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FEASIBILITY STUDY REPORT FOR OPERABLE UNIT 1

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
FERNALD, OHIO

REMEDIAL INVESTIGATION AND FEASIBILITY STUDY

VOLUME 2 OF 3

MARCH 1994

U.S. DEPARTMENT OF ENERGY
FERNALD FIELD OFFICE

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APPENDIX A

REMEDIAL INVESTIGATION DATA SUMMARY

A.1.0 INTRODUCTION

Appendix A summarizes and compiles data presented the Draft Final Remedial Investigation (RI) Report for Operable Unit 1 issued in February 1994. The primary objective of data collection conducted for the RI Report for Operable Unit 1 was to develop a detailed understanding of the nature of wastes contained in the Waste Pits, their impacts on the surrounding environment, and the threat posed to human health and the environment. This detailed understanding was developed to the degree necessary to: (1) support a decision process that determines if remedial action for Operable Unit 1 is or is not warranted; and (2) support an evaluation of available remedial action alternatives presented in the Feasibility Study (FS).

A.2.0 CONTENT OVERVIEW

The data in Appendix A are presented in the following order:

- Waste pit content summaries
- Radiological, metals, and organic profiles of each waste pit, the Burn Pit, and the Clearwell
- Specific media sampling results—surface water, sediment, soil, and air (radon flux)
- Biological sampling results

Summary statistics were performed on the large volume of RI data to simplify presentation for this FS Report. Appendix A presents only those data which were determined through the data validation process and data useability assessment (both of which are described in detail in the Draft Final RI Report for Operable Unit 1) to be usable for the purposes described above. Where appropriate, the summary data tables presented here contain descriptive notes that provide additional explanations to assist in understanding of this information.

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TABLE A-1

SUMMARY OF OPERABLE UNIT 1 WASTE PIT CONSTITUENTS BASED ON PROCESS KNOWLEDGE

Constituent	Solids to Waste Pits (MT)[a]					
	Waste Pit 1	Waste Pit 2	Waste Pit 3	Waste Pit 4	Waste Pit 5	Waste Pit 6
Uranium (U)	1,075	171	284	2,203	100	1,432
Aluminum (Al)	9	55	687	0	706	0
Antimony (Sb)	0	0	0	0	0	0
Arsenic (As)	0	3	43	0	48	0
Barium (Ba)	0	1	15	0	16	0
Boron (B)	0	0	0	0	0	0
Bismuth (Bi)	0	0	0	0	0	0
Cadmium (Cd)	0	0	3	0	3	0
Calcium (Ca)	456	1,028	453	0	502	0
Lime [$Ca(OH)_2$ from neutralization]	3,776	2,308	37,939	0	40,645	0
Chloride (Cl)	0	2	26	0	29	0
Chromium (Cr)	0	0	2	0	3	0
Cobalt (Co)	0	0	1	0	1	0
Copper (Cu)	7	17	94	0	61	0
Dysprosium (Dy)	0	0	1	0	2	0
Erbrium (Er)	0	0	0	0	0	0
Europium (Eu)	0	0	0	0	0	0
Fluoride (F)	173	380	5	0	6	0
Gadolinium (Gd)	0	0	1	0	1	0
Holmium (Ho)	0	0	0	0	0	0
Iron (Fe)	48	135	1,056	0	886	0
Lead (Pb)	2	4	26	0	17	0
Lutetium (Lu)	0	0	0	0	0	0
Magnesium (Mg)	684	1,528	539	0	634	0
Manganese (Mn)	156	343	1,797	0	1,071	0
Molybdenum (Mo)	0	2	37	0	41	0
Nickel (Ni)	0	0	0	0	0	0

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TABLE A-1
(Continued)

Constituent	Solids to Waste Pits (MT)[a]					
	Waste Pit 1	Waste Pit 2	Waste Pit 3	Waste Pit 4	Waste Pit 5	Waste Pit 6
Samarium (Sm)	0	0	0	0	0	0
Sodium (Na)	0	38	655	0	726	0
Terbium (Tb)	0	0	0	0	0	0
Thorium (Th) - 230	0	4	65	0	76	0
Thorium (Th) - 232	0.4	0	0.4	73.8	5.0	0
Thulium (Tm)	0	0	0	0	0	0
Tin (Sn)	3	7	40	0	25	0
Vanadium (V)	0	16	270	0	299	0
Yttrium (Yt)	0	0	2	0	2	0
Ytterbium (Yb)	0	0	0	0	0	0
Zinc (Zn)	0	0	6	0	7	0
Ammonia (NH_3)	0	2	34	0	38	0
Carbonate (CO_3)	0	9	1,817	0	2,573	0
Magnesium Fluoride (MgF_2)	11,952	10,694	41,183	18,263	5,056	7,750
Phosphate (PO_4)	137	321	511	0	487	0
Lead Oxide (Pb_2O_5)	0	25	425	0	471	0
Filter Aid (SiO_2)	586	553	2,334	334	1,241	0
Sulfate (SO_4)	0	116	1,990	0	2,205	0
Vanadium Pentoxide (V_2O_5)	0	12	212	0	234	0
Nitrate (NO_3)	0	11	324	0	291	0
Hydroxide and Oxygen Ions (OH^-,$O^=$)	0	0	1,042	0	1,041	0
Dolomite (CaO=MgO)	11,953	3,592	0	0	0	0
Unaccounted[b]	9,037	4,452	27,641	3,241	35,710	753
Totals	40,054	25,829	121,083	24,115	95,259	9,935

[a] See RI Appendix F.6.11 for further details.
[b] Includes unidentified materials in individual waste streams, such as unknown precipitated metals from the General Sump, non-uranium portions of the graphite/ceramics and depleted residues, and non-thorium portion of the thorium wastes.

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TABLE A-2

WASTE UNIT CHARACTERISTICS

Waste Unit	Operation Period	Cover Type	RCRA Status	Liner Type	Est. Waste Volume (CY)	Est. Total Volume (CY)	Approx Depth (feet)	Surface Area (acre)	Principal Constituents
Pit 1	1952 - 1959	Soil	SWMU [a]	Clay [b]	48,500	68,400	29.5	2.11	U-238, Th-230, U-234, B, Cd, Cr, Mg
Pit 2	1957 - 1964	Soil	SWMU	Clay	24,200	37,400	23.5	0.90	U-238, U-234, Th-230, Ra-226, As, Ba, Be, Cd, Co, Cu, Pb, Mo, Ni, Zn
Pit 3	1958 - 1977	Soil	SWMU	Clay	204,100	307,500	42	5.00	Th-230, U-238, U-234, Ra-226, As, Ba, Cd, Cr, Cu, Pb, Mg, Mo, Ni, V, Zn
Pit 4	1960 - 1986	RCRA Cap	HWMU [c]	Clay	55,100	72,800	32	1.50	U-238, U-234, Th-230, Th-232, Sb, Ba, Be, Cr, Mg, Mo, Ni, Ag
Pit 5	1968 - 1983	Water	HWMU	EPDM [d]	97,900	97,900	29	3.74	Tc-99, U-238, U-234, Th-230, As, Ba, Be, Cu, Mg, Mo, Ni, Tl, V, Zn
Pit 6	1979 - 1985	Water	SWMU	EPDM	9,600	9,600	20	0.74	U-238, U-234, U-235, As, Mg, Se, Tl
Burn Pit	1957 - 1968	Soil	SWMU	None	30,300	30,300	26	0.50	Th-230, U-238, U-234, Ba, Cr, Co, Cu, Pb, Mg, Ni, Ag, Zn
Clearwell	1959 -1987	Water	SWMU	Clay	3,700	4,300	12	0.65	U-238, U-234, Th-230, U-235, As, Ba,Cr, Cu, Pb, Mg, Mn, Ni, Zn

[a] - RCRA Solid Waste Management Unit

[b] - Native clay liner

[c] - RCRA Hazardous Waste Management Unit

[d] - 60-mil thick Royal Seal ethylene propylene diene monomer elastomeric membrane

TABLE A-3

SUMMARY OF OPERABLE UNIT 1 WASTE PIT CONTENTS BASED ON PROCESS KNOWLEDGE

Source	Solids to Waste Pits[i]																	
	Waste Pit 1			Waste Pit 2			Waste Pit 3			Waste Pit 4			Waste Pit 5			Waste Pit 6		
	Uranium (MTU)	Mass (MT)	Volume (m^3)	Uranium (MTU)	Mass (MT)	Volume (m^3)	Uranium (MTU)	Mass (MT)	Volume (m^3)	Uranium (MTU)	Mass (MT)	Volume (m^3)	Uranium (MTU)	Mass (MT)	Volume (m^3)	Uranium (MTU)	Mass (MT)	Volume (m^3)
General Sump Sludge[a]	2	10,764	7,500	1	6,578	4,600	12	41,720	29,000	0	0	0	20	53,493	37,100	0	0	0
Raffinate[b]	0	0	0	2	431	500	59	32,826	34,130	0	0	0	54	30,068	31,310	0	0	0
Magnesium Fluoride																		
Depleted Slag[c]	636	6,784	4,700	59	634	400	0	0	0	329	7,845	5,300	0	0	0	332	8,082	5,500
Trailer Cake[d]	92	18,401	13,000	71	14,208	9,900	150	30,072	20,900	55	11,136	7,700	0	0	0	0	0	0
Slag Leach[d]	0	0	0	0	0	0	63	12,605	8,700	0	0	0	26	5,239	3,600	0	0	0
UAP Filtrate[e]	3	1,712	1,200	6	3,763	2,600	0	0	0	0	0	0	0	0	0	0	0	0
Depleted Residues[e]	339	2,163	1,500	32	202	100	0	0	0	1,818	3,590	2,500	0	0	0	1,100	1,853	1,200
Graphite/Ceramics[f]	3	150	60	0	13	5	0	0	0	1	451	230	0	0	0	0	0	0
Water Treatment Sludge[g]	0	0	0	0	0	0	0	3,771	2,925	0	0	0	0	5,452	4,230	0	0	0
Thorium -232 Wastes[h]	-	80	100	-	0	0	-	89	100	-	1,093	800	-	1,007	1,000	-	0	0
Totals	1,075	40,054	28,060	171	25,829	18,105	284	121,083	95,755	2,203	24,115	16,530	100	95,259	77,240	1,432	9,935	6,700

[a] See RI Appendix F.6.3.
[b] See RI Appendix F.6.4.
[c] See RI Appendix F.6.7.
[d] See RI Appendix F.6.5.
[e] See RI Appendix F.6.8.
[f] See RI Appendix F.6.6.
[g] See RI Appendix F.6.9.
[h] See RI Appendix F.6.10.
[i] See RI Appendix F.6.11.

TABLE A-4

SUMMARY OF OPERABLE UNIT 1 ENVIRONMENTAL STUDIES

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Studies	Years	Use in RI: Nature and Extent	Use in RI: Risk Assessment	Objective
Groundwater	1984 to 1985	X		Identify the sources for the above-background concentrations of uranium detected in the off-site wells near the FEMP.
RCRA Groundwater Monitoring Program	1985 to Present	X		Maintain site-wide compliance with RCRA regulations.
1986 Radiological Survey and Analysis of Sediment Samples from Paddys Run Creek	1986	X		Identify elevated concentrations of radiological constituents and identify if sediment could be acting as an intermediate or secondary source of contaminants in support of the FEMP Environmental Monitoring Program.
Characterization Investigation Study (CIS)	1986 to 1988	X	X	Aid in the formation of disposition alternatives for FEMP waste in support of a Remedial Investigation/Feasibility Study.
Best Management Practices Plan	1988	X		Evaluate liquid discharges from a series of drainages located on FEMP property.
Waste Pit Area Storm Water Runoff Control Removal Action	1989 to 1992	X		Characterize the soils in the proposed construction area for transportation and disposal under RCRA regulations.
Remedial Investigation/Feasibility Study Sampling (RI/FS)	1987 to 1992	X	X	Characterize the nature and extent of contamination, determine the associated risk to human health and the environment, and evaluate potential remedial options.
Experimental Treatment Facility (ETF) Removal Action	1991 to 1992	X		Determine the extent of soil contamination from waste pit 5 sludge stored in the ETF.
Waste Pit Radon Flux Survey	1991 to 1992	X		Provide estimate of long-term average radon emissions and verify average radon emissions below National Emission Standard for Hazardous Air Pollutants limit.
CERCLA/RCRA Background Soil Study	1992	X	X	Establish nature of variability of background concentrations with respect to depth and soil type. Obtain samples from area with geology representative of the FEMP, and analyze for constituents of potential concern.

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TABLE A-5

WASTE UNIT CONSTITUENT INVENTORY[a] BASED ON ANALYTICAL RESULTS

Constituent	Pit 1	Pit 2	Pit 3	Pit 4	Pit 5	Pit 6	Burn Pit	Clearwell	Total
Radionuclides (Ci)									
Cesium-137	0.04	0.02	U	U	2.8	0.3	U	0.55	4
Neptunium-237	U[b]	U	0.12	0.02	6.4	0.03	0.02	0	7
Plutonium-238	U	0.00	0.1	0.03	0.24	0.01	0.01	0	0
Plutonium-239/240	U	0.00	0.52	0.02	0.59	0.10	0.01	0	1
Radium-226	4.7	7.7	40	2.3	11	0.07	1.0	0.21	67
Radium-228	1.8	3.2	66	10	2.6	0.91	0.45	0.05	85
Ruthenium-106	U	0.06	U	U	0.14	U	U	0	0
Strontium-90	0.22	0.05	0.31	4.0	1.2	0.1	0.02	0.03	6
Technetium-99	0.33	2.3	54	10	180	2.2	2.0	1.0	252
Thorium-228	28	12	U	90	3.6	0.02	8.0	0.11	142
Thorium-230	350	193	1160	100	530	0.54	80	4.9	2,418
Thorium-232	17	3.9	28	20	3.5	0.01	4.0	0.06	76
Uranium-234	53	68	150	270	75	57	49	1.3	723
Uranium-235/236[b]	7.8	32	12	40	4.0	17	4.0	0.55	117
Uranium-238	360	82	230	1900	95	286	58	2.3	3,013
Inorganics (kg)									0
Antimony	4500	700	7500	9900	4000	0	660	25	27,285
Arsenic	600	3000	2,100,000	330	110,000	700	1200	95	2,215,925
Barium	23,000	19,000	980,000	240,000	2,700,000	1600	75,000	8400	4,047,000
Beryllium	410	280	2100	1700	1100	32	200	8	5,830
Boron	52,000	2800	23,000	26,000	0	0	2100	0	105,900
Cadmium	830	150	3100	1200	600	27	410	10	6,327
Chromium	10,000	3200	29,000	46,000	14,000	250	3700	270	106,420
Cobalt	1700	11,000	5400	5800	2700	440	2900	43	29,983
Copper	4300	12,000	260,000	18,000	550,000	1400	9500	3800	859,000
Cyanide	22	25	210	21	110	0	8	8	404
Lead	1700	8600	89,000	4200	18,000	1000	11,000	710	134,210
Manganese	130,000	25,000	560,000	290,000	210,000	2700	30,000	18,000	1,265,700
Mercury	15	30	380	31	130	0	39	7	632

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TABLE A-5
(Continued)

Constituent	Pit 1	Pit 2	Pit 3	Pit 4	Pit 5	Pit 6	Burn Pit	Clearwell	Total
Molybdenum	1500	1700	33,000	3500	36,000	0	1000	61	76,761
Nickel	2800	14,000	33,000	8300	15,000	270	6100	280	79,750
Selenium	20	800	5200	0	850	0	88	4	6,962
Silver	5400	500	6700	24,000	1200	670	5900	17	44,387
Thallium	24	32	750	0	2500	820	17	3	4,146
Tin	0	0	18,000	6400	3800	170	0	32	28,402
Uranium (MT)	1600	51	800	5100	250	220	140	3.5	8,165
Vanadium	4600	4600	630,000	18,000	320,000	1700	4000	2200	985,100
Zinc	1800	13,000	31,000	6700	20,000	560	19,000	460	92,520

[a] Summarized from RI Tables 4-1.1.A through 4-1.8.B with values rounded to two significant figures.
[b] U = non-detected.

TABLE A-6

COMPARISION OF PROCESS KNOWLEDGE AND RI/FS SAMPLING ESTIMATE WASTE PIT INVENTORIES

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Constituent	Pit 1				Pit 2				Pit 3			
	Process Knowledge[b]			RI/FS[c] Samp. Est.	Process Knowledge			RI/FS Samp. Est.	Process Knowledge			RI/FS Samp. Est.
	Min	Max	Best Est.		Min	Max	Best Est.		Min	Max	Best Est.	
Uranium	–	–	1075	1600	–	–	171	51	–	–	284	810
Antimony	–	–	0	4.5	–	–	0	0.7	0	2	1	7.5
Arsenic	–	–	0	0.6	0	7	3	3.0	2	460	43	2100
Barium	–	–	0	23	–	–	1	19	–	–	15	1100
Berylluim	–	–	–	0.4	–	–	–	0.3	–	–	–	2.3
Boron	–	–	0	52	–	–	0	2.8	0	5	0	23
Cadmium	–	–	0	0.8	–	–	0	0.2	4	4	3	31
Chronium	–	–	0	10	–	–	0	3.2	2	30	2	29
Cobalt	–	–	0	1.7	–	–	0	11	1	2	1	5.4
Copper	–	–	7	4.6	–	–	17	12	3	180	94	250
Cyanide	–	–	–	0	–	–	–	0	–	–	–	0.3
Lead	–	–	20	2.9	–	–	4	8.7	1	–	26	89
Manganese	–	–	156	130	–	–	343	25	2	–	179	2200
Mercury	–	–	–	0	–	–	–	0	–	–	–	0.4
Molybdenum	–	–	0	1.5	0	6	2	1.7	6	460	37	33
Nickel	–	–	0	2.8	–	–	0	14	1	3	0	37
Selenium	–	–	–	0	–	–	–	0.8	–	–	–	6.1
Silver	–	–	–	5.4	–	–	–	0.5	–	–	–	6.8
Thallium	–	–	–	0	–	–	–	0	–	–	–	0.9
Tin	–	–	3	2.5	–	–	7	0	0	88	40	18
Vanadium	–	–	0	4.6	0	27	16	4.5	2	1500	270	700
Zinc	–	–	0	1.8	–	–	0	15	3	82	6	31

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TABLE A-6
(Continued)

Constituent	Pit 4				Pit 5				Pit 6			
	Process Knowledge			RI/FS Samp. Est.	Process Knowledge			RI/FS Samp. Est.	Process Knowledge			RI/FS Samp. Est.
	Min	Max	Best Est.		Min	Max	Best Est.		Min	Max	Best Est.	
Uranium	–	–	2203	5700	–	–	100	250	–	–	1432	210
Antimony	–	–	0	9.9	–	–	0	4.4	–	–	0	0.1
Arsenic	–	–	0	0.3	1	310	48	140	–	–	0	0.7
Barium	–	–	0	240	–	–	16	2600	–	–	0	1.6
Beryllium	–	–	–	1.7	–	–	–	1.2	–	–	–	0.1
Boron	–	–	0	25	–	–	0	0	–	–	0	0
Cadmium	–	–	0	1.1	3	3	3	0.7	–	–	0	0.1
Chromium	–	–	0	46	1	15	3	9.5	–	–	0	0.5
Cobalt	–	–	0	5.8	1	2	1	2.9	–	–	0	0.4
Copper	–	–	0	17	2	100	61	700	–	–	0	3.7
Cynanide	–	–	–	0	–	–	–	0.2	–	–	–	0
Lead	–	–	0	4.2	–	–	17	16	–	–	0	1.0
Manganese	–	–	0	290	–	–	1071	160	–	–	0	2.7
Mercury	–	–	–	0	–	–	–	0.1	–	–	–	0
Molybdenum	–	–	0	3.5	0	300	41	46	–	–	0	0.3
Nickel	–	–	0	8.3	–	–	0	11	–	–	0	0.9
Selenium	–	–	–	0	–	–	–	2.9	–	–	–	3.3
Silver	–	–	–	24	–	–	–	1.2	–	–	–	2.7
Thallium	–	–	–	0	–	–	–	2.6	–	–	–	0.8
Tin	–	–	0	6.4	0	50	25	3.8	–	–	0	0.2
Vanadium	–	–	0	18	1	299	257	380	–	–	0	1.7
Zinc	–	–	0	6.7	2	54	7	20	–	–	0	0.8

[a] All units are metric tons.
[b] Based on information from RI Table 1-12 and Appendix F.6.
[c] Based on information in RI Table 4-1.2.B through 4-1.8.B.

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TABLE A-7
RADIOLOGICAL PROFILE OF PIT 1

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (pCi/g)[a b]	(3) ESTIMATED RADIONUCLIDE QUANTITY IN PIT 1 (Ci)[e]	(4) AVERAGE CONCENTRATION IN PIT 1 FROM RI/FS (pCi/g)[f]	(5) HIGHEST HIT IN PIT 1 FROM RI/FS (pCi/g)[f]	(6) LOCATION OF HIGHEST HIT[h]	(7) VERTICAL PROFILE[h]	(8) HORIZONTAL PROFILE[h]	(9) POSSIBLE SOURCES[i j] (Refer to RI Sections 1 and 4.2)
Total waste volume in pit (yard3)[c]		48,500						
Total dry waste in pit (kg)[d]		92,137,858						
Specific gravity of waste[d]		3.04						
Water content (wt. of water/dry wt.) (%)[d]		22.40						
URANIUM-TOTAL	3.68	1,600,000 kg	17, 000 µg/g	48,000 µg/g	1767	12 to 20 ft	scattered	Depleted magnesium fluoride (MgF2) slag, slag leach filter cake, general sump sludge, dust collector residue.
URANIUM-238	0.92	360	3,900	16,000	1767	12 to 20 ft	scattered	Refinery sump from the processing of uranium ore.
URANIUM-234	0.94	53	570	1200 CIS	01-03	0 to 12 ft	scattered	
THORIUM-230	1.85	350	3,800	5,500	1766	7 to 14 ft	scattered	
RADIUM-226	1.27	4.7	51	100	1766	7 to 14 ft	scattered	
URANIUM-235/236	0.13	7.8	85	260	1767	12 to 20 ft	scattered	Refinery sump from the processing of uranium ore.
THORIUM-232	1.24	17	180	490	1765	14 to 22 ft	scattered	Thorium production, or impurities in the ore or ore concentrates.
RADIUM-228	1.25	1.8	20	41	1766	7 to 14 ft	scattered	Re-growth from Th-232 in the refinery sump.
THORIUM-228	1.25	28	300	790	1765	14 to 22 ft	scattered	Thorium production, or impurities in the ore or ore concentrates.
CESIUM-137	<0.01	0.040	0.43 CIS	1.1 CIS	01-04	0 to 12 ft		Fission material from the processing of irradiated uranium from Hanford.
NEPTUNIUM-237	<0.01	U	U	U CIS				
PLUTONIUM-238	<0.01	U	U	U				
PLUTONIUM-239/240	<0.01	U	U	U				
RUTHENIUM-106	<0.06	U	U	U				
STRONTIUM-90	0.5	0.22	2.43	7.7	1767	6 to 12 ft	scattered	
TECHNETIUM-99	<0.9	0.33	3.6 CIS	15 CIS	01-03	0 to 12 ft	discreet	

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TABLE A-7
RADIOLOGICAL PROFILE OF PIT 1

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (pCi/g) [a b]	(3) ESTIMATED RADIONUCLIDE QUANTITY IN PIT 1 (Ci) [e]	(4) AVERAGE CONCENTRATION IN PIT 1 FROM RI/FS (pCi/g) [f]	(5) HIGHEST HIT IN PIT 1 FROM RI/FS (pCi/g) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h]	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i j] (Refer to RI Sections 1 and 4.2)
Total waste volume in pit (yard3) [c]		48,500						
Total dry waste in pit (kg) [d]		92,137,858						
Specific gravity of waste [d]		3.04						
Water content (wt. of water/dry wt.) (%) [d]		22.40						

[a] Wastestream volumes and calculations were based on:
1. Materials Controls and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

[b] From RI Table 4.2 Subsurface Soils
[c] Refer to Sample Calculations 1 and 34 in RI Appendix F
[d] Refer to RI Appendix A, and Sample Calculation 34 in RI Appendix F
[e] Based on average concentration. Refer to Sample Calculation 35 in RI Appendix F.
[f] From RI Tables 4.4 and 4.5
[h] RI Appendix A
[i] Operable Unit 3 Work Plan Addendum, June 1992
[j] RI Sections 1 and 4.2

U = non detected and is entered as a zero in all calculations
CIS = Characterization Investigation Study (Refer to RI Appendix A)
pCi/g = picocuries per gram
µg/g = microgram/gram
kg = kilogram

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TABLE A-8
RADIOLOGICAL PROFILE OF PIT 2

(1) ANALYTE	(2) BACKGROUND CONCENT. FOR SOIL (pCi/g) [a b]	(3) ESTIMATED RADIONUCLIDE QUANTITY IN PIT 2 (Ci) [e]	(4) AVERAGE CONCENTRATION IN PIT 2 FROM RI/FS (pCi/g) [f]	(5) HIGHEST HIT IN PIT 2 FROM RI/FS (pCi/g) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h]	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i j] (Refer to RI Sections 1 and 4.2)
Total waste volume in pit (yard3) [c]		24,200						
Total dry waste quantity in pit (kg) [d]		17,514,507						
Specific gravity of waste [d]		2.62						
Water content (wt. of water/dry wt.) (%) [d]		176.90						
URANIUM-TOTAL	3.68	51,000 kg	2,900 µg/g	5,800 µg/g	1768	7 to 14 ft	scattered	Depleted magnesium flouride (MgF2) slag, slag leach filter cake, general sump sludge, dust collector residue.
URANIUM-238	0.92	82	4,700 CIS	18,000 CIS	02 - 02	0 to 10 ft	scattered	Refinery sump from the processing of uranium ore.
URANIUM-234	0.94	68	3,900 CIS	18,000 CIS	02 - 02	0 to 10 ft	scattered	
THORIUM-230	1.85	192.66	11,000	1,800	1768	7 to 14 ft	scattered	
RADIUM-226	1.27	7.7	440	950	1768	7 to 14 ft	scattered	
URANIUM-235/236	0.13	32.0	1,800 CIS	8,800 CIS	02 - 02	0 to 10 ft	scattered	Refinery sump from the processing of uranium ore.
THORIUM-232	1.24	3.9	220	340	1768	7 to 14 ft	scattered	Thorium production, or impurities in the ore or ore concentrates.
RADIUM-228	1.25	3.2	180	440	1768	7 to 14 ft	scattered	Re-growth from Th-232 in the refinery sump.
THORIUM-228	1.25	12	660	700	1768	14 to 17.5 ft	scattered	Thorium production, or impurities in the ore or ore concentrates.
CESIUM-137	<0.01	.018	1.15 CIS	3.6 CIS	02 - 01	0 to 8 ft	scattered	Fission material from the processing of irradiated uranium from Hanford.
NEPTUNIUM-237	<0.01	U	U	U				
PLUTONIUM-238	<0.01	0.0018	0.10 CIS	0.10 CIS	02 - 01	0 to 8 ft	scattered	
PLUTONIUM-239/240	<0.01	0.0028	0.16 CIS	0.60 CIS	02 - 02	0 to 10 ft	scattered	
RUTHENIUM-106	<0.06	0.058	3.3	11	1768	7 to 14 ft	scattered	
STRONTIUM-90	0.5	0.046	2.6	4.0	1769	16 to 22 ft	scattered	
TECHNETIUM-99	<0.9	2.3	130 CIS	620 CIS	02 - 02	0 to 10 ft	scattered	

TABLE A-8
RADIOLOGICAL PROFILE OF PIT 2

(1) ANALYTE	(2) BACKGROUND CONCENT. FOR SOIL (pCi/g) [a b]	(3) ESTIMATED RADIONUCLIDE QUANTITY IN PIT 2 (Ci) [e]	(4) AVERAGE CONCENTRATION IN PIT 2 FROM RI/FS (pCi/g) [f]	(5) HIGHEST HIT IN PIT 2 FROM RI/FS (pCi/g) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h]	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i j] (Refer to RI Sections 1 and 4.2)
Total waste volume in pit (yard3) [c]		24,200						
Total dry waste quantity in pit (kg) [d]		17,514,507						
Specific gravity of waste [d]		2.62						
Water content (wt. of water/dry wt.) (%) [d]		176.90						

[a] Wastestream volumes and calculations were based on:
1. Materials Controls and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel

[b] From RI Table 4.2 Subsurface Soils
[c] Refer to Sample Calculations 1 and 34 in RI Appendix F
[d] Refer to RI Appendix A, and Sample Calculation 34 in RI Appendix F
[e] Based on average concentration, refer to Sample Calculation 35 in RI Appendix F
[f] From RI Table 4.4 and 4.5
[h] RI Appendix A
[i] Operable Unit 3 Work Plan Addendum, June 1992
[j] RI Sections 1 and 4.2

U = non detected and is entered as a zero in all calculations
CIS = Characterization Investigation Study (Refer to RI Appendix A)
pCi/g = picocuries per gram
µg/g = microgram/gram
kg = kilogram

TABLE A-9
RADIOLOGICAL PROFILE OF PIT 3

(1) ANALYTE	(2) BACKGROUND CONCENT. FOR SOIL (pCi/g) [a b]	(3) ESTIMATED RADIONUCLIDE QUANTITY IN PIT 3 (Ci) [e]	(4) AVERAGE CONCENTRATION IN PIT 3 FROM RI/FS (pCi/g) [f]	(5) HIGHEST HIT IN PIT 3 FROM RI/FS (pCi/g) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h]	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i j] (Refer to RI Sections 1 and 4.2)
Total waste volume in pit (yard3) [c]		204,100						
Total dry waste quantity in pit (kg) [d]		235,071,108						
Specific gravity of waste [d]		2.62						
Water content (wt. of water/dry wt.) (%) [d]		74.00						
URANIUM-TOTAL	3.68	800,000 kg	3,400 µg/g	5,900 µg/g	1772	18 to 36 ft	scattered	Depleted magnesium flouride (MgF2) slag, slag leach filter cake, general sump sludge, dust collector residue.
URANIUM-238	0.92	230	978	1,700	1772	18 to 36 ft	scattered	Refinery sump from the processing of uranium ore.
URANIUM-234	0.94	150	640	990	1771	28 to 41 ft	scattered	
THORIUM-230	1.85	1,160	4,930	12,000 CIS	03-02	0 to 20	scattered	
RADIUM-226	1.27	40	170	450	1770	12 to 24 ft	scattered	
URANIUM-235/236	0.13	12	49	52	1770	24 to 39 ft	scattered	Refinery sump from the processing of uranium ore.
THORIUM-232	1.24	28	170	400	1770	24 to 39 ft	scattered	Thorium production, or impurities in the ore or ore concentrates.
RADIUM-228	1.25	66	120	240	1770	24 to 39 ft	scattered	Re-growth from Th-232 in the refinery sump.
THORIUM-228	1.25	U	280	820	1771	14 to 28 ft	scattered	Thorium production, or impurities in the ore or ore concentrates.
CESIUM-137	<0.01	U	U	U	U	0 to 20	scattered	Fission material from the processing of irradiated uranium from Hanford.
NEPTUNIUM-237	<0.01	0.12	0.53 CIS	2.1 CIS	03-03	24 to 39 ft		
PLUTONIUM-238	<0.01	0.10	0.44	0.98	1770	0 to 20	scattered	
PLUTONIUM-239/240	<0.01	0.52	2.2 CIS	14 CIS	03-03	0 to 20	scattered	
RUTHENIUM-106	<0.06	U	U	U	03-03	0 to 20	scattered	
STRONTIUM-90	0.5	0.31	1.32 CIS	5.2 CIS	03-03	0 to 20	scattered	
TECHNETIUM-99	<0.9	54	230 CIS	1,100 CIS	03-03	0 to 20	scattered	

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TABLE A-9
RADIOLOGICAL PROFILE OF PIT 3

(1) ANALYTE	(2) BACKGROUND CONCENT. FOR SOIL (pCi/g) [a b]	(3) ESTIMATED RADIONUCLIDE QUANTITY IN PIT 3 (Ci) [e]	(4) AVERAGE CONCENTRATION IN PIT 3 FROM RI/FS (pCi/g) [f]	(5) HIGHEST HIT IN PIT 3 FROM RI/FS (pCi/g) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h]	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i j] (Refer to RI Sections 1 and 4.2)
Total waste volume in pit (yard3) [c]		204,100						
Total dry waste quantity in pit (kg) [d]		235,071,108						
Specific gravity of waste [d]		2.62						
Water content (wt. of water/dry wt.) (%) [d]		74.00						

[a] Wastestream volumes and calculations were based on:
1. Materials Controls and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

[b] From RI Table 4.2
[c] Refer to Sample Calculations 1 and 34 in RI Appendix F
[d] Refer to RI Appendix A, and Sample Calculation 34 in RI Appendix F
[e] Based on average concentration, refer to Sample Calculation 35 in RI Appendix F
[f] From RI Tables 4.4 and 4.5
[h] RI Appendix A
[i] Operable Unit 3 Work Plan Addendum, June 1992
[j] RI Sections 1 and 4.2

U = non detected and is entered as a zero in all calculations
CIS = Characterization Investigation Study (Refer to RI Appendix A)
pCi/g = picocuries per gram
µg/g = microgram/gram
kg = kilogram

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TABLE A-10
RADIOLOGICAL PROFILE OF PIT 4

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (pCi/g) [a b]	(3) ESTIMATED RADIONUCLIDE QUANTITY IN PIT 4 (Ci) [e]	(4) AVERAGE CONCENTRATION IN PIT 4 FROM RI/FS (pCi/g) [f]	(5) HIGHEST HIT IN PIT 4 FROM RI/FS (pCi/g) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h]	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i j] (Refer to RI Sections 1 and 4.2)
Total waste volume in pit (yard3) [c]		55,100						
Total dry waste quantity in pit (kg) [d]		98,590,826						
Specific gravity of waste [d]		3.02						
Water content (wt. of water/dry wt.) (%) [d]		29.10						
URANIUM-TOTAL	3.68	5,100,000 kg	52,000 µg/g	120,000 µg/g	1773	9 to 18 ft	scattered	Depleted magnesium flouride (MgF2) slag, slag leach filter cake, general sump sludge, dust collector residue.
URANIUM-238	0.92	1,900	19,000	42,000	1775	10 to 19 ft	scattered	Refinery sump from the processing of uranium ore.
URANIUM-234	0.94	270	2,700	4,100	1775	10 to 19 ft	scattered	
THORIUM-230	1.85	100	1,000	1,800	1773	9 to 18 ft	scattered	
RADIUM-226	1.27	2.3	23	50	1775	19 to 30 ft	scattered	
URANIUM-235/236	0.13	40.0	380	930	1775	10 to 19 ft	scattered	Refinery sump from the processing of uranium ore.
THORIUM-232	1.24	20	230	840	1773	9 to 18 ft	scattered	Thorium production, or impurities in the ore or ore concentrates.
RADIUM-228	1.25	10.0	59	140	1773	9 to 18 ft	scattered	Re-growth from Th-232 in the refinery sump.
THORIUM-228	1.25	90	950	2,500	1773	9 to 18 ft	scattered	Thorium production, or impurities in the ore or ore concentrates.
CESIUM-137	<0.01	U	U	U				Fission material from the processing of irradiated uranium from Hanford.
NEPTUNIUM-237	<0.01	0.018	0.18 CIS	0.4 CIS	04 - 04	0 to 20 ft	scattered	
PLUTONIUM-238	<0.01	0.025	0.25 CIS	0.5 CIS	04 - 03	0 to 20 ft	scattered	
PLUTONIUM-239/240	<0.01	0.015	0.15 CIS	0.4 CIS	04 - 03	0 to 20 ft	scattered	
RUTHENIUM-106	<0.06	U	U	U				
STRONTIUM-90	0.5	4.0	44	140.0	1773	9 to 18 ft	scattered	
TECHNETIUM-99	<0.9	10	80 CIS	230 CIS	04 - 04	0 to 20 ft	scattered	

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TABLE A-10
RADIOLOGICAL PROFILE OF PIT 4

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (pCi/g)[a b]	(3) ESTIMATED RADIONUCLIDE QUANTITY IN PIT 4 (Ci)[e]	(4) AVERAGE CONCENTRATION IN PIT 4 FROM RI/FS (pCi/g)[f]	(5) HIGHEST HIT IN PIT 4 FROM RI/FS (pCi/g)[f]	(6) LOCATION OF HIGHEST HIT[h]	(7) VERTICAL PROFILE[h]	(8) HORIZONTAL PROFILE[h]	(9) POSSIBLE SOURCES[i j] (Refer to RI Sections 1 and 4.2)
Total waste volume in pit (yard3)[c]		55,100						
Total dry waste quantity in pit (kg)[d]		98,590,826						
Specific gravity of waste[d]		3.02						
Water content (wt. of water/dry wt.) (%)[d]		29.10						

[a] Wastestream volumes and calculations were based on:
1. Materials Controls and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

[b] From RI Table 4.2
[c] Refer to Sample Calculations 1 and 34 in RI Appendix F
[d] Refer to RI Appendix A, and Sample Calculation 34 in RI Appendix F
[e] Based on average concentration - refer to Sample Calculation 35 in RI Appendix F
[f] From RI Tables 4.4 and 4.5
[h] RI Appendix A
[i] Operable Unit 3 Work Plan Addendum, June 1992
[j] RI Sections 1 and 4.2

U = non detected and is entered as a zero in all calculations
CIS = Characterization Investigation Study (Refer to RI Appendix A)
pCi/g = picocuries per gram
µg/g = microgram/gram
kg = kilogram

TABLE A-11
RADIOLOGICAL PROFILE OF PIT 5

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL [a b] c (pCi/g)	(3) ESTIMATED RADIONUCLIDE QUANTITY IN PIT 5 [e] (Ci)	(4) AVERAGE CONCENTRATION IN PIT 5 FROM RI/FS [f] (pCi/g)	(5) HIGHEST HIT IN PIT 5 FROM RI/FS [f] (pCi/g)	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h]	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i j] (Refer to RI Sections 1 and 4.2)
Total waste volume in pit (yard3)		97,900						
Total dry waste quantity in pit (kg) [d]		117,625,873						
Specific gravity of waste [d]		2.43						
Water content (wt. of water/dry wt.) (%) [d]		54.70						
URANIUM-TOTAL	3.68	250,000 kg	2,100 µg/g	3,700 µg/g	05 - 03	0 to 18 ft	scattered	Depleted magnesium flouride (MgF2) slag, slag leach filter cake, general sump sludge, dust collector residue.
URANIUM-238	0.92	95	809	1,200 CIS	05 - 02	0 to 14 ft	scattered	Refinery sump from the processing of uranium ore.
URANIUM-234	0.94	75	640	1,300 CIS	05 - 02	0 to 14 ft	scattered	
THORIUM-230	1.85	530	4,500 CIS	8,500 CIS	05 - 05	0 to 15 ft	scattered	
RADIUM-226	1.27	11	93	150	05 - 03	0 to 18 ft	scattered	
URANIUM-235/236	0.13	4.0	34 CIS	79 CIS	05 - 02	0 to 14 ft	scattered	Refinery sump from the processing of uranium ore.
THORIUM-232	1.24	3.50	30 CIS	55 CIS	05 - 03	0 to 28 ft	scattered	Thorium production, or impurities in the ore or ore concentrates.
RADIUM-228	1.25	2.6	22.3	39	05 - 07	0 to 6 ft	scattered	Re-growth from Th-232 in the refinery sump.
THORIUM-228	1.25	3.60	31 CIS	44 CIS	05 - 03	0 to 28 ft	scattered	Thorium production, or impurities in the ore or ore concentrates.
CESIUM-137	<0.01	2.8	24 CIS	78.0	05 - 04	0 to 16 ft	scattered	Fission material from the processing of irradiated uranium from Hanford.
NEPTUNIUM-237	<0.01	6.4	40	46	05 - 06	0 to 8 ft	scattered	
PLUTONIUM-238	<0.01	0.24	2 CIS	4.4 CIS	05 - 04	0 to 30 ft	scattered	
PLUTONIUM-239/240	<0.01	0.59	5 CIS	13 CIS	05 - 02	0 to 14 ft	scattered	
RUTHENIUM-106	<0.06	0.14	1.2	3.3	05 - 06	0 to 8 ft	scattered	
STRONTIUM-90	0.5	1.20	10 CIS	31 CIS	05 - 06	0 to 6 ft	scattered	
TECHNETIUM-99	<0.9	180.00	1,500.0	3,000	05 - 08	0 to 6 ft	scattered	

TABLE A-11
RADIOLOGICAL PROFILE OF PIT 5

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL [a b] [c] (pCi/g)	(3) ESTIMATED RADIONUCLIDE QUANTITY IN PIT 5 [e] (Ci)	(4) AVERAGE CONCENTRATION IN PIT 5 FROM RI/FS [f] (pCi/g)	(5) HIGHEST HIT IN PIT 5 FROM RI/FS [f] (pCi/g)	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h]	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i j] (Refer to RI Sections 1 and 4.2)
Total waste volume in pit (yard3)		97,900						
Total dry waste quantity in pit (kg) [d]		117,625,873						
Specific gravity of waste [d]		2.43						
Water content (wt. of water/dry wt.) (%) [d]		54.70						

[a] Wastestream volumes and calculations were based on:
1. Materials Controls and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; , and
3. Interviews with knowledgeable plant personnel.

[b] From RI Table 4.2 Subsurface Soils
[c] Refer to Sample Calculations 1 and 34 in RI Appendix F
[d] Refer to RI Appendix A and Sample Calculation 34 in RI Appendix F
[e] Based on average concentration - refer to Sample Calculation 35 in RI Appendix F
[f] From RI Tables 4.4 and 4.5
[h] RI Appendix A
[i] Operable Unit 3 Work Plan Addendum, June 1992
[j] RI Sections 1 and 4.2

U = non detected and is entered as a zero in all calculations
CIS = Characterization Investigation Study (Refer to RI Appendix A)
pCi/g = picocuries per gram
µg/g = microgram/gram
kg = kilogram

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TABLE A-12
RADIOLOGICAL PROFILE OF PIT 6

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (pCi/g)[a b]	(3) ESTIMATED RADIONUCLIDE QUANTITY IN PIT 5 (Ci)[e]	(4) AVERAGE CONCENTRATION IN PIT 5 FROM RI/FS (pCi/g)[f]	(5) HIGHEST HIT IN PIT 5 FROM RI/FS (pCi/g)[f]	(6) LOCATION OF HIGHEST HIT[h]	(7) VERTICAL PROFILE[h]	(8) HORIZONTAL PROFILE[h]	(9) POSSIBLE SOURCES[i j] (Refer to RI Sections 1 and 4.2)
Total waste volume in pit (yard3)[c]		9,600						
Total dry waste quantity in pit (kg)[d]		16,805,824						
Specific gravity of waste[d]		2.87						
Water content (wt. of water/dry wt.) (%)[d]		25.40						
URANIUM-TOTAL	3.68	220,000 kg	13,000 µg/g	28,000 µg/g	06 - 08	0 to 6 ft	scattered	Depleted magnesium flouride (MgF2) slag, slag leach filter cake, general sump sludge, dust collector residue.
URANIUM-238	0.92	285.70	17,000 CIS	29,000	06 - 05	0 to 6 ft	scattered	Refinery sump from the processing of uranium ore.
URANIUM-234	0.94	57.00	3,400 CIS	5,300 CIS	06 - 02	0.7 to 4 ft	scattered	
THORIUM-230	1.85	0.54	32	62	06 - 06	0 to 6 ft	scattered	
RADIUM-226	1.27	0.066	3.9	4.9	06 - 07	0 to 6 ft	scattered	
URANIUM-235/236	0.13	17.00	1,000 CIS	1,800 CIS	06 - 02	0.7 to 4	scattered	Refinery sump from the processing of uranium ore.
THORIUM-232	1.24	0.0090	0.53	1.2 CIS	06 - 01	1.2 to 4.5 ft	scattered	Thorium production, or impurities in the ore or ore concentrates.
RADIUM-228	1.25	0.91	54	190	06 - 01	0 to 6 ft	scattered	Re-growth from Th-232 in the refinery sump.
THORIUM-228	1.25	0.020	1.2	1.7	06 - 06	0 to 6 ft	scattered	Thorium production, or impurities in the ore or ore concentrates.
CESIUM-137	<0.01	0.30	17 CIS	31 CIS	06 - 02	0.7 to 4.0 ft	scattered	Fission material from the processing of irradiated uranium from Hanford.
NEPTUNIUM-237	<0.01	0.034	2.0 CIS	3.6 CIS	06 - 02	0.7 to 4.0 ft	scattered	
PLUTONIUM-238	<0.01	0.013	0.78 CIS	1.4 CIS	06 - 01	1.2 to 4.5 ft	scattered	
PLUTONIUM-239/240	<0.01	0.10	8.7 CIS	15 CIS	06 - 01	1.2 to 4.5 ft	scattered	
RUTHENIUM-106	<0.06	U	U	U				
STRONTIUM-90	0.5	0.10	4.1 CIS	5.1 CIS	06 - 01	1.2 to 4.5 ft	scattered	
TECHNETIUM-99	<0.9	2.2	130 CIS	160 CIS	03 - 06	0 to 15 ft	scattered	

TABLE A-12
RADIOLOGICAL PROFILE OF PIT 6

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (pCi/g) [a b]	(3) ESTIMATED RADIONUCLIDE QUANTITY IN PIT 5 (Ci) [e]	(4) AVERAGE CONCENTRATION IN PIT 5 FROM RI/FS (pCi/g) [f]	(5) HIGHEST HIT IN PIT 5 FROM RI/FS (pCi/g) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h]	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i j] (Refer to RI Sections 1 and 4.2)
Total waste volume in pit (yard3) [c]		9,600						
Total dry waste quantity in pit (kg) [d]		16,805,824						
Specific gravity of waste [d]		2.87						
Water content (wt. of water/dry wt.) (%) [d]		25.40						

[a] Wastestream volumes and calculations were based on:
1. Materials Controls and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

[b] Refer to RI Table 4.2 Subsurface Soils
[c] Refer to Sample Calculations 1 and 34 in RI Appendix F
[d] Refer to RI Appendix A and Sample Calculation 34 in RI Appendix F
[e] Based on average concentration - refer to Sample Calculation 37 in RI Appendix F
[f] From RI Tables 4.4 and 4.5
[h] From RI Appendix A
[i] Operable Unit 3 Work Plan Addendum, June 1992
[j] RI Sections 1 and 4.2

U = Non detected and is entered as a zero in all calculations
CIS = Characterization Investigation Study (refer to RI Appendix A)
pCi/g = picocuries per gram
µg/kg = microgram per kilogram
kg = kilogram

TABLE A-13
RADIOLOGICAL PROFILE OF THE BURN PIT

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (pCi/g)[a b]	(3) ESTIMATED RADIONUCLIDE QUANTITY IN THE BURN PIT (Ci)[e]	(4) AVERAGE CONCENTRATION IN THE BURN PIT FROM RI/FS (pCi/g)[f]	(5) HIGHEST HIT IN THE BURN PI FROM RI/FS (pCi/g)[f]	(6) LOCATION OF HIGHEST HIT[h]	(7) VERTICAL PROFILE[h]	(8) HORIZONTAL PROFILE[h]	(9) POSSIBLE SOURCES[j i] (Refer to RI Sections 1 and 4.2)
Total waste volume in pit (yard3)[c]		30,300						
Total dry waste quantity in pit (kg)[d]		67,771,624						
Specific gravity of waste[d]		3.74						
Water content (wt. of water/dry wt.) (%)[d]		27.90						
URANIUM-TOTAL	3.68	140,000 kg	2, 000 µg/g	4,500 µg/g	1776	19.5 to 32.5 ft	scattered	Depleted magnesium flouride (MgF2) slag, slag leach filter cade, general sump sludge, dust collector residue.
URANIUM-238	0.92	58	850	2,000	1776	19.5 to 32.5 ft	scattered	Refinery sump from the processing of uranium ore.
URANIUM-234	0.94	49	720	1,700	1776	19.5 to 32.5 ft	scattered	
THORIUM-230	1.85	80	1,180	4,500	1776	19.5 to 32.5 ft	scattered	
RADIUM-226	1.27	1.0	15	39	1776	19.5 to 32.5 ft	scattered	
URANIUM-235/236	0.13	4.0	53	100	1776	19.5 to 32.5 ft	scattered	Refinery sump from the processing of uranium ore.
THORIUM-232	1.24	4.0	57	410	1776	19.5 to 32.5 ft	scattered	Thorium production, or impurities in the ore or ore concentrates.
RADIUM-228	1.25	0.45	6.6	10	1776	6.5 to 19.5 ft	scattered	Re-growth from Th-232 in the refinery sump.
THORIUM-228	1.25	8.0	120	900	1776	19.5 to 32.5 ft	scattered	Thorium production, or impurities in the ore or ore concentrates.
CESIUM-137	<0.01	U	U	U				Fission material from the processing of irradiated uranium from Hanford.
NEPTUNIUM-237	<0.01	0.018	0.27 CIS	0.6 CIS	07 - 04	0 to 16 ft	scattered	
PLUTONIUM-238	<0.01	0.008	0.12 CIS	0.5 CIS	07 - 03	0 to 14 ft	scattered	
PLUTONIUM-239/240	<0.01	0.008	0.12 CIS	0.4 CIS	07 - 05	0 to 12 ft	scattered	
RUTHENIUM-106	<0.06	U	U	U				
STRONTIUM-90	0.5	0.021	0.31	0.5	1777	0 to 6.5 ft	scattered	
TECHNETIUM-99	<0.9	2.0	29 CIS	64 CIS	07 - 05	0 to 12 ft	scattered	

TABLE A-13
RADIOLOGICAL PROFILE OF THE BURN PIT

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (pCi/g) [a b]	(3) ESTIMATED RADIONUCLIDE QUANTITY IN THE BURN PIT (Ci) [e]	(4) AVERAGE CONCENTRATION IN THE BURN PIT FROM RI/FS (pCi/g) [f]	(5) HIGHEST HIT IN THE BURN PI FROM RI/FS (pCi/g) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h]	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [j i] (Refer to RI Sections 1 and 4.2)
Total waste volume in pit (yard3) [c]		30,300						
Total dry waste quantity in pit (kg) [d]		67,771,624						
Specific gravity of waste [d]		3.74						
Water content (wt. of water/dry wt.) (%) [d]		27.90						

a Wastestream volumes and calculations were based on:
1. Materials Controls and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

b From RI Table 4.2 Subsurface Soils

c Refer to Sample Calculations 1 and 34 in RI Appendix F

d Refer to RI Appendix A and Sample Calculation 34 in RI Appendix F

e Based on average concentration - refer to Sample Calculation 35 in RI Appendix F

f From RI Tables 4.4 and 4.5

h RI Appendix A

i Operable Unit 3 Work Plan Addendum, June 1992

j RI Sections 1 and 4.2

U = non detected and is entered as a zero in all calculations

CIS = Characterization Investigation Study (Refer to RI Appendix A)

pCi/g = picocuries per gram

µg/g = microgram/gram

kg = kilogram

TABLE A-14
RADIOLOGICAL PROFILE OF THE CLEARWELL

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (pCi/g) [a b]	(3) ESTIMATED RADIONUCLIDE QUANTITY IN THE CLEARWELL (Ci) [e]	(4) AVERAGE CONCENTRATION IN THE CLEARWELL FROM RI/FS (pCi/g) [f]	(5) HIGHEST HIT IN THE CLEARWELL FROM RI/FS (pCi/g) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h]	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i j] (Refer to RI Sections 1 and 4.2)
Total waste volume in pit (yard3) [c]		3,700						
Total dry waste quantity in pit (kg) [d]		2,982,394						
Specific gravity of waste [d]		1.44						
Water content (wt. of water/dry wt.) (%) [d]		40.90						
URANIUM-TOTAL	3.68	3,500 kg	1,200 µg/g	2,800 µg/g	CW-D	11 to 13 ft	scattered	Slag leach filter cake, neutralized raffinate, dust collector residue, uranium ore processing.
URANIUM-238	0.92	2.3	810	1,600	CW-D	11 to 13 ft	scattered	
URANIUM-234	0.94	1.3	457	1,100	CW-F	11 to 13 ft	scattered	
THORIUM-230	1.85	4.9	1,680 CIS	5,600 CIS	08 - 005	11 to 13 ft	scattered	
RADIUM-226	1.27	0.21	74	170	CW - E	11 to 13 ft	scattered	
URANIUM-235/236	0.13	0.55	190	370	CW - D	11 to 13 ft	scattered	Refinery sump from the processing of uranium ore.
THORIUM-232	1.24	0.055	19 CIS	39 CIS	08 - 005	11 to 13 ft	scattered	Thorium production, or impurities in the ore or ore concentrates.
RADIUM-228	1.25	0.052	18	26	CW - D	11 to 13 ft	scattered	Re-growth from Th-232 in the refinery sump.
THORIUM-228	1.25	0.11	37	56 CIS	08 - 001	11 to 13 ft	scattered	Thorium production, or impurities in the ore or ore concentrates.
CESIUM-137	<0.01	0.55	190 CIS	450 CIS	08 - 005	11 to 13 ft	scattered	Fission material from the fallout of weapons testing uranium from Hanford.
NEPTUNIUM-237	<0.01	0.0032	1.0	2.2 CIS	08 - 008	11 to 13 ft	scattered	
PLUTONIUM-238	<0.01	0.00072	0.25	0.49	CW - D	11 to 13 ft	scattered	
PLUTONIUM-239/240	<0.01	0.00081	0.28	0.54	CW - E	11 to 13 ft	scattered	
RUTHENIUM-106	<0.06	0.0032	1.1	3.1	CW - D	11 to 13 ft	scattered	
STRONTIUM-90	0.5	0.025	8.5 CIS	26 CIS	08 - 005	11 to 13 ft	scattered	
TECHNETIUM-99	<0.9	1.0	360.0	700	CW - B	11 to 13 ft	scattered	

TABLE A-14
RADIOLOGICAL PROFILE OF THE CLEARWELL

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (pCi/g)[a b]	(3) ESTIMATED RADIONUCLIDE QUANTITY IN THE CLEARWELL (Ci)[e]	(4) AVERAGE CONCENTRATION IN THE CLEARWELL FROM RI/FS (pCi/g)[f]	(5) HIGHEST HIT IN THE CLEARWELL FROM RI/FS (pCi/g)[f]	(6) LOCATION OF HIGHEST HIT[h]	(7) VERTICAL PROFILE[h]	(8) HORIZONTAL PROFILE[h]	(9) POSSIBLE SOURCES[i j] (Refer to RI Sections 1 and 4.2)
Total waste volume in pit (yard3)[c]		3,700						
Total dry waste quantity in pit (kg)[d]		2,982,394						
Specific gravity of waste[d]		1.44						
Water content (wt. of water/dry wt.) (%)[d]		40.90						

a Wastestream volumes and calculations were based on:
1. Materials Controls and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

b From RI Table 4.2 Subsurface Soils

c Refer to Sample Calculations 1 and 34 in RI Appendix F

d Refer to RI Appendix A and Sample Calculation 34 in RI Appendix F

e Based on average concentration -refer to Sample Calculation 35 in RI Appendix F

f From RI Tables 4.4 and 4.5

h RI Appendix A

i Operable Unit 3 Work Plan Addendum, June 1992

j RI Sections 1 and 4.2

U = non detected and is entered as a zero in all calculations

CIS = Characterization Investigation Study (Refer to RI Appendix A)

pCi/g = picocuries per gram

µg/g = microgram/gram

kg = kilogram

TABLE A-15
METALS PROFILE OF PIT 1

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (mg/kg) [a b]	(3) ESTIMATED METALS QUANTITY IN PIT 1 (kg) [e]	(4) AVERAGE CONCENTRATION IN PIT 1 FROM RI/FS (mg/kg) [f]	(5) HIGHEST HIT IN PIT 1 FROM RI/FS (mg/kg) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h] (ft)	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i] (Refer to RI Sections 1 and 4.2 for detail sources)
Total waste volume in pit (yard3) [c]		48,500						
Total dry waste quantity in pit (kg) [d]		92,137,858						
Specific gravity of waste [d]		3.0						
Water content (wt. of water/dry wt.) (%) [d]		22.4						
ANTIMONY	6.7	4,515	49	130	1767	12 to 20.7	scattered	
ARSENIC	8.79	599	6.5 CIS	15 CIS	01 - 03	0 - 12	scattered	Raffinate from concentrated ores, Scrap Recovery Plant sump.
BARIUM	99.2	23034	250 CIS	440	1765	14 - 22	scattered	Raffinate from concentrated ores, Pilot Plant Wet Side.
BERYLLIUM	0.62	405	4.4	13	1767	12 - 20.7	scattered	
BORON	42.7	51,597	560	1,700	1765	14 - 22	scattered	
CADIUM	0.59	829	9	19	1765	14 - 22	scattered	Raffinate from concentrated ores, Pilot Plant Wet Side, Metals Production and Fabrication Plants, Reconditioning Bldg.
CHROMIUM	19	10,135	110	350	1767	12 - 20.7	scattered	Raffinate from concentrated ores, refinery, Metals Plants, Pilot Plant Wet Side, Cooling Towers.
COBALT	15.7	1,658	18	47	1767	12 - 20.7	scattered	
COPPER	16.3	4,330	47	160 CIS	01 - 03	0 - 12	scattered	Plant 1 Storage, Scrap Recovery Plant, production plant, Plant 9 Sump, Pilot Plant Wet Side, Plant 8 W. Pad, Copper Scrap.
CYANIDE	0.11	22	0.24	0.73	1765	14 - 22	scattered	
LEAD	13.4	1,658	18	90 CIS	01 - 03	0 - 12	scattered	Raffinate from concentrated ores.
MANGANESE	922	128,993	1,400 CIS	3,700	1766	14 - 20.5	scattered	Raffinate from concentrated ores.
MERCURY	0.29	15	0.16 CIS	0.3 CIS	01 - 01	0 - 12	scattered	
MOLYBDENUM	2.7	1,474	16	33	1767	12 - 20.7	scattered	
NICKEL	28.5	2,764	30	65 CIS	01 - 03	0 - 12	scattered	Special Products Plant, Plant 9 Sump, Treatment Pilot Plant Wet Side.

TABLE A-15
METALS PROFILE OF PIT 1

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (mg/kg) [a b]	(3) ESTIMATED METALS QUANTITY IN PIT 1 (kg) [e]	(4) AVERAGE CONCENTRATION IN PIT 1 FROM RI/FS (mg/kg) [f]	(5) HIGHEST HIT IN PIT 1 FROM RI/FS (mg/kg) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h] (ft)	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i] (Refer to RI Sections 1 and 4.2 for detail sources)
Total waste volume in pit (yard3) [c]		48,500						
Total dry waste quantity in pit (kg) [d]		92,137,858						
Specific gravity of waste [d]		3.0						
Water content (wt. of water/dry wt.) (%) [d]		22.4						
SELENIUM	0.6	20.27	.22	U				Raffinate from concentrated ores.
SILVER	2.2	5436	59	33 CIS	01 - 03	0 - 12	scattered	Ore Refinery Plant Laboratory, Main Maintenance Building.
THALLIUM	0.43	23.96	.26	0.3 CIS	01 - 03	0 - 12	scattered	
TIN		0	U	U				
URANIUM	4.64							
VANADIUM	36.9	4,607	50	140	1767	12 - 20.7	scattered	Slag leach filter cake, MgF2 slag.
ZINC	59	1,843	20 CIS	58 CIS	01 - 03	0 - 12	scattered	Raffinate from concentrated ores, Pilot Plant Annex, UF6 to UF4.
TOTAL METALS		239,443						

a Waste stream volumes and calculations were based on:
1. Materials Controls and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

b From RI Table 4.2 Subsurface Soils

c Refer to Sample Calculations 1 and 34 in RI Appendix F

d Refer to RI Appendix A, and Sample Calculation 34 in RI Appendix F

e Based on average concentration - refer to Sample Calculation 36 in RI Appendix F

f From RI Tables 4.7 and 4.8

h From RI Appendix A

i Refer to RI Sections 1 and 4.2, and Table A.4.0 in Operable Unit 3 Work Plan Addendum, June 1992

U = non detected and is entered as a zero in all calculations

CIS = Characterization Investigation Study (Refer to RI Appendix A)

mg/kg = milligrams/kilogram

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TABLE A-16
METALS PROFILE OF PIT 2

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (mg/kg) [a b]	(3) ESTIMATED METALS QUANTITY IN PIT 2 (kg) [e]	(4) AVERAGE CONCENTRATION IN PIT 2 FROM RI/FS (mg/kg) [f]	(5) HIGHEST HIT IN PIT 2 FROM RI/FS (mg/kg) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h] (ft)	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i] (Refer to RI Sections 1 and 4.2 for sources of detals)
Total waste volume in pit (yard3) [c]		24,200						
Total dry waste quantity in pit (kg) [d]		17,514,507						
Specific gravity of waste [d]		2.6						
Water content (wt. of water/dry wt.) (%) [d]		176.9						
ANTIMONY	6.7	701	40	55	1769	16 - 22	scattered	
ARSENIC	8.79	2,977	170	420	1768	7 - 14	scattered	Raffinate from concentrated ores, Scrap Recovery Plant sump.
BARIUM	99.2	19,266	1,100	1,900	1768	14 - 17.5	scattered	Raffinate from concentrated ores, Pilot Plant Wet Side.
BERYLLIUM	0.62	280	16	27	1769	16 - 22	scattered	
BORON	42.7	2,802	160	240	1768	7 - 14	scattered	
CADIUM	0.59	152	8.7	13	1768	7 - 14	scattered	Raffinate from concentrated ores, Pilot Plant Wet Side, Metals Production and Fabrication Plants, Reconditioning Bldg.
CHROMIUM	19	3,153	180	280	1768	7 - 14	scattered	Raffinate from concentrated ores, refinery, Metals Plants, Pilot Plant Wet Side, Cooling Towers.
COBALT	15.7	11,384	650	1,500	1768	7 - 14	scattered	
COPPER	16.3	11,735	670	1,300	1768	7 - 14	scattered	Plant 1 Storage, Scrap Recovery Plant, production plant, Plant 9 Sump, Pilot Plant Wet Side, Plant 8 W. Pad, Copper Scrap.
CYANIDE	0.11	25	1.4	2.9	1769	16 - 22	scattered	
LEAD	13.4	8,582	490	760	1768	7 - 14	scattered	Raffinate from concentrated ores.
MANGANESE	922	24,520	1,400 CIS	2,900	1768	7 - 14	scattered	Raffinate from concentrated ores.
MERCURY	0.29	30	1.7	2.6	1768	7 - 14	scattered	
MOLYBDENUM	2.7	1,734	99	220	1768	7 - 14	scattered	
NICKEL	28.5	13,661	780	1,700	1768	7 - 14	scattered	Special Products Plant, Plant 9 Sump Treatment Pilot Plant Wet Side.

TABLE A-16
METALS PROFILE OF PIT 2

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (mg/kg) [a b]	(3) ESTIMATED METALS QUANTITY IN PIT 2 (kg) [e]	(4) AVERAGE CONCENTRATION IN PIT 2 FROM RI/FS (mg/kg) [f]	(5) HIGHEST HIT IN PIT 2 FROM RI/FS (mg/kg) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h] (ft)	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i] (Refer to RI Sections 1 and 4.2 for sources of detals)
Total waste volume in pit (yard3) [c]		24,200						
Total dry waste quantity in pit (kg) [d]		17,514,507						
Specific gravity of waste [d]		2.6						
Water content (wt. of water/dry wt.) (%) [d]		176.9						
SELENIUM	0.6	806	46	U	1769	8 - 16	scattered	Raffinate from concentrated ores.
SILVER	2.2	500.1	28.6 CIS	23 CIS	02 - 01	0 - 10	scattered	Ore Refinery Plant Laboratory, Main Maintenance Building.
THALLIUM	0.43	31.5	1.8 CIS	U CIS				
TIN			U	U				
URANIUM	4.64							
VANADIUM	36.9	4,554	260	590	1768	7 - 14	scattered	Slag leach filter cake, MgF2 slag.
ZINC	59	12,663	723 CIS	3,300 CIS	02 - 03	0 - 8	scattered	Raffinate from concentrated ores, Pilot Plant Annex, UF6 to UF4.
TOTAL METALS		119,557						

a Waste stream volumes and calculations were based on:
1. Materials Controls and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

b From RI Table 4.2 Subsurface Soils

c Refer to Sample Calculations 1 and 34 in RI Appendix F

d Refer to RI Appendix A, and Sample Calculation 34 in RI Appendix F

e Based on average concentration - refer to Sample Calculation 36 in RI Appendix F

f From RI Tables 4.7 and 4.8

h From Appendix A of the RI

i Refer to RI Sections 1 and 4.2, and Table A.4.0 in Operable Unit 3 Work Plan Addendum, June 1992

U = non detected and is entered as a zero in all calculations

CIS = Characterization Investigation Study (Refer to RI Appendix A)

mg/kg = milligrams/kilogram

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TABLE A-17
METALS PROFILE OF PIT 3

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (mg/kg)[a b]	(3) ESTIMATED METALS QUANTITY IN PIT 3 (kg)[e]	(4) AVERAGE CONCENTRATION IN PIT 3 FROM RI/FS (mg/kg)[f]	(5) HIGHEST HIT IN PIT 3 FROM RI/FS (mg/kg)[f]	(6) LOCATION OF HIGHEST HIT[h]	(7) VERTICAL PROFILE[h] (ft)	(8) HORIZONTAL PROFILE[h]	(9) POSSIBLE SOURCES[i] (Refer to RI Sections 1 and 4.2 for details of sources)
Total waste volume in pit (yard3)[c]		204,100						
Total dry waste quantity in pit (kg)[d]		235,071,108						
Specific gravity of waste[d]		2.6						
Water content (wt. of water/dry wt.) (%)[d]		74						
ANTIMONY	6.7	7,522	32	64	1771	14 - 28	scattered	
ARSENIC	8.79	2,125,000	9,040	15,000	1771	14 - 28	scattered	Raffinate from concentrated ores, Scrap Recovery Plant sump.
BARIUM	99.2	975,500	4,150 CIS	14,000 CIS	03 - 04	0 - 12	scattered	Raffinate from concentrated ores, Pilot Plant Wet Side.
BERYLLIUM	0.62	2,069	8.8 CIS	24 CIS	03 - 04	0 - 12	scattered	
BORON	42.7	22,570	96	240	1771	14 - 28	scattered	
CADIUM	0.59	3,056	13	39	1770	24 - 39	scattered	Raffinate from concentrated ores, Pilot Plant Wet Side, Metals Production and Fabrication Plants, Reconditioning Bldg.
CHROMIUM	19	28,910	123	230	1770	24 - 39	scattered	Raffinate from concentrated ores, refinery, Metals Plants, Pilot Plant Wet Side, Cooling Towers.
COBALT	15.7	5,407	23	51	1770	24 - 39	scattered	
COPPER	16.3	258,578	1,100 CIS	2,300 CIS	03 - 03	0 - 12	scattered	Plant 1 Storage, Scrap Recovery Plant, production plant, Plant 9 Sump, Pilot Plant Wet Side, Plant 8 W. Pad, Copper Scrap.
CYANIDE	0.11	212	0.9	1.7	1771	28 - 41	scattered	
LEAD	13.4	89,300	380	840	1770	24 - 39	scattered	Raffinate from concentrated ores.
MANGANESE	922	562,000	2390 CIS	20,000	1770	24 - 39	scattered	Raffinate from concentrated ores.
MERCURY	0.29	376	1.6	5.1	1771	14 - 28	scattered	
MOLYBDENUM	2.7	32,900	140	280	1770	12 - 24	scattered	
NICKEL	28.5	32,910	140 CIS	500 CIS	03 - 03	0 - 12	scattered	Special Products Plant, Plant 9 Sump Treatment Pilot Plant Wet Side.

TABLE A-17
METALS PROFILE OF PIT 3

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (mg/kg)[a b]	(3) ESTIMATED METALS QUANTITY IN PIT 3 (kg)[e]	(4) AVERAGE CONCENTRATION IN PIT 3 FROM RI/FS (mg/kg)[f]	(5) HIGHEST HIT IN PIT 3 FROM RI/FS (mg/kg)[f]	(6) LOCATION OF HIGHEST HIT[h]	(7) VERTICAL PROFILE[h] (ft)	(8) HORIZONTAL PROFILE[h]	(9) POSSIBLE SOURCES[i] (Refer to RI Sections 1 and 4.2 for details of sources)
Total waste volume in pit (yard3)[c]		204,100						
Total dry waste quantity in pit (kg)[d]		235,071,108						
Specific gravity of waste[d]		2.6						
Water content (wt. of water/dry wt.) (%)[d]		74						
SELENIUM	0.6	5,219	22.2 CIS	90 CIS	03 - 04	0 - 12	scattered	Raffinate from concentrated ores.
SILVER	2.2	6,723	28.6	8.1 CIS	03 - 05	0 - 12	scattered	Ore Refinery Plant Laboratory, Main Maintenance Building.
THALLIUM	0.43	752	3.2 CIS	12 CIS	03 - 04	0 - 12	scattered	
TIN		17,865	76	190	1770	24 - 39	scattered	
URANIUM	4.64	0						
VANADIUM	36.9	634,700	2700 CIS	9,700 CIS	03 - 04	0 - 12	scattered	Slag leach filter cake, MgF2 slag.
ZINC	59	30,600	130	330	1770	24 - 39	scattered	Raffinate from concentrated ores, Pilot Plant Annex, UF6 to UF4.
TOTAL METALS		4,842,169						

a Waste stream volumes and calculations were based on:
1. Materials Controls and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

b From RI Table 4.2 Subsurface Soils

c Refer to Sample Calculations 1 and 34 in RI Appendix F

d Refer to RI Appendix A, and Sample Calculation 34 in RI Appendix F

e Based on average concentration - refer to Sample Calculation 36 in RI Appendix F

f From RI Tables 4.7 and 4.8

h From RI Appendix A

i Refer to RI Sections 1 and 4.2, and Table A.4.0 in Operable Unit 3 Work Plan Addendum, June 1992

U = non detected and is entered as a zero in all calculations

CIS = Characterization Investigation Study (Refer to RI Appendix A)

mg/kg = milligrams/kilogram

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TABLE A-18
METALS PROFILE OF PIT 4

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (mg/kg) [a b]	(3) ESTIMATED METALS QUANTITY IN PIT 4 (kg) [e]	(4) AVERAGE CONCENTRATION IN PIT 4 FROM RI/FS (mg/kg) [f]	(5) HIGHEST HIT IN PIT 4 FROM RI/FS (mg/kg) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h] (ft)	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i] (Refer to RI Sections 1 and 4.2 for details of sources)
Total waste volume in pit (yard3) [c]		55,100						
Total dry waste quantity in pit (kg) [d]		98,590,826						
Specific gravity of waste [d]		3						
Water content (wt. of water/dry wt.) (%) [d]		29.10						
ANTIMONY	6.7	9,859	100	320	1773	9 - 18	scattered	
ARSENIC	8.79	325	3.3	6.5	1775	10 - 19	scattered	Raffinate from concentrated ores, Scrap Recovery Plant sump.
BARIUM	99.2	236,618	2,400 CIS	6,700 CIS	04 - 04	0 - 20	scattered	Raffinate from concentrated ores, Pilot Plant Wet Side.
BERYLLIUM	0.62	1,666	17	51	1773	9 - 18	scattered	
BORON	42.7	25,634	260	1,000	1773	9 - 18	scattered	
CADIUM	0.59	1,183	12	35	1773	9 - 18	scattered	Raffinate from concentrated ores, Pilot Plant Wet Side, Metals Production and Fabrication Plants, Reconditioning Bldg.
CHROMIUM	19	46,338	470	1,500	1773	9 - 18	scattered	Raffinate from concentrated ores, refinery, Metals Plants, Pilot Plant Wet Side, Cooling Towers.
COBALT	15.7	5,817	59	180	1773	9 - 18	scattered	
COPPER	16.3	17,746	180	480	1773	9 - 18	scattered	Plant 1 Storage, Scrap Recovery Plant, production plant, Plant 9 Sump, Pilot Plant Wet Side, Plant 8 W. Pad, Copper Scrap.
CYANIDE	0.11	21	0.21	0. 64	1775	10 - 19	scattered	
LEAD	13.4	4,239	43 CIS	63	1775	10 - 19	scattered	Raffinate from concentrated ores.
MANGANESE	922	285,913	2,900	5,600	1775	10 - 19	scattered	Raffinate from concentrated ores.
MERCURY	0.29	30.6	.31	0.62	1773	9 - 18	scattered	
MOLYBDENUM	2.7	3,451	35	96	1773	9 - 18	scattered	
NICKEL	28.5	8,282	84	220	1773	9 - 18	scattered	Special Products Plant, Plant 9 Sump Treatment Pilot Plant Wet Side.

TABLE A-18
METALS PROFILE OF PIT 4

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (mg/kg) [a b]	(3) ESTIMATED METALS QUANTITY IN PIT 4 (kg) [e]	(4) AVERAGE CONCENTRATION IN PIT 4 FROM RI/FS (mg/kg) [f]	(5) HIGHEST HIT IN PIT 4 FROM RI/FS (mg/kg) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h] (ft)	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i] (Refer to RI Sections 1 and 4.2 for details of sources)
Total waste volume in pit (yard3) [c]		55,100						
Total dry waste quantity in pit (kg) [d]		98,590,826						
Specific gravity of waste [d]		3						
Water content (wt. of water/dry wt.) (%) [d]		29.10						
SELENIUM	0.6	0	U	U				Raffinate from concentrated ores.
SILVER	2.2	23,662	240	760	1773	9 - 18	scattered	Ore Refinery Plant Laboratory, Main Maintenance Building.
THALLIUM	0.43	0	U	U				
TIN		6,408	65	130	1773	9 - 18	scattered	
URANIUM	4.64							
VANADIUM	36.9	17,746	180	560	1773	9 - 18	scattered	Slag leach filter cake, MgF2 slag.
ZINC	59	6,704	68	200	1773	9 - 18	scattered	Raffinate from concentrated ores, Pilot Plant Annex, UF6 to UF4.
TOTAL METALS		701,643						

[a] Waste stream volumes and calculations were based on:
1. Materials Controls and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

[b] From RI Table 4.2 Subsurface Soils

[c] Refer to Sample Calculations 1 and 34 in RI Appendix F

[d] Refer to RI Appendix A and Sample Calculation 34 in RI Appendix F

[e] Based on average concentration - refer to Sample Calculation 36 in RI Appendix F.

[f] From RI Tables 4.7 and 4.8

[h] From RI Appendix A

[i] Refer to RI Sections 1 and 4.2, and Table A.4.0 in Operable Unit 3 Work Plan Addendum, June 1992

U = non detected and is entered as a zero in all calculations

CIS = Characterization Investigation Study (Refer to RI Appendix A)

mg/kg = milligrams/kilogram

TABLE A-19
METALS PROFILE OF PIT 5

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (mg/kg)[a b]	(3) ESTIMATED METALS QUANTITY IN PIT 5 (kg)[e]	(4) AVERAGE CONCENTRATION IN PIT 5 FROM RI/FS (mg/kg)[f]	(5) HIGHEST HIT IN PIT 5 FROM RI/FS (mg/kg)[f]	(6) LOCATION OF HIGHEST HIT[h]	(7) VERTICAL PROFILE[h] (ft)	(8) HORIZONTAL PROFILE[h]	(9) POSSIBLE SOURCES[i] (Refer to RI Sections 1 and 4.2 for details of sources)
Total waste volume in pit (yard3)[c]		97,900						
Total dry waste quantity in pit (kg)[d]		117,625,873						
Specific gravity of waste[d]		2.4						
Water content (wt. of water/dry wt.) (%)[d]		54.70						
ANTIMONY	6.7	3,999	34 CIS	88	05 - 01	N/A - 15	scattered	
ARSENIC	8.79	112,921	960 CIS	2,800 CIS	05 - 05	0 - 12	scattered	Raffinate from concentrated ores, Scrap Recovery Plant sump
BARIUM	99.2	2,705,395	23,000 CIS	37,000 CIS	05 - 01	0 - 3	scattered	Raffinate from concentrated ores, Pilot Plant Wet Side.
BERYLLIUM	0.62	1,094	9.3	22	05 - 01	N/A - 15	scattered	
BORON	42.7	0	no data	no data				
CADIUM	0.59	600	5.1 CIS	17 CIS	05 - 06	0 - 12	scattered	Raffinate from concentrated ores, Pilot Plant Wet Side, Metals Production and Fabrication Plants, Reconditioning Bldg.
CHROMIUM	19	14,115	120 CIS	220 CIS	05 - 02	0 - 14	scattered	Raffinate from concentrated ores, refinery, Metals Plants, Pilot Plant Wet Side, Cooling Towers.
COBALT	15.7	2,705	23 CIS	44 CIS	05 - 01	0 - 3	scattered	
COPPER	16.3	552800.00	4700 CIS	18,000 CIS	05 - 06	0 - 12	scattered	Plant 1 Storage, Scrap Recovery Plant, production plant, Plant 9 Sump, Pilot Plant Wet Side, Plant 8 W. Pad, Copper Scrap.
CYANIDE	0.11	114	.97	U				
LEAD	13.4	17,600	150 CIS	240 CIS	05 - 03	0 - 12	scattered	Raffinate from concentrated ores.
MANGANESE	922	211,727	1,800 CIS	4,700 CIS	05 - 03	0 - 12	scattered	Raffinate from concentrated ores.
MERCURY	0.29	129	1.1 CIS	1.8 CIS	05 - 04	0 - 12	scattered	
MOLYBDENUM	2.7	36,460	310	1,400	05 - 01	N/A - 15	scattered	
NICKEL	28.5	15,291	130 CIS	250 CIS	05 - 03	0 - 12	scattered	Special Products Plant, Plant 9 Sump Treatment Pilot Plant Wet Side.

TABLE A-19
METALS PROFILE OF PIT 5

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (mg/kg)[a b]	(3) ESTIMATED METALS QUANTITY IN PIT 5 (kg)[e]	(4) AVERAGE CONCENTRATION IN PIT 5 FROM RI/FS (mg/kg)[f]	(5) HIGHEST HIT IN PIT 5 FROM RI/FS (mg/kg)[f]	(6) LOCATION OF HIGHEST HIT[h]	(7) VERTICAL PROFILE[h] (ft)	(8) HORIZONTAL PROFILE[h]	(9) POSSIBLE SOURCES[i] (Refer to RI Sections 1 and 4.2 for details of sources)
Total waste volume in pit (yard3)[c]		97,900						
Total dry waste quantity in pit (kg)[d]		117,625,873						
Specific gravity of waste[d]		2.4						
Water content (wt. of water/dry wt.) (%)[d]		54.70						
SELENIUM	0.6	847	7.2	18 CIS	05 - 05	0 - 12	scattered	Raffinate from concentrated ores.
SILVER	2.2	1,153	9.8	22	05 - 08	N/A - 6	scattered	Ore Refinery Plant Laboratory, Main Maintenance Building.
THALLIUM	0.43	2,470	21	100	05 - 08	N/A - 6	scattered	
TIN		3,776	32	93	05 - 08	N/A - 6	scattered	
URANIUM	4.64							
VANADIUM	36.9	317,590	2,700 CIS	5,400 CIS	05 - 05	0 - 12	scattered	Slag leach filter cake, MgF2 slag.
ZINC	59	19,996	170 CIS	280	05 - 05	N/A - 8	scattered	Raffinate from concentrated ores, Pilot Plant Annex, UF6 to UF4.
TOTAL METALS		4,020,782						

a Waste stream volumes and calculations were based on:
1. Materials Controls and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

b From RI Table 4.2 Subsurface Soils

c Refer to Sample Calculations 1 and 34 in RI Appendix F

d Refer to RI Appendix A and Sample Calculation 34 in RI Appendix F

e Based on average concentration. Refer to Sample Calculation 36 in RI Appendix F

f From RI Tables 4.7 and 4.8

h RI Appendix A

i Refer to RI Sections 1 and 4.2, and Table A.4.0 in Operable Unit 3 Work Plan Addendum, June 1992

U = non detected and is entered as a zero in all calculations

CIS = Characterization Investigation Study (Refer to RI Appendix A)

mg/kg = milligrams/kilogram

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TABLE A-20
METALS PROFILE OF PIT 6

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (mg/kg) [a b]	(3) ESTIMATED METALS QUANTITY IN PIT 6 (kg) [e]	(4) AVERAGE CONCENTRATION IN PIT 6 FROM RI/FS (mg/kg) [f]	(5) HIGHEST HIT IN PIT 6 FROM RI/FS (mg/kg) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h] (ft)	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i] (Refer to RI Sections 1 and 4.2 for details of sources)
Total waste volume in pit (yard3) [c]		9,600						
Total dry waste quantity in pit (kg) [d]		16,805,824						
Specific gravity of waste [d]		2.9						
Water content (wt. of water/dry wt.) (%) [d]		25.40						
ANTIMONY	6.7	0	U	26	06 - 07	N/A - 6	scattered	
ARSENIC	8.79	705	42	77	06 - 06	N/A - 6	scattered	Raffinate from concentrated ores, Scrap Recovery Plant sump
BARIUM	99.2	1,597	95 CIS	95 CIS	06 - 04	0 - 10	scattered	Raffinate from concentrated ores, Pilot Plant Wet Side
BERYLLIUM	0.62	32	1.9 CIS	5.7 CIS	06 - 04	0 - 10	scattered	
BORON	42.7	0	no data	no data				
CADIUM	0.59	27	1.6 CIS	12	06 - 05	N/A - 6	scattered	Raffinate from concentrated ores, Pilot Plant Wet Side, Metals Production and Fabrication Plants, Reconditioning Bldg
CHROMIUM	19	252	15	60	06 - 08	N/A - 6	scattered	Raffinate from concentrated ores, refinery, Metals Plants, Pilot Plant Wet Side, Cooling Towers
COBALT	15.7	437	26 CIS	26 CIS	06 - 04	0 - 10	scattered	
COPPER	16.3	1,412	84 CIS	220 CIS	06 - 04	0 - 10	scattered	Plant 1 Storage, Scrap Recovery Plant, production plant, Plant 9 Sump, Pilot Plant Wet Side, Plant 8 W. Pad, Copper Scrap
CYANIDE	0.11	0	U	U				
LEAD	13.4	1,042	62	110	06 - 06	N/A - 6	scattered	Raffinate from concentrated ores
MANGANESE	922	2,689	160	310	06 - 01	N/A - 7	scattered	Raffinate from concentrated ores
MERCURY	0.29	0	U	1.1	06 - 01	N/A - 7	scattered	
MOLYBDENUM	2.7	0	U	U				
NICKEL	28.5	269	16	51 CIS	06 - 04	0 - 10	scattered	Special Products Plant, Plant 9 Sump Treatment Pilot Plant Wet Side

TABLE A-20
METALS PROFILE OF PIT 6

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (mg/kg) [a] [b]	(3) ESTIMATED METALS QUANTITY IN PIT 6 (kg) [e]	(4) AVERAGE CONCENTRATION IN PIT 6 FROM RI/FS (mg/kg) [f]	(5) HIGHEST HIT IN PIT 6 FROM RI/FS (mg/kg) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h] (ft)	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i] (Refer to RI Sections 1 and 4.2 for details of sources)
Total waste volume in pit (yard3) [c]		9,600						
Total dry waste quantity in pit (kg) [d]		16,805,824						
Specific gravity of waste [d]		2.9						
Water content (wt. of water/dry wt.) (%) [d]		25.40						
SELENIUM	0.6	0	U	U			scattered	Raffinate from concentrated ores
SILVER	2.2	672	40 CIS	160 CIS	06 - 06	0 - 10	scattered	Ore Refinery Plant Laboratory, Main Maintenance Building
THALLIUM	0.43	824	49	110	06 - 06	N/A - 6	scattered	
TIN		168	10	22	06 - 06	N/A - 6	scattered	
URANIUM	4.64							
VANADIUM	36.9	1,681	100 CIS	120	06 - 05	N/A - 7	scattered	Slag leach filter cake, MgF2 slag
ZINC	59	555	33 CIS	61	06 - 01	N/A - 7	scattered	Raffinate from concentrated ores, Pilot Plant Annex, UF6 to UF4
TOTAL METALS		12,361						

[a] Waste stream volumes and calculations were based on:
1. Materials Controls and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

[b] From RI Table 4.2 Subsurface Soils
[c] Refer to Sample Calculations 1 and 34 in RI Appendix F
[d] Refer to RI Appendix A, and Sample Calculation 34 in RI Appendix F
[e] Based on average concentration. Refer to Sample Calculation 36 in RI Appendix F
[f] From RI Tables 4.7 and 4.8
[h] From RI Appendix A
[i] Refer to RI Sections 1 and 4.2, and Table A.4.0 in Operable Unit 3 Work Plan Addendum, June 1992

U = non detected and is entered as a zero in all calculations
CIS = Characterization Investigation Study (Refer to RI Appendix A)
mg/kg = milligrams/kilogram

TABLE A-21
METALS PROFILE OF THE BURN PIT

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (mg/kg) [a b]	(3) ESTIMATED METALS QUANTITY IN BURN PIT (kg) [e]	(4) AVERAGE CONCENTRATION IN BURN PIT FROM RI/FS (mg/kg) [f]	(5) HIGHEST HIT IN BURN PIT FROM RI/FS (mg/kg) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h] (ft)	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i] (Refer to RI Sections 1 and 4.2 for details of sources)
Total waste volume in pit (yard3) [c]		30,300						
Total dry waste quantity in pit (kg) [d]		67,771,624						
Specific gravity of waste [d]		3.7						
Water content (wt. of water/dry wt.) (%) [d]		27.90						
ANTIMