specified, documented, reviewed, and approved. These requirements shall define the functions to be performed by the software and shall provide the detail and information necessary to design the software.

   b. Software requirements shall be verifiable and traceable throughout all stages of the software development cycle.

   c. Documentation

      Software requirements documentation shall define requirements for, functionality, performance, design inputs, design constraints, installation considerations, operating systems (if applicable), and external interfaces necessary to design the software. Acceptance criteria shall be established in the software requirements documentation for each of the identified requirements. Such criteria shall be used for verification/validation planning and performance as defined in each related life cycle phase.

   d. Review and Approval

      The CTF shall assure that the software requirement documentation is reviewed and approved by the responsible organization at the completion of this phase. This review shall assure that the requirements are complete, verifiable, consistent, and technically feasible. The review shall also assure that the requirements will result in a feasible and usable final product.

3. Design Phase

   a. During this phase a software design shall be developed, documented, and reviewed and controlled. The responsible design organization shall prescribe and document the design activities to the level of detail necessary to permit the design process to be carried out and to permit verification that the design meets requirements.

   b. Design Elements

      (1) The design shall specify the interfaces, overall structure (control and data flow) and the reduction of the overall structure into physical solutions (algorithms, equations, control logic, and data structures).

      (2) Computer programs are designed as an integral part of an overall system. Therefore, software design shall consider the computer program's operating environment.

(3) Measures to mitigate the consequences of problems shall be an integral part of software design. These potential problems include external and internal abnormal conditions and events that can affect the computer program

c. Documentation

Software design documentation shall contain:

(1) a description of the major components of the software design as they relate to the software requirements;

(2) a technical description of the software with respect to the theoretical basis, mathematical model, control flow, data flow, control logic, data structure, numerical methods, physical models, process flow, process structures, and applicable relationship between data structure and process standards;

(3) a description of the allowable or prescribed ranges for inputs and outputs;

(4) the design described in a manner that can be translated into code; and

(5) a description of the approach to be taken for intended test activities based on the requirements and design that specify the hardware and software configuration to be used during test execution.

d. Review and Approval

(1) The organization responsible for the design shall identify and document particular verification methods to be used and assure that an Independent Review (IR) is performed and documented. This review shall evaluate the technical adequacy of the design approach; assure internal completeness, consistency, clarity, and correctness of the software design; and verify the software design is traceable to the requirements.

(2) The organization responsible for the design shall also assure that the test results adequately demonstrate the requirements have been met (See Section D. 5. "Test Phase").

(3) The IR shall be performed by competent individual(s) other than those who developed and documented the original design, but who may be from the same organization. The results of the IR shall be documented with the identification of the verifier indicated. When review alone is not adequate to determine if requirements are met, alternate calculations shall be used, or tests shall be developed and integrated into the appropriate activities of the software development cycle. Software design documentation shall be completed prior to finalizing the IR.

(4) The extent of the IR and the methods chosen are a function of:

(a) the importance to safety,

(b) the complexity of the software,

(c) the degree of standardization, and

(d) the similarity with previously proven software.

4. Implementation Phase

a. Implementation Phase

During this phase the implementation process shall result in software products such as computer program listings and instructions for computer program use. The implemented software shall be analyzed to identify and correct errors. The source code for development of software classified

A/B or SC/SS shall be placed under configuration control in accordance with Section E (Software Configuration Control) prior to commencement of the Test Phase.

b. Documentation

Implementation documentation shall include a copy of the software, test cases and associated criteria that are traceable to the software requirements, and design documentation.

c. Review and Approval

The CTF shall assure that specified design constraints, standards, and conventions are implemented. In addition, the CTF shall assure that reviews of the test cases are performed and the test cases are approved by the responsible organization at the completion of this phase.

