0049678

ENGINEERING CHANGE NOTICE

1. ECN 636890

Proj. ECN

2. ECN Category (mark one)	3. Originator's Name, Organization, MSIN, and Telephone No.	4. USQ Required?	5. Date
Supplemental [] Direct Revision [X] Change ECN [] Temporary [] Standby [] Supersedure [] Cancel/Void []	M. J. Kupfer, LMHC, H5-49, 376-6631	[] Yes [X] No	8/27/98
	6. Project Title/No./Work Order No. Tank 241-T-104	7. Bldg./Sys./Fac. No. NA	8. Approval Designator NA
	9. Document Numbers Changed by this ECN (includes sheet no. and rev.) HNF-SD-WM-ER-372, Rev. 1A	10. Related ECN No(s). NA	11. Related PO No. NA

12a. Modification Work	12b. Work Package No.	12c. Modification Work Complete	12d. Restored to Original Condition (Temp. or Standby ECN only)
[] Yes (fill out Blk. 12b) [X] No (NA Blks. 12b, 12c, 12d)	NA	NA Design Authority/Cog. Engineer Signature & Date	NA Design Authority/Cog. Engineer Signature & Date

13a. Description of Change

13b. Design Baseline Document? [] Yes [X] No

This ECN compiles all reconciliation changes made to the Best-Basis Inventory in FY 1998 and should replace Section 3.0 and Appendix D, Evaluation to Establish Best-Basis Inventory for Single-Shell Tank 241-T-104, of the Tank Characterization Report. The reconciliation process involved correction of errata, reassessment of data outlyers, verification of uranium isotopic distribution and other alpha isotope distribution, and removal of "less than" values, etc. Changes were made to both text and tables. The inventory estimates of several waste components were revised.

14a. Justification (mark one)

Criteria Change	[]	Design Improvement	[]	Environmental	[]	Facility Deactivation	[]
As-Found	[X]	Facilitate Const	[]	Const. Error/Omission	[]	Design Error/Omission	[]

14b. Justification Details

Tank waste inventory estimates are being provided as standard source term for the various waste management activities. FY 1997 evaluation of available information for all 177 underground storage tanks was performed and published in TCRs, preliminary TCRs, or revisions to existing TCRs. In FY 1998, a reconciliation process is being performed to update the best-basis inventories. This process ensures that the latest inventory estimates are available as a consistent source-term to support the activities of TWRS disposal and other users.

15. Distribution (include name, MSIN, and no. of copies)

Central Files	B1-07	K. M. Hodgson	R2-11
DIMC	H6-15	M. J. Kupfer	R3-75
DOE Reading Room	H2-53	M. D. LeClair (3)	R3-75
TCSRC	R1-10	L. M. Sasaki	R2-12
K. M. Hall	R2-12		

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A-7900-013-1

ENGINEERING CHANGE NOTICE

1. ECN (use no. from pg. 1): 636890

16. Design Verification Required	17. Cost Impact				18. Schedule Impact (days)	
	ENGINEERING		CONSTRUCTION			
[] Yes	Additional	[] $	Additional	[] $	Improvement	[]
[X] No	Savings	[] $	Savings	[] $	Delay	[]

19. Change Impact Review: Indicate the related documents (other than the engineering documents identified on Side 1) that will be affected by the change described in Block 13. Enter the affected document number in Block 20.

SDD/DD	[]	Seismic/Stress Analysis	[]	Tank Calibration Manual	[]
Functional Design Criteria	[]	Stress/Design Report	[]	Health Physics Procedure	[]
Operating Specification	[]	Interface Control Drawing	[]	Spares Multiple Unit Listing	[]
Criticality Specification	[]	Calibration Procedure	[]	Test Procedures/Specification	[]
Conceptual Design Report	[]	Installation Procedure	[]	Component Index	[]
Equipment Spec.	[]	Maintenance Procedure	[]	ASME Coded Item	[]
Const. Spec.	[]	Engineering Procedure	[]	Human Factor Consideration	[]
Procurement Spec.	[]	Operating Instruction	[]	Computer Software	[]
Vendor Information	[]	Operating Procedure	[]	Electric Circuit Schedule	[]
OM Manual	[]	Operational Safety Requirement	[]	ICRS Procedure	[]
FSAR/SAR	[]	IEFD Drawing	[]	Process Control Manual/Plan	[]
Safety Equipment List	[]	Cell Arrangement Drawing	[]	Process Flow Chart	[]
Radiation Work Permit	[]	Essential Material Specification	[]	Purchase Requisition	[]
Environmental Impact Statement	[]	Fac. Proc. Samp. Schedule	[]	Tickler File	[]
Environmental Report	[]	Inspection Plan	[]	Other	[X]
Environmental Permit	[]	Inventory Adjustment Request	[]		[]

20. Other Affected Documents: (NOTE: Documents listed below will not be revised by this ECN.) Signatures below indicate that the signing organization has been notified of other affected documents listed below.

Document Number/Revision	Document Number/Revision	Document Number Revision
NA		

21. Approvals

	Signature	Date		Signature	Date
Design Authority			Design Agent		
Cog. Eng. M. J. Kupfer	M J Kupfer	8-31-98	PE		
Cog. Mgr. K. M. Hodgson	K. M. Hodgson	9-8-98	QA		
QA			Safety		
Safety			Design		
Environ.			Environ.		
Other L. M. Sasaki R2-12	L M Sasaki	9/1/98	Other		

DEPARTMENT OF ENERGY

Signature or a Control Number that tracks the Approval Signature

ADDITIONAL

Tank Characterization Report for Single-Shell Tank 241-T-104

T. M. Hohl
COGEMA Engineering Corporation, Richland, WA 99352
U.S. Department of Energy Contract DE-AC06-96RL13200

EDT/ECN: 636890 UC: 721
Org Code: 7A110 Charge Code: N4G3A
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Key Words: TCR, best-basis inventory, standard inventory

Abstract: The best-basis inventory provides waste inventory estimates that serve as standard characterization source terms for the various waste management activities. To establish a best-basis inventory for single-shell tank 241-T-104, an evaluation of available information was performed. This work follows the methodology established in *Standard Inventories of Chemicals and Radionuclides in Hanford Site Tank Wastes*, HNF-SD-WM-TI-740, Rev. 0A (Kupfer et al. 1997).

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RECORD OF REVISION	(1) Document Number HNF-SD-WM-ER-372	Page 1

(2) Title
Tank Characterization Report for Single-Shell Tank 241-T-104

CHANGE CONTROL RECORD

(3) Revision	(4) Description of Change - Replace, Add, and Delete Pages	Authorized for Release (5) Cog. Engr.	(6) Cog. Mgr. Date
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1-B RS	Incorporate per ECN-636890.	M.J. Kupfer M.J. Kupfer 8-31-98	K.M. Hodgson K.M. Hodgson 9-8-98

A-7320-005 (08/91) WEF168

3.0 BEST-BASIS ESTIMATE INVENTORY

Information about chemical, radiological, and/or physical properties is used to perform safety analyses, engineering evaluations, and risk assessment associated with waste management activities, as well as regulatory issues. These activities include overseeing tank farm operations and identifying, monitoring, and resolving safety issues associated with these operations and with the tank wastes. Disposal activities involve designing equipment, processes, and facilities for retrieving wastes and processing them into a form that is suitable for long-term storage. Chemical and radiological inventory information are generally derived using three approaches: (1) component inventories are estimated using the results of sample analyses, (2) component inventories are predicted using the HDW model based on process knowledge and historical information, or (3) a tank-specific process estimate is made based on process flowsheets, reactor fuel data, essential material usage, and other operating data. Not surprisingly, the information derived from these different approaches is often inconsistent.

An effort is underway to provide waste inventory estimates that will serve as the standard characterization for the various waste management activities (Hodgson and LeClair 1996). As part of this effort, an evaluation of available chemical information for tank 241-T-104 was performed, including the following:

- Data from two 1992 core samples
- An inventory estimate generated by the HDW model (Agnew et al. 1997)
- Evaluation of the 1C/CW flowsheet and MTU comparisons.

Based on this evaluation, a best-basis inventory was developed. In general, the sample-based TCR results were preferred when they were reasonable and consistent with other results.

The best-basis inventory for tank 241-T-104 is presented in Tables 3-1 and 3-2. The inventory values reported in Tables 3-1 and 3-2 are subject to change. Refer to the Tank Characterization Database (TCD) (LMHC 1998) for the most current inventory values. Appendix D contains the complete narrative regarding the derivation of the inventory estimates shown in Tables 3-1 and 3-2.

Best-basis tank inventory values are derived for 46 key radionuclides (as defined in Section 3.1 of Kupfer et al. 1997), all decayed to a common report date of January 1, 1994. Often, waste sample analyses have only reported ^{90}Sr, ^{137}Cs, $^{239/240}$Pu, and total uranium, or (total beta and total alpha) while other key radionuclides such as ^{60}Co, ^{99}Tc, ^{129}I, ^{154}Eu, ^{155}Eu, and ^{241}Am, etc., have been infrequently reported. For this reason it has been necessary to derive most of the 46 key radionuclides by computer models. These models estimate radionuclide activity in batches

of reactor fuel, account for the split of radionuclides to various separations plant waste streams, and track their movement with tank waste transactions. (These computer models are described in Kupfer et al. 1997, Section 6.1 and in Watrous and Wootan 1997.) Model generated values for radionuclides in any of 177 tanks are reported in the Hanford Defined Waste Rev. 4 model results (Agnew et al. 1997). The best-basis value for any one analyte may be either a model result or a sample or engineering assessment-based result if available. For a discussion of typical error between model derived values and sample derived values, see Kupfer et al. 1997, Section 6.1.10.

Table 3-1. Best-Basis Inventory Estimates for Nonradioactive Components in Tank 241-T-104 (Effective November 19, 1996). (2 Sheets)

Analyte	Total Inventory (kg)	Basis (S, M, E or C)[1]	Comment
Al	35,000	S	
Bi	40,800	S	
Ca	3,120	S	
Cl	1,450	S	
TIC as CO_3	1,080	S/E	Upper bound
Cr	1,940	S	
F	18,500	S	
Fe	19,500	S	
Hg	0.274	S	Simpson 1998
K	192	S	
La	0	E	
Mn	133	S	
Na	139,000	S	
Ni	24.4	S	
NO_2	8,810	S	
NO_3	125,000	S	
OH_{TOTAL}	153,000	C	Charge balance calculation
Pb	1.35	M	
PO_4	162,000	S	
Si	14,100	S	

Table 3-1. Best-Basis Inventory Estimates for Nonradioactive Components in Tank 241-T-104 (Effective November 19, 1996). (2 Sheets)

Analyte	Total Inventory (kg)	Basis (S, M, E or C)[1]	Comment
SO_4	8,420	S	
Sr	213	S	
TOC	1,520	S	
U_{TOTAL}	1,940	S	
Zr	146	S	

Notes:

[1]S = Sample-based
M = Hanford Defined Waste model-based
E = Engineering assessment-based
C =Calculated by charge balance; includes oxides as hydroxides, not including CO_3, NO_2, NO_3, PO_4, SO_4, and SiO_3.

Table 3-2. Best-Basis Inventory Estimate for Radioactive Components in Tank 241-T-104, Decayed to January 1, 1994 (Effective November 19, 1996). (3 Sheets)

Analyte	Total Inventory (Ci)	Basis (S, M or E)[1]	Comment
^{3}H	2.73	M	
^{14}C	0.0968	S/E	Method/sample prep: (RA/ Water) Expected upper bound
^{59}Ni	0.0722	M	
^{60}Co	0.342	M	
^{63}Ni	6.64	M	
^{79}Se	0.0680	M	
^{90}Sr	5660	S	Method/sample prep: (RA/ Fusion)
^{90}Y	5660	S	Based on ^{90}Sr
^{93m}Nb	0.260	M	
^{93}Zr	0.327	M	
^{99}Tc	1.24	S	Method/sample prep: (RA/ Water)

Table 3-2. Best-Basis Inventory Estimate for Radioactive Components in Tank 241-T-104, Decayed to January 1, 1994 (Effective November 19, 1996). (3 Sheets)

Analyte	Total Inventory (Ci)	Basis (S, M or E)[1]	Comment
^{106}Ru	5.67E-05	M	
^{113m}Cd	1.17	M	
^{125}Sb	1.34	M	
^{126}Sn	0.102	M	
^{129}I	0.00617	M	
^{134}Cs	0.0240	M	
^{137m}Ba	405	S	Based on ^{137}Cs
^{137}Cs	428	S	Method/sample prep: (RA/ Fusion)
^{151}Sm	248	M	
^{152}Eu	0.0911	M	
^{154}Eu	7.35	S	Method/sample prep: (RA/ Fusion)
^{155}Eu	6.36	M	
^{226}Ra	1.24E-05	M	
^{227}Ac	6.45E-05	M	
^{228}Ra	9.12E-04	M	
^{229}Th	2.16E-05	M	
^{231}Pa	1.57E-04	M	
^{232}Th	6.00E-05	M	
^{232}U	1.34E-04	S/M	
^{233}U	4.69E-04	S/M	
^{234}U	0.638	S/M	
^{235}U	0.0284	S/M	
^{236}U	0.00545	S/M	
^{237}Np	0.0152	M	Sample considered high
^{238}Pu	2.02	S/M	Based on $^{239/240}Pu$ and HDW model isotopic distribution.
^{238}U	0.648	S/M	
^{239}Pu	276	S/M	Calculated from $^{239/240}Pu$ hybrid inventory (301 Ci) Method/ sample prep: (RA/Fusion)

Table 3-2. Best-Basis Inventory Estimate for Radioactive Components in Tank 241-T-104, Decayed to January 1, 1994 (Effective November 19, 1996). (3 Sheets)

Analyte	Total Inventory (Ci)	Basis (S, M or E)[1]	Comment
^{240}Pu	25.1	S/M	Calculated from $^{239/240}Pu$ hybrid inventory (301 Ci) Method/ sample prep: (RA/Fusion)
^{241}Am	37.2	S	Method/sample prep: (RA/ Fusion)
^{241}Pu	84.6	S/M	Based on $^{239/240}Pu$ and HDW model isotopic distribution.
^{242}Cm	0.104	S/M	Based on ^{241}Am and HDW model radionuclide distribution.
^{242}Pu	3.87E-04	S/M	Based on $^{239/240}Pu$ and HDW model isotopic distribution.
^{243}Am	8.83E-04	S/M	Based on ^{241}Am and HDW model radionuclide distribution.
^{243}Cm	0.00628	S/M	Based on ^{241}Am and HDW model radionuclide distribution.
^{244}Cm	0.054	S/M	Based on ^{241}Am and HDW model radionuclide distribution.

[1]S=Sample-based
M=Hanford Defined Waste model-based (Agnew et al 1997)
E=Engineering assessment-based

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APPENDIX D

EVALUATION TO ESTABLISH BEST-BASIS INVENTORY FOR SINGLE-SHELL TANK 241-T-104

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APPENDIX D

EVALUATION TO ESTABLISH BEST-BASIS INVENTORY FOR SINGLE-SHELL TANK 241-T-104

An effort is underway to provide waste inventory estimates that will serve as standard characterization source terms for the various waste management activities (Hodgson and LeClair 1996). As part of this effort, an evaluation of available chemical information for tank 241-T-104 was performed, and a best-basis inventory was established. This work, detailed in the following sections, follows the methodology that was established by the standard inventory task.

D1.0 CHEMICAL INFORMATION SOURCES

The data package for single-shell tank 241-T-104 (Pool 1994) provided characterization results from the most recent core sampling event for this tank; the results are presented in Appendix B. Two core samples were obtained and analyzed. Jensen et al. (1994) summarizes the results from the statistical analysis of data from two core composites. Estimates of the spatial variance, compositing variance, and the spatial variance for the core composite data were provided. Both the analytical and systematic error of the tank 241-T-104 core samples were presented. Mean concentrations and confidence intervals are presented in Appendix B.

Component inventories at the time of sampling were calculated by multiplying the mean concentration of an analyte (presented in Table B3-6) by the density of the waste (1.29 g/mL) and the volume of the sludge at the time of sampling (1,673 kL [442 kgal]). Sample-based inventories listed in Tables D2-1 and D2-2 are derived from the mean concentrations in Table B3-6 and the Hanford defined waste (HDW) model developed at Los Alamos National Laboratory (Agnew et al. 1997). The chemical species are reported without charge designation per the best-basis inventory convention. The HDW model (Agnew et al. 1997) provides tank content estimates, in terms of component concentrations and inventories. The HDW model estimated the tank inventory using the total waste volume of 1,684 kL (445 kgal), consisting of 1,673 kL (442 kgal) of sludge and 11.4 kL (3 kgal) of supernate, reported by Hanlon (1992) at the time of sampling and prior to the start of saltwell pumping. The sampling-based inventory is based upon the sludge volume (1,673 kL [442 kgal]) only.

D2.0 COMPARISON OF COMPONENT INVENTORY VALUES

Sample-based inventories derived from analytical concentration data and HDW model inventories are compared in Tables D2-1 and D2-2. The sludge volume used to generate the sample-based inventory is 1,673 kL (442 kgal) (Hanlon 1992). The HDW model included the 11.4 kL (3 kgal) of supernate present prior to saltwell pumping, for a total tank waste volume of 1,684 kL (445 kgal) (Hanlon 1992). The mean sludge density, which includes interstitial liquid, used to calculate the sample-based component inventories is 1.29 g/mL (the mean of the values in Table B2-4). The means from the ICP fusion digestion analyses were used for aluminum, beryllium, bismuth, cerium, chromium, iron, phosphorus, silicon, magnesium, manganese, and sodium. The ICP acid digestion means were used for cadmium, nickel, and potassium and the IC water digestion means were used for chloride, fluoride, nitrite, and nitrate. The HDW model density for the sludge and total waste is estimated to be 1.25 g/mL (approximately 3 percent less than the measured density). Note the significant differences between the sample-based and HDW model inventories for several of the bulk components, e.g., bismuth, fluoride, nitrate, nitrite, uranium, zirconium, and silicon.

Table D2-1. Sample- and Historical Tank Content-Based Inventory Estimates for Nonradioactive Components. (2 sheets)

Analyte	Sample Inventory Estimate (kg)	HDW[1] Inventory Estimate (kg)	Analyte	Sample Inventory Estimate (kg)	HDW[1] Inventory Estimate (kg)
Al	35,000	23,000	Ni	24.4	122
Ag	13.8	NR	NO_2	8,810	21,800
As	1.63	NR	NO_3	125,000	107,000
Ba	18.4	NR	OH	NR	106,000
Be	<3.29	NR	oxalate	NR	0.0231
Bi	40,800	21,300	Pb	NR	1.35
Ca	3,130	5,010	Pd	NR	NR
Ce	419	NR	PO_4	162,000	179,000
Cd	3.65	NR	Pt	NR	NR

Table D2-1. Sample- and Historical Tank Content-Based Inventory Estimates for Nonradioactive Components. (2 sheets)

Analyte	Sample Inventory Estimate (kg)	HDW[1] Inventory Estimate (kg)	Analyte	Sample Inventory Estimate (kg)	HDW[1] Inventory Estimate (kg)
Cl	1,450	1,930	Rh	NR	NR
Co	23.2	NR	Ru	NR	NR
Cr	1,940	481	Sb	<381	NR
Cs	NR	NR	Se	<1.08	NR
Cu	27	NR	Si	14,100	8,980
F	18,500	4,500	SO_4	8,420	8,670
Fe	19,500	23,100	Sr	213	0
FeCN/CN	<4.3	NR	Te	NR	NR
formate	NR	NR	CO_3	<1,080	7,690
Hg	0.274	33.1	Th	NR	NR
K	192	467	Tl	NR	NR
La	<22.4	0.0278	TOC	1,520	NR
Mg	303	NR	U_{TOTAL}	1,940	77,100
Mn	133	1.47	V	NR	NR
Mo	NR	NR	W	NR	NR
Na	139,000	199,000	Zn	295	NR
Nd	NR	NR	Zr	146	37.3
NH_3	<9,680	1,950	H_2O (wt%)	70.5	64.8
			density (kg/L)	1.29	1.37

Notes:

HDW = Hanford Defined Waste
NR = Not reported
[1]Agnew et al. (1997)

Table D2-2. Sample- and Historical Tank Content-Based Inventory Estimates for Radioactive Components.

Analyte	Sample Inventory Estimate (Ci)	HDW[1] Inventory Estimate (Ci)	Analyte	Sample Inventory Estimate (Ci)	HDW[1] Inventory Estimate (Ci)
^{14}C	<0.097	0.459	^{237}Np	295	0.0152
^{90}Sr	5,680	19,500	$^{239/240}Pu$	300	66.1
^{99}Tc	1.24	3.23	^{241}Am	37.2	0.833
^{129}I	<99.8	0.00617	Total α	234	NR
^{137}Cs	429	23,000	Total β	16,300	NR
^{155}Eu	7.38	6.36			

Notes:

HDW = Hanford Defined Waste
NR = Not reported
[1]Agnew et al. (1997).

Since the time of core sampling, saltwell liquid has been removed from the tank. Because solids have not been removed from the tank and because the core composite used to generate the concentrations in Table B3-6 did not include drainable liquids recovered from the core samples, the present tank sludge inventory should be close to that calculated in the manner described above. To provide a lower bound on the tank inventory, one could assume that the saltwell liquid pumped has the same composition as the drainable liquid that was analyzed, calculate the inventory of waste pumped from the tank (by multiplying the drainable liquid concentrations by the 317 kL [83.8 kgal] pumped as of September 30, 1996), and subtracting this amount from the initial tank inventory.

D3.0 COMPONENT INVENTORY EVALUATION

The following evaluation of tank contents is performed to identify potential errors and/or missing information that would influence the sample-based and HDW model component inventories.

D3.1 PROCESS KNOWLEDGE

Tank 241-T-104 began receiving first cycle decontamination (1C) waste in March 1946 and was filled in August 1946. There was no cascading at this time. Nearly 3,400 kL (900 kgal) of 1C waste was received by tank 241-T-104 in a series of additions in 1948 and 1949 (Jungfleisch 1984). The tank was already full, so this waste all cascaded to tanks 241-T-105 and 241-T-106. Since it was the primary tank in the cascade, most of the solids in the 1C waste settled in tank 241-T-104. When the supernate was removed from the tanks in the cascade and sent to cribs in 1953, tank 241-T-104 held 1,410 kL (372 kgal) of solids (Anderson 1990). A discrepancy in the historical records is found here. Up to this time, 5,360 kL (1,440 kgal) of waste additions (all pre-1951 1C) to tank 241-T-104 are documented (Jungfleisch 1984). For 5,360 kL of waste to deposit 1,410 kL of solids in a tank, the waste stream must be at least 26 percent solids. Pre-1951 1C waste, however, is expected to be only about 13.7 percent solids (Agnew et al. 1996). Agnew, et al. (1996) estimates a slightly larger waste addition volume of 6,386 kL (1,687 kgal), though not enough to account for all the solids estimated by Anderson (1990).

In 1954, a series of additions of 1C waste to tank 241-T-104 brought 3,900 kL (1,030 kgal) of waste into the tank (Jungfleisch 1984). (Agnew, et al. [1996] estimates a volume of 6,711 kL [1,773 kgal].) This 1C waste included coating waste and stack drainage that were combined with 1C waste after May 1951 (Agnew et al. 1996). Coating waste was produced from the dissolution of aluminum fuel cladding in a sodium nitrate-sodium hydroxide solution. Much of this waste was cascaded to tank 241-T-105; some of the waste was pumped to other tanks. This was the last time tank 241-T-104 received waste. A supernate transfer out of the tank brought the volume to 1,830 kL (483 kgal). Salt well pumping and settling of the waste brought the tank to its current waste volume of 1,408 kL (372 kgal). Table D3-1 uses transaction records to present an estimate of the total volume of waste that has been received by tank 241-T-104 (Jungfleisch 1984). These volumes differ somewhat from the estimates of Agnew et al. (1996) which were presented in Appendix A (Table A3-1).

Table D3-1. Estimated Total Volume of Waste Types Received By Tank 241-T-104.[1]

Waste type	Estimated volume[2]
1C 1944 to 1951	5,360 kL (1,415 kgal)
1C 1951 to 1956[3]	3,900 kL (1,030 kgal)

Notes:

[1]Jungfleisch (1984)

[2]Total volume is greater than 2,010 kL (530 kgal) because waste was routinely pumped from tank 241-T-104 and also cascaded to tank 241-T-105

[3]Coating waste and stack drainage were added to 1C waste after May 1951.

D3.2 HISTORICAL ESTIMATION OF THE CONTENTS OF TANK 241-T-104

A preliminary estimate of the waste constituents in tank 241-T-104 can be developed by reviewing historical data for the tank. This section uses the process history of the tank and past sampling efforts to develop an estimation of the contents of tank 241-T-104.

D3.3 PROCESS HISTORY ESTIMATION

Section D3.1 describes the history of tank 241-T-104 as repeated filling of the tank with 1C decontamination waste and cascading to tank 241-T-105 or pumping of the supernate. There is no record of any waste type other than 1C waste being received by the tank. However, the composition of 1C waste varied. As discussed in Section D3.1, coating waste and stack drainage were included in 1C waste after May 1951.

D3.4 CONTRIBUTING WASTE TYPES

Waste volumes (kgal)	Agnew et al. (1997):	1946 through 1956, 1C, 13,100 kL (3,460 kgal)
	Hill et al. (1995):	1C

Notes: 1C, First-cycle decontamination bismuth phosphate waste, that includes bismuth phosphate cladding waste (CW).

In the bismuth phosphate process, the 1C waste stream was neutralized with aluminum cladding waste. This neutralized waste stream, that contains approximately 7 percent CW, also is commonly referred to as 1C. Cascade overflows from tank 241-T-104 to tanks 241-T-105 and 241-T-106. Tables D2-1 and D2-2 compare sampling inventory estimates with HDW inventory estimates.

D3.5 TECHNICAL FLOWSHEET INFORMATION

Technical flowsheet (Kupfer 1997) information for the bismuth phosphate 1C stream, which includes bismuth phosphate CW, is provided in Table D3-2. The comparative HDW model defined 1C waste stream is also provided in Table D3-2. The HDW model 1C defined waste stream appears to be a "second generation" flowsheet waste stream, derived by Jungfleisch (1984) for an earlier modeling effort (the Tracks Radioactive Components model [TRAC]).

D3.6 EXPECTED SOLIDS

SORWT (Hill et al. 1995): 1C/CW
LANL (HDW model) (Agnew et al. 1997): 1C

Note: 1C/CW refers to mixture of CW from the bismuth phosphate process with 1C.
SORWT = Sorts on Radioactive Waste Types qualitative grouping model
LANL = Los Alamos National Laboratory

Table D3-2. Technical Flowsheet and Los Alamos National Laboratory Defined Waste Streams (Hanford Defined Waste Model). (2 Sheets)

Analyte	Flowsheet[1] 1C[2] (*M*)	Defined waste 1C2[3] (*M*)
NO_3	1.44	1.63
NO_2	0.0577	0.044
SO_4	0.0631	0.0696
Bi	0.0115	0.012
Fe	0.0315	0.05
Si	0.0312	0.053
U	9.63E-04	0.0301
Al	0.0826	0.062

Table D3-2. Technical Flowsheet and Los Alamos National Laboratory Defined Waste Streams (Hanford Defined Waste Model). (2 Sheets)

Analyte	Flowsheet[1] 1C[2] (*M*)	Defined waste 1C2[3] (*M*)
Cr	0.00306	0.0065
Ce	1.93 E-04	NR
PO_4	0.258	0.289
Zr	2.96 E-4	3.2 E-04
F	0.170	0.186
Na	2.17	2.94

Notes:

[1]This flowsheet stream includes Bismuth phosphate cladding waste in the 1C bismuth phosphate waste.
[2]Bismuth phosphate process flowsheet.
[3]Agnew et al. (1997).
NR = Not reported.

D3.7 EVALUATION OF COMPONENT INVENTORIES

Reference inventories of certain components in tank 241-T-104 were estimated using an engineering assessment that is based on a set of simplified assumptions. The inventories were then compared with the tank 241-T-104 sample-based inventories and the HDW model inventories. The assumptions and observations for the engineering assessment were based on best technical judgement pertaining to parameters that can significantly influence tank inventories. These parameters include: 1) correct prediction of contributing waste types and correct relative proportions of the waste types; 2) accurate predictions of model flowsheet conditions, fuel processed, and waste volumes; 3) accurate prediction of partitioning of components; 4) accurate predictions of physical parameters such as density, percent solids, void fraction (porosity), etc. By using this evaluation, the assumptions can be modified as necessary to provide a basis for identifying potential errors and/or missing information that could influence the sampling- and model-based inventories. Following are the simplified assumptions and observations used for the evaluation.

- Components listed in the technical flowsheets summarized in Kupfer (1997) and Table D3-2 were used for the evaluation.

- Tank waste mass is calculated using the tank volume listed in Hanlon (1992) prior to the start of saltwell pumping.

- All bismuth, iron, silicon, cerium, and uranium precipitate as water insoluble components. These assumptions are based on known chemistry of the components in alkaline solutions. Chromium was assumed to precipitate as $Cr(OH)_3$ or $Cr_2O_3(XH_2O)$ in alkaline media.

- Sodium, nitrate, nitrite, phosphate, sulfate, aluminum, and fluoride are assumed to partition between the liquid and solid phases based on known chemical solubilities and properties of compounds in alkaline solutions.

- No radiolysis of nitrate to nitrite and no additions of nitrite to the waste for corrosion purposes are factored into this independent assessment.

- Only the 1C bismuth phosphate waste streams which includes bismuth phosphate CW, contributed to solids formation.

D3.7.1 Solids Concentration Factor and Partition Factors for First Cycle Bismuth Phosphate Waste in Tank 241-T-104

One method for estimating a component inventory for a particular waste type in a tank (e.g., 1C waste) is to derive a concentration factor (CF) for that component. This approach was used to estimate inventories in tank 241-T-104. Concentration factors are a means of reconciling process-based information and sample-based information for particular waste types. The CF is derived by dividing the concentration of a component found in the tank samples by the concentration of that component in the neutralized process waste stream (i.e., flowsheet concentrations in Table D3-2). The CF for components of a defined waste are best determined if the tank contains only one waste type (e.g., only 1C waste in tank 24-T-104) and when abundant representative analytical data are available. The relative concentrations of components expected to precipitate essentially 100 percent to the waste solids (e.g., bismuth, iron, and uranium) should be approximately proportional to the respective flowsheet concentrations for those components; i.e., these components should exhibit nearly the same CFs. If this is the case, it can generally be concluded that the sample data are consistent with the flowsheet basis, and thus, are quite representative of the tank contents. Since the CFs are often consistent for the same waste type in different tanks, inventories for components in tanks that do not have samples can be estimated if it is known that the defined waste is indeed present in the tank, and the volume of the defined waste is known or can be predicted.

It was noted in Assumption 3 that this evaluation assumes bismuth as well as iron, silicon, uranium, cerium, and chromium precipitate nearly 100 percent from the neutralized waste. The assumption for bismuth is based on sludge and supernatant analyses performed on typical Hanford Site tank wastes and is consistent with known chemistry for bismuth phosphate and for bismuth in alkaline solutions. The following procedure is used to calculate the CF for bismuth in tank 241-T-104. From Table D2-1, the analytical-based inventory for bismuth is 33,000 kg which corresponds to a bismuth concentration in the solids of 0.107 M. The flowsheet concentration for bismuth is 0.0115 M (Table D3-2). The CF_{Bi} is:

$$\frac{0.107 \text{ moles Bi/L}}{0.0115 \text{ moles Bi/L}} = 9.3$$

The silicon and cerium which are expected to fully precipitate form 1C waste have CFs of 9.6 and 7.6, respectively, for tank 241-T-104. This variation for precipitated components is considered to be quite small and provides a high degree of confidence that the tank sample is representative of waste produced by the 1C flowsheet. However, the CFs for iron and uranium are approximately 7 and 5, respectively, which could indicate some partitioning of these components (see Section D3.7.2).

The CFs can be quite different for different waste types. For example, the CF based on bismuth for the bismuth phosphate process 224 waste is 95 and for 2C waste the CF is approximately 20.

Once the CFs for fully precipitated components for a waste type are determined, the sample analysis can be used to establish how other components such as sulfate or phosphate partition between solids and supernatants. Concentration factors for components not expected to precipitate 100 percent can be ratioed to CF_{Bi} to obtain the partitioning factors (PF) for those components. The PF for any component N, defined as CF_N/CF_{Bi}, is the fraction of N partitioned to the sludge.

Thus the PF for phosphate (tank 241-T-104) is:

$$\frac{CF_{PO4}}{CF_{Bi}} = \frac{4.0}{9.3} = 0.43$$

Using this method, the estimated PFs for other components for 1C waste based on tank 241-T-104 are as follows when using a CF of 9.3 for fully precipitated components:

Na:	0.17	Al:	0.97	SO_4:	0.09	PO_4:	0.43
NO_3:	0.09	NO_2:	0.21	F:	0.37		

Several anomalies are seemingly apparent, however, when considering Assumptions 3 and 4 defined earlier in Section D3.7. The PF for aluminum is surprisingly high; i.e., based on the analytical data, it could be concluded that this component is essentially fully precipitated. As noted earlier, it was also unexpected that both iron and uranium apparently partition between the solids and supernatant. Possible explanations for these unexpected conclusions are summarized in Section D3.7.2.

The calculated CFs and PFs for tank 241-T-104 provide significant confidence that the analytical data for the tank is quite representative of the tank contents and could be used as a basis for component inventories. This is substantiated by the following:

- CFs for components in tank 241-T-104 that are expected to fully precipitate are quite consistent which indicates that the sample likely represents the 1C flowsheet basis (Table D3-32) for the waste.

- The PFs indicate reasonable partitioning of components based on experience and knowledge of the typical chemical behavior of the components in alkaline media.

D3.7.2 Inventory of Components Assumed to Precipitate 100 Percent

The following calculations provide estimates (rounded) of tank 241-T-104 inventories for components assumed to precipitate 100 percent based on a bismuth CF of 9.3.

Fe: 0.032 moles Fe/L_{1C} x $9.3_{CF(1C)}$ x 442 kgal x 3,785 L/kga x 55.85 g/mole Fe x kg/1,000 g = 27,800 kg

Similarly,

Si: 13,680 kg
Zr: 420 kg
Ce: 420 kg

U: 3,580 kg
Cr: 2,490 kg

Estimated inventories from this evaluation for components assumed to fully precipitate are compared with sample and HDW model-based inventories in Table D3-3. Observations regarding these inventories are provided by component in the following text.

Waste composition estimates for some tanks also can be developed from process flowsheets, fuel production, and waste transaction records. Tank 241-T-104, as the first tank in a three tank cascade, is known to have received 1C and CW waste from T Plant from the first quarter of 1945 through the third quarter of 1954. The composition of this waste can be estimated from a spreadsheet analysis of the bismuth phosphate flowsheet, T Plant fuel production records, and WSTR for this tank. Altogether, tank 241-T-104 received 13,096 kL (3,460 kgal) of 1C and CW waste from T Plant. The equivalent metric tons of uranium (MTUs) can be estimated by multiplying the MTUs processed each quarter by the total fraction of 1C/CW waste sent to tank 241-T-104. Based on this approach, tank 241-T-104 received 978.14 MTUs of equivalent 1C and CW waste. For insoluble components such as bismuth, cerium, iron, silicon, and zirconium and semi-soluble components such as aluminum, chromium, and phosphate, these values can be easily converted into equivalent waste inventory estimates for the three tank cascade. The results are summarized in Table D3-4, together with sample and HDW model derived estimates for tank 241-T-104.

Table D3-3. Comparison of Selected Component Inventory Estimates for Tank 241-T-104 Waste.

Component	This Evaluation (kg)[1]	Sample-based (kg)	HDW Model (kg)
Bi	37,400	40,800	21,300
Ce	420	419	NR
Cr	2,490	1,940	481
Si	13,680	14,100	8,980
Fe	27,800	19,500	32,100
U	3,580	1,940	77,100
Zr	420	146	37.3

Note:

NR = not reported.

[1]Based on assumptions defined in Section D3.7 and calculations in Section D3.7.1.

Table D3-4. Comparisons Based on Fuel Production.

Components	1C/CW waste sent to tanks 241-T-104/T-105/ T-106 (kg)	Tank 241-T-104 sample inventory (kg)	Tank 241-T-104 HDW model inventory (kg)
Al	32,278	35,000	23,000
Bi	35,213	40,800	21,300
Ce	390	419	NR
Cr	2,348	1,940	481
Fe	25,431	19,500	32,100
Si	12,911	14,100	8,980
PO_4	353,109	162,000	179,000
Zr	391	146	37.3

Note:

HDW = Hanford Defined Waste.

NR = Not Reported

Bismuth. The bismuth inventory based on the core sample data is almost twice that predicted by the HDW model. The 1C defined waste from the HDW model does not differ significantly from the 1C flowsheet basis given in Table D3-4. Although the HDW model assumes that only 73 percent of the bismuth in the 1C waste stream precipitates, this does not account for all of the discrepancy. The CFs for other components that are expected to fully precipitate are quite consistent with that for bismuth, which indicates that the sample is likely representative of the waste produced by the bismuth phosphate process 1C flowsheet. Examination of process flowsheets, fuel production records, and waste transaction records provides evidence that less than 37,400 kg may be in the tank. This agrees well with the sample inventory and the sample based inventory is considered to be the best basis for bismuth.

Chromium. This inventory assessment predicts the total chromium content to be fairly close to that based on the sample analysis. However, these values are approximately 4 to 5 fold higher than that predicted by the HDW model. The HDW model assumes that none of the chromium precipitated in the 1C stream (i.e., the only chromium contribution to the solids is from the interstitial liquids associated with the solids). Additionally, since the chromium was added primarily as chromium (III) in the bismuth phosphate process, it is expected that the majority of the chromium will precipitate as $Cr(OH)_3$ or $Cr_2O_3(XH_2O)$.

Iron. The iron inventory predicted by this assessment is approximately 45 percent higher than the sample-based inventory. This assessment assumed that the iron would fully precipitate; however, some partitioning is likely either by loss as fine particles or (less likely) approximately 30 percent of the iron is soluble. The sample-based inventory is thus, considered the best basis. The HDW inventory is slightly more than that for the sample-based inventory and assumes that approximately 96 percent of the iron precipitates.

Aluminum. The sample-based inventory is approximately 52 percent greater than the HDW model estimate. This assessment assumed that aluminum would partition to the supernatant; however, the sample-based inventory for tank 241-T-104 indicates that essentially all of the aluminum precipitates. It is not surprising that most of the aluminum in 1C waste would partition to the solids. There is historical evidence that wastes from the bismuth phosphate process were made alkaline to an approximate pH of only 9 which would promote precipitation of the metal hydroxide. If the waste was neutralized to a higher pH (e.g., 12), there is significant dissolution of the hydroxide with conversion to soluble sodium aluminate.

Lanthanum. The lanthanum inventory is predicted to be zero for this tank. This is based on the history of the tank which shows that no lanthanum bearing waste was disposed or transferred to the tank. The engineering assessment is in relative agreement with the inventory predicted by the HDW model.

Sodium. Based on the sample analysis of tank 241-T-104, approximately 17 percent of the sodium partitions to the solids. This is somewhat lower than observed for tank BX-112 which also contains 1C waste. This may indicate that some B saltcake is present in tank 241-BX-112 as predicted by the HDW model.

Silicon. The silicon inventory predicted by this assessment is approximately equal to the sample-based inventory. The silicon inventory was estimated based on the CF for bismuth. As previously mentioned, the CFs for components expected to fully precipitate should be approximately the same if the samples are representative of the waste results from the 1C bismuth phosphate process. It is concluded in the assessment that the sample-based inventory is reasonably close to the predicted inventory. The HDW model-based inventory is lower than the sample-based inventory. The apparent explanation is that this assessment assumes that all silicon precipitates while the HDW model assumes that only approximately 10 percent of the silicon precipitates.

Fluoride. The sample-based inventory for fluoride is approximately four times higher than the HDW model inventory. The analytical data show that a major portion of the fluoride is partitioned to the solids. This is consistent with analyses for tank 241-BX-112. The HDW model assumes that no fluoride precipitates with the solids although some remains with the interstitial liquid associated with the solids.

Uranium. The uranium inventory predicted by this assessment is approximately twice the sample-based inventory. As stated previously, it is concluded that some of the uranium partitions to the supernatant and interstitial liquid, likely as soluble uranate, but most remains with the solids. The HDW model-based inventory is approximately forty times higher than the sample-based inventory and is suspected to be in error.

Nitrate. The sample-based inventory is approximately 17 percent higher than predicted by the HDW model.

Nitrite. The sample-based inventory for nitrite is approximately two and a half times higher than predicted by the HDW model. The sample-based inventory indicates that 21 percent of the nitrite added in the 1C bismuth phosphate process partitioned to the solids. This is expected based on the high solubility of nitrite in the alkaline solutions.

Phosphate. The sample-based inventory for phosphate is within 10 percent of that predicted by the HDW model. Analytical data indicate that a significant portion of the phosphate in 1C waste partitions to the solids. The HDW model also assumes that much of the phosphate partitions.

Sulfate. The HDW model-based inventory is approximately equal to that based on the samples. The sample-based inventory for sulfate indicates that less than ten percent of the sulfate in 1C waste partitions to the solids. The HDW model predicts that all sulfate will remain soluble and will be present only in the interstitial liquids associated with the solids.

Total Hydroxide. Once the best basis inventories were determined, the hydroxide inventory was calculated by performing a charge balance with the valences of other analytes. This charge balance approach was consistent with that used by Agnew et al. (1997).

D4.0 DEFINE THE BEST-BASIS AND ESTABLISH COMPONENT INVENTORIES

Information about chemical, radiological, and/or physical properties is used to perform safety analyses, engineering evaluations, and risk assessment associated with waste management activities, as well as regulatory issues. These activities include overseeing tank farm operations and identifying, monitoring, and resolving safety issues associated with these operations and with the tank wastes. Disposal activities involve designing equipment, processes, and facilities for retrieving wastes and processing them into a form that is suitable for long-term storage. Chemical and radiological inventory information are generally derived using three approaches: (1) component inventories are estimated using the results of sample analyses, (2) component inventories are predicted using the HDW model based on process knowledge and historical information, or (3) a tank-specific process estimate is made based on process flowsheets, reactor fuel data, essential material usage, and other operating data. Not surprisingly, the information derived from these different approaches is often inconsistent.

An effort is underway to provide waste inventory estimates that will serve as the standard characterization for the various waste management activities (Hodgson and LeClair 1996). As part of this effort, an evaluation of available chemical information for tank 241-T-104 was performed, including the following:

- Data from two 1992 core samples
- An inventory estimate generated by the HDW model (Agnew et al. 1997)
- Evaluation of the 1C/CW flowsheet and MTU comparisons.

Based on this evaluation, a best-basis inventory was developed. In general, the sample-based TCR results were preferred when they were reasonable and consistent with other results.

The best-basis inventory for tank 241-T-104 is presented in Tables D4-1 and D4-2. The inventory values reported in Tables D4-1 and D4-2 are subject to change. Refer to the Tank Characterization Database (TCD) (LMHC 1998) for the most current inventory values.

Best-basis tank inventory values are derived for 46 key radionuclides (as defined in Section 3.1 of Kupfer et al. 1997), all decayed to a common report date of January 1, 1994. Often, waste sample analyses have only reported ^{90}Sr, ^{137}Cs, $^{239/240}$Pu, and total uranium, or (total beta and total alpha) while other key radionuclides such as ^{60}Co, ^{99}Tc, ^{129}I, ^{154}Eu, ^{155}Eu, and ^{241}Am, etc., have been infrequently reported. For this reason it has been necessary to derive most of the 46 key radionuclides by computer models. These models estimate radionuclide activity in batches of reactor fuel, account for the split of radionuclides to various separations plant waste streams, and track their movement with tank waste transactions. (These computer models are

described in Kupfer et al. 1997, Section 6.1 and in Watrous and Wootan 1997.) Model generated values for radionuclides in any of 177 tanks are reported in the Hanford Defined Waste Rev. 4 model results (Agnew et al. 1997). The best-basis value for any one analyte may be either a model result or a sample or engineering assessment-based result if available. For a discussion of typical error between model derived values and sample derived values, see Kupfer et al. 1997, Section 6.1.10.

Table D4-1. Best-Basis Inventory Estimates for Nonradioactive Components in Tank 241-T-104 (Effective November 19, 1996). (2 Sheets)

Analyte	Total Inventory (kg)	Basis (S, M, E or C)[1]	Comment
Al	35,000	S	
Bi	40,800	S	
Ca	3,120	S	
Cl	1,450	S	
TIC as CO_3	1,080	S/E	Upper bound
Cr	1,940	S	
F	18,500	S	
Fe	19,500	S	
Hg	0.274	S	Simpson 1998
K	192	S	
La	0	E	
Mn	133	S	
Na	139,000	S	
Ni	24.4	S	
NO_2	8,810	S	
NO_3	125,000	S	
OH_{TOTAL}	153,000	C	Charge balance calculation
Pb	1.35	M	
PO_4	162,000	S	
Si	14,100	S	
SO_4	8,420	S	

Table D4-1. Best-Basis Inventory Estimates for Nonradioactive Components in Tank 241-T-104 (Effective November 19, 1996). (2 Sheets)

Analyte	Total Inventory (kg)	Basis (S, M, E or C)[1]	Comment
Sr	213	S	
TOC	1,520	S	
U_{TOTAL}	1,940	S	
Zr	146	S	

Notes:

[1]S = Sample-based
M = Hanford Defined Waste model-based
E = Engineering assessment-based
C = Calculated by charge balance; includes oxides as hydroxides, not including CO_3, NO_2, NO_3, PO_4, SO_4, and SiO_3.

Table D4-2. Best-Basis Inventory Estimate for Radioactive Components in Tank 241-T-104, Decayed to January 1, 1994 (Effective November 19, 1996). (3 Sheets)

Analyte	Total Inventory (Ci)	Basis (S, M or E)[1]	Comment
^{3}H	2.73	M	
^{14}C	0.0968	S/E	Method/sample prep: (RA/ Water) Expected upper bound
^{59}Ni	0.0722	M	
^{60}Co	0.342	M	
^{63}Ni	6.64	M	
^{79}Se	0.0680	M	
^{90}Sr	5660	S	Method/sample prep: (RA/ Fusion)
^{90}Y	5660	S	Based on ^{90}Sr
^{93m}Nb	0.260	M	
^{93}Zr	0.327	M	
^{99}Tc	1.24	S	Method/sample prep: (RA/ Water)
^{106}Ru	5.67 E-05	M	

Table D4-2. Best-Basis Inventory Estimate for Radioactive Components in Tank 241-T-104, Decayed to January 1, 1994 (Effective November 19, 1996). (3 Sheets)

Analyte	Total Inventory (Ci)	Basis (S, M or E)[1]	Comment
^{113m}Cd	1.17	M	
^{125}Sb	1.34	M	
^{126}Sn	0.102	M	
^{129}I	0.00617	M	
^{134}Cs	0.0240	M	
^{137m}Ba	405	S	Based on ^{137}Cs
^{137}Cs	428	S	Method/sample prep: (RA/ Fusion)
^{151}Sm	248	M	
^{152}Eu	0.0911	M	
^{154}Eu	7.35	S	Method/sample prep: (RA/ Fusion)
^{155}Eu	6.36	M	
^{226}Ra	1.24E-05	M	
^{227}Ac	6.45E-05	M	
^{228}Ra	9.12E-04	M	
^{229}Th	2.16E-05	M	
^{231}Pa	1.57E-04	M	
^{232}Th	6.00E-05	M	
^{232}U	1.34E-04	S/M	
^{233}U	4.69E-04	S/M	
^{234}U	0.638	S/M	
^{235}U	0.0284	S/M	
^{236}U	0.00545	S/M	
^{237}Np	0.0152	M	Sample considered high
^{238}Pu	2.02	S/M	Based on $^{239/240}Pu$ and HDW model isotopic distribution.
^{238}U	0.648	S/M	
^{239}Pu	276	S/M	Calculated from $^{239/240}Pu$ hybrid inventory (301 Ci) Method/ sample prep: (RA/Fusion)

Table D4-2. Best-Basis Inventory Estimate for Radioactive Components in Tank 241-T-104, Decayed to January 1, 1994 (Effective November 19, 1996). (3 Sheets)

Analyte	Total Inventory (Ci)	Basis (S, M or E)[1]	Comment
^{240}Pu	25.1	S/M	Calculated from $^{239/240}Pu$ hybrid inventory (301 Ci) Method/ sample prep: (RA/Fusion)
^{241}Am	37.2	S	Method/sample prep: (RA/ Fusion)
^{241}Pu	84.6	S/M	Based on $^{239/240}Pu$ and HDW model isotopic distribution.
^{242}Cm	0.104	S/M	Based on ^{241}Am and HDW model radionuclide distribution.
^{242}Pu	3.87E-04	S/M	Based on $^{239/240}Pu$ and HDW model isotopic distribution.
^{243}Am	8.83E-04	S/M	Based on ^{241}Am and HDW model radionuclide distribution.
^{243}Cm	0.00628	S/M	Based on ^{241}Am and HDW model radionuclide distribution.
^{244}Cm	0.054	S/M	Based on ^{241}Am and HDW model radionuclide distribution.

[1]S=Sample-based
M=Hanford Defined Waste model-based (Agnew et al 1997)
E=Engineering assessment-based

D5.0 REFERENCES

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