5. Test Phase

a. During this phase the software shall be validated by executing the test cases. Failure to successfully execute the test cases shall be reviewed to determine if modification of the requirements, the design, the implementation, or the test plans and test cases are required. Testing shall demonstrate the capability of the software to produce valid results for test cases encompassing the range of permitted usage defined by the program documentation. Such activities shall ensure that the software adequately and correctly performs all intended functions.

b. Testing shall demonstrate, as appropriate, that the computer program:

(1) properly handles abnormal conditions and events as well as credible failures

(2) does not perform adverse unintended functions; and

(3) does not degrade the system either by itself, or in combination with other functions or configuration items.

c. Test Phase activities shall consist of the testing of the software to assure adherence to requirements, and to assure that the software produces correct results for the test cases specified. Acceptable methods for evaluating the adequacy of the software test case results include:

(1) analysis without computer assistance

(2) other validated computer program(s),

(3) experiments and tests,

(4) standard problems with known solutions,

(5) confirmed published data and correlation's

d. Documentation

Test Phase documentation shall include test procedures or plans and the results of the execution of test cases. The test results documentation shall demonstrate successful completion of all test cases or the resolution of unsuccessful test cases and provide direct traceability between the test results and specified software requirements.

e. Test procedures or plans shall specify the following, as applicable:

(1) required tests and test sequence,

(2) required range of input parameters,

(3) identification of the stages at which testing is required,

(4) requirements for testing logic branches,

(5) requirements for hardware integration,

(6) anticipated output values,

(7) acceptance criteria,

(8) reports, records, standard formatting, and conventions,

(9) identification of operating environment, support software, software tools or system software,

(10) Hardware Operating System(s) and/or limitation

f. Review and Approval

The CTF shall ensure that a technical review of the test procedures/plans and test results are performed. The technical review of the test results shall ensure that the test requirements have been satisfied. When software design is required, ITR of the test results is required in accordance with the design phase section of this procedure.

6. Installation and Acceptance Phase

a. During this phase the software becomes part of a system incorporating applicable software components, hardware, and data and is accepted for use. For the installation and acceptance phase:

(1) The CTF shall determine the acceptance testing to be performed.

(2) Acceptance testing shall include a comprehensive test in the operating environment.

(3) Acceptance testing shall be performed prior to approval of the computer program for use.

(4) Software validation shall be performed to ensure that the installed software product satisfies the specified software requirements. The engineering function shall determine the acceptance testing to be performed prior to approval of the computer program for use.

b. Documentation

Installation and acceptance phase documentation shall include results of the execution of test cases for system installation and integration, user instructions, and documentation of the acceptance of the software for operational use.

c. User instructions shall include:

(1) approved operating systems

(2) a description of the user's interaction with the software,

(3) a description of any required training necessary to use the software,

(4) input and output specifications,

(5) input and output formats,

(6) a description of software and hardware limitations,

(7) a description of user messages initiated as a result of improper input and how the user can respond,

(8) information for obtaining user and maintenance support.

d. Review and Approval

The CTF shall assure that design verification activities and a technical review of the acceptance testing, installation results, and user instructions is performed and completed prior to computer program use. Installation testing shall ensure the integrity of the software and its interfaces (for example, associated system and memory resident software, associated run-time libraries, and the hardware configuration). If any of these dependent features are changed in any way, installation testing shall be re-performed. The documentation of the acceptance of the software for operational use shall ensure that configuration baselines, documentation, and reviews have been completed.

7. Operations and Maintenance Phase

a. During this phase, software shall be controlled to remove latent errors (corrective maintenance), to respond to new or revised requirements (preventive maintenance), or to adapt the software to changes in the operating environment (adaptive maintenance). Software modifications shall be approved, documented, verified and validated, and controlled in accordance with the related life cycle phases.

b. The validation of modifications shall be subject to selective regression testing to detect errors introduced during the modification of software or operating system components to verify that the modifications have not caused unintended adverse effects and to verify that the modified software still meets its specified requirements.

c. Test cases shall be developed and documented to permit confirmation of acceptable performance of the software in the environment in which the software is used. Test cases shall be run whenever the software is installed on a different computer, or when significant hardware or operating system configuration changes are made.

d. Periodic in-use manual or automatic self-check in-use tests shall be prescribed and performed for those computer programs where computer program errors, data errors, computer hardware failures, or instrument drift can affect required performance.

8. Retirement Phase

During the retirement phase, the support for a software product shall be terminated and the routine use of the software prevented.

E. Software Configuration Control

1. Introduction

The methods to be used to control, uniquely identify, describe, and document the configuration of each version or update of a computer program (for example, source, object, back-up files) and its related documentation (for example, software design requirements, instructions for computer program use, test plans, and results) shall be described in implementing procedures. Such procedures shall meet the following criteria for configuration identification, change control and configuration status accounting.

2. Configuration Identification

a. A configuration baseline shall be defined at the completion of each major phase of the software life cycle. Approved changes created subsequent to a baseline shall be added to the baseline. A baseline shall define the most recently approved software configuration.

b. A baseline labeling system shall be implemented that:

(1) uniquely identifies each configuration item,

(2) identifies changes to configuration items by revision,

(3) provides the ability to uniquely identify each configuration of the revised software available for use.

3. Configuration Change Control

a. Proposed changes to software shall be formally documented. This documentation shall contain a description of the change, the rationale for the change, requirements for re-testing and acceptance of the test results, and the identification of other life cycle documentation that will require modification to address the proposed change. For example, a change in the design documentation may require a change in the requirements, implementation, and user documentation.

b. The change shall be evaluated and approved for release by the organization responsible for the original design, unless an alternative organization has been given the authority to approve the changes. Modification to the life cycle documentation will require the same level of review and approval as the original. Only approved changes shall be made to software baselines. Software verification activities shall be performed for the change as necessary to ensure the change is appropriately reflected in software documentation, and to ensure that document traceability is maintained. Software validation shall be performed as necessary to ensure that the change does not adversely affect the performance of the software.

4. Configuration Status Accounting and Control

The information that is needed to manage a configuration baseline shall be documented. This information shall identify the approved configuration baseline, the status of proposed changes to the configuration baseline, the status of approved changes, and information to support the functions of configuration identification and configuration control. Configuration control is to include configuration status notification of organizations affected by configuration changes.

F. Existing and Acquired Software

1. Software, which was not developed in accordance with this procedure, shall be classified, evaluated, validated, placed under configuration control, and controlled in accordance with the life cycle requirements specified in the applicable attachment. Management shall ensure that an implementation schedule for affected software is developed. The CTF shall perform and document an evaluation of existing software which:

a. determines the adequacy of software documentation to support testing, operation, and maintenance.

b. identifies activities to be performed throughout the applicable life cycle of the software including preparation of required documentation and performance of required reviews and/or tests,

c. determines the software's capabilities and limitations for intended use,

d. specifies test plans and test cases required to validate the capabilities within the stated limitations,

e. identifies instructions for software use within the limits of its capabilities,

f. identifies any exceptions to the life cycle documentation and its justification.

2. This evaluation may be documented in a work request, plan, procedure, project level instruction, or other method, as appropriate. Exceptions to the life cycle documentation shall be approved by the CQF.

3. As an alternative, the user organization shall obtain the above documentation from the supplier or perform a documented review of the documentation at the supplier facility to determine acceptability.

4. Revisions to previously baseline software received from organizations not required to follow WSRC Computer Software QA Requirements shall be evaluated in accordance with the WSRC requirements.

5. The results of the above documentation and the performance of the actions necessary to accept the software shall be reviewed and approved. The documentation and associated computer program(s) shall establish the current baseline.

G. Software Procurement

1. Procurement

   a. Software and software services shall be procured in accordance with WSRC procurement procedures. Procurement documents shall identify requirements for Supplier's reporting of software errors to the Purchaser and, as appropriate, the Purchaser's reporting of software errors to the Supplier.

   b. Procurement of software, including development of specifications, shall be in accordance with the requirements of Procedure Manual 3E, Procurement Specification Procedure Manual, and the following matrix.

A through E Classified Software	SSC Classified Software	Procurement Level
A	SC	1
B	SS	2
C	PS	3
D or E	GS	3

   c. Software intended for commercial dedication may be procured as a standard commercial grade item. Procured software shall be classified, placed under configuration control, and controlled in accordance with the life cycle requirements prior to installation.

2. Dedication of Commercial Grade Software

   Organizations planning to use off-the-shelf software in applications classified as A/B or SC/SS shall review the intended application sufficiently to determine the critical functions that provide evidence of the software's suitability for use. Once the critical functions have been established, the user or support organization's CTF shall define the methods to verify their adequacy and provide verifiable acceptance criteria. Acceptable dedication methods and required dedication documentation shall be prepared in an appropriate manner similar to Procedure Manual 1Q, Procedure 7-3, "Commercial Grade Item Dedication".

H. Problem Reporting and Corrective Action

1. The problem reporting and corrective action process shall address the appropriate requirements of the WSRC QA program corrective action system and the following elements:

   a. Method(s) for documenting, evaluating, and correcting software problems shall:

      (1) describe the evaluation process for determining whether a reported problem is an error; and

      (2) define the responsibilities for disposition of the problem reports, including notification to the originator of the results of the evaluation.

   b. When the problem is determined to be an error, the method shall provide, as appropriate, for:

(1) how the error relates to appropriate software engineering elements;

(2) how the error impacts past and present use of the computer program;

(3) how the corrective action impacts previous development activities;

(4) how the users are notified of the identified error, its impact; and how to avoid the error, pending implementation of corrective actions.

2. The methods to be used for reporting operational software problems and taking appropriate action shall be described in implementing procedures which comply with paragraphs above and the requirements of Procedure Manual 1Q, Procedure 15-1, "Control of Nonconforming Items" and Procedure Manual 1B, Management Requirements and Procedures, Procedure 4.21, "Problem Identification and Resolution Process".

I. Access Control

The methods to be used to permit authorized and prevent unauthorized access to a computer system shall be described in implementing procedures. The CTF shall ensure that access control complies with applicable site automated data processing system security requirements specified in Procedure Manual 10Q, *Computer Security Manual*. The CTF shall ensure that software generated by WSRC organizations receive reviews for classified or sensitive information in accordance with the requirements of Procedure Manual 7Q, *Security Manual*.

Records

Records shall be controlled in accordance with the requirements of Procedure Manual 1Q, Procedure 17-1, "Quality Assurance Records Management". The following shall be retained as Quality Assurance records based on software classification:

- software quality assurance plan(s) or procedure(s)
- software design requirements documentation
- software design documentation
- implementation documentation
- user documentation
- test procedures/plans, test cases, and test results
- evidence of required reviews, review comments and their disposition, and approvals

References

- For a current list of Source Document references, go to the Standards/Requirements Identification Document (S/RID) webpage accessible through ShRINE
- Department of Energy (DOE) Radioactive Waste (RW) DOE/RW-0333P, "Quality Assurance Requirements and Description for the Civilian Radioactive Waste Management Program"
- Procedure Manual 1B, Management Requirements and Procedures, Procedure 4.21, "Problem Identification and Resolution Process"
- Procedure Manual 7B, *Procurement Management Manual*
- Procedure Manual 12B, *Information Management*, Procedure 1.05, "Software Management"
- Procedure Manual 3E, Procurement Specification Procedure Manual

- Procedure Manual 1Q, Quality Assurance Manual
  - Procedure 2-3, "Control of Research and Development Activities"
  - Procedure 2-7, "QA Program Requirements for Analytical measurement Systems"
  - Procedure 7-3, "Commercial Grade Item Dedication"
  - Procedure 12-1, "Control of Measuring and Test Equipment"
  - Procedure 15-1, Control of Nonconforming Items"
  - "Glossary of Terms"

- Procedure Manual 7Q, *Security Manual*
- Procedure Manual 10Q, *Computer Security Manual*
- Procedure Manual E7, Conduct of Engineering and Technical Support
  - Procedure 1.30, "Component Numbering System"
  - Procedure 2.25, "Functional Classifications"
  - Procedure 2.31, "Engineering Calculations"

Forms

None

Attachments

Attachment 1. A through E Graded Approach to Software Classification
Attachment 2. A through E Life Cycle Documentation Requirements Matrix
Attachment 3. SSC Life Cycle Documentation Requirements Matrix

Attachment 1: A through E Graded Approach to Software Classification

Level "A"

- Software applications that have a direct effect on nuclear safety protection systems that keep exposure to the general public below the off-site regulatory or evaluation guidelines.

Level "B"

- Software applications whose failure to properly function may have an indirect effect on nuclear safety protection systems or toxic materials hazard systems that are used to keep nuclear or toxic material hazard exposure to the general public and workers below regulatory or evaluation guidelines
- Software applications whose results are used to make decisions that could result in death or serious injury or are part of the evaluation in accident analyses.

Level "C"

- Software applications whose failure to perform as expected would not affect nuclear safety but would have an unacceptable impact by causing loss of:
  - greater than $2 Million Dollars production investment value and/or recovery cost
  - primary program capabilities in excess of six months.
- Software applications important to continued operations of the business and that which is used to support decisions regarding operating activities.
- Software applications used to comply with regulatory laws, environmental permits or regulations and/or commitments to compliance.
- Software applications required by the SRS Emergency Plan for environmental monitoring or for communications with Local, State and Federal Government agencies.

Level "D"

- Software applications important to the day-to-day administration of the business but whose failure to perform as intended will not adversely affect the safety or reliability of operations or will not result in losses exceeding $2 Million Dollars or result in a six month loss of program capabilities.

Level "E"

- Software that is within scope of this procedure but does not meet the criteria specified in the above classification levels.

Attachment 2. A through E Life Cycle Documentation Requirements Matrix

This attachment is for reference only. Please verify and use the current version of the required implementing procedure, per the CTF / process for latest guidance.	Level A Software Development	Level A Existing Software	Level A Purchased Software	Level B Software Development	Level B Existing Software	Level B Purchased Software	Level C Software Development	Level C Existing Software	Level C Purchased Software	Level D Software	Level E Software
Software Classification	R	R	R	R	R	R	R	R	R	R	R
SQA Procedures / Plans	R	R	R	R	R	R	R	R	R	R	N
Dedication	G	G	R	G	G	R	G	G	G	G	N
Evaluation	G	R	G	G	R	G	G	R	G	G	N
Requirements	R	R	R	R	R	R	R	G	G	G	N
Design	R	G	G	R	G	G	G	G	G	G	N
Implementation	R	G	G	R	G	G	G	G	G	G	N
Testing	R	G	R	R	G	R	G	G	G	G	N
User Instructions	R	R	R	R	R	R	G	G	G	G	N
Acceptance Test	R	R	R	R	R	R	R	G	R	G	N
Operation & Maintenance	R	R	R	R	R	R	G	G	G	G	N
Configuration control	R	R	R	R	R	R	R	R	R	G	N
Error Impact	R	R	R	G	G	G	G	G	G	G	N
Access Control	R	R	R	R	R	R	G	G	G	G	N
General Note											
R= Required											
G = Graded Approach											
N = no applicability											

Attachment 3. SSC Software Life Cycle Documentation Requirements Matrix

Guidance for Structure, System, Competent Class software. This attachment is for reference only. Please verify and use the current version of the required implementing procedure / process for latest guidance.	SC/SS Software Development	SC/SS Existing Software	SC/SS Purchased Software	PS Software Development	PS Existing Software	PS Purchased Software	GS Software
Software Classification	R	R	R	R	R	R	R
SQA Procedures / Plans	R	R	R	R	R	R	R
Dedication	G	G	R	G	G	G	N
Evaluation	G	R	G	G	R	G	N
Requirements	R	R	R	R	G	G	N
Design	R	G	G	G	G	G	N
Implementation	R	G	G	G	G	G	N
Testing	R	G	R	G	G	G	N
User Instructions	R	R	R	G	G	G	N
Acceptance Test	R	R	R	R	G	R	N
Operation & Maintenance	R	R	R	G	G	G	N
Configuration control	R	R	R	R	R	R	N
Error Impact	G	R	R	G	G	G	N
Access Control	R	R	R	G	G	G	N
General Note							
R= Required							
G = Graded Approach							
N = no applicability							

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5/31/2005

Key Words:
Vadose Zone
Porflow

Retention:
Permanent

SOFTWARE QUALITY ASSURANCE PLAN FOR THE PORFLOW CODE

Prepared By:

Leonard Collard

September 20, 2002

Rev. 0

Boundary	Old Sign	New Sign	Comments
Lower	Negative	Positive	Right, inward
Lower	Positive	Negative	Left, outward
Upper	Negative	Negative	Right, outward
Upper	Positive	Positive	Left, inward

These two tables show between the old and new PORFLOW versions that the flux boundary conditions are switched at the upper boundaries, while the gradient boundary conditions are switched at the lower boundaries.

DESCRIPTION OF APPLICABLE VERIFICATION AND BENCHMARK TEST CASES

Each test case that directly affects the use of PORFLOW at SRS is described below. Of special interest are those test cases that include the flow of water in the vadose zone and the aquifer and the transport of contaminants by diffusion and advection.

Given the above-stated PORFLOW changes and the requisite changes in the input files, each applicable verification and benchmark test case will be described in further detail.

Verification Test Cases

The verification cases are generally simple and can be compared to analytic solutions.

Verification Test Case 3

Verification Test Case 3 examines the Theis solution for transient drawdown. On the GRID command line the descriptor NODES was added. This ensures that the numbers on the command are interpreted as nodes rather than corners and provides consistency between old and new versions of PORFLOW. This descriptor appears throughout most of the test cases and will not be discussed further.

The first node was moved from 0.0 to 0.25 (halfway between the original 0.0 and 0.50) but the last node at 2000 was not moved to 1900.0 (halfway between the original 1800.0 and 2000.0). This likely caused little change in the results and it is unknown which, if either set of input is accurate.

On the BOUNDARY command line for Y, the "-2" was replaced by "Y-" as required. The DIAGNOSTIC and OUTPUT commands were changed with no impact on actual results, because the key information was saved in the archive file, "V3.ARC."

Verification Test Case5

Verification Test Case 5 involves coupled flow and heat transfer in a regional flow system. While isothermal models are typically executed at SRS, results from a nonisothermal case that involves flow is applicable in that it demonstrates that the flow portion operates correctly.

For this test case the number of nodes was increased from 41 by 41 to 42 by 42. Rather than

specifying the location for each node, the RANGE command was used as a substitute. These develop an identical model, except that in the second case the mesh is finer. Of possible concern would be the location of sources, however, only boundary conditions are applied. The boundary conditions changed according to the convention of "-1" changing to "X-", etc. The nonzero gradient for temperature at the lower Y boundary correctly switched signs. Finally, some of the output specifications were modified.

VALIDATION

VERSION 2.50

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CHAPTER 1

INTRODUCTION AND OVERVIEW

This document describes the results of verification and benchmark tests to validate the mathematical and numerical formulation of PORFLOW Version 2.50. PORFLOW is a software tool for solution of multi-phase fluid flow, heat transfer, and mass transport problems in variably saturated porous or fractured media. The software employs the FREEFORM command language pre-processor to provide a flexible, simple to use, and format-free user-interface. It interfaces with the acrPLOT post-processor to display the computed results as a variety of graphical images. A detailed description of the test problems, PORFLOW results, and comparison of these results with analytic, semi-analytic or numerical solutions is given in the following chapters. This chapter provides an introduction and overview of the test problems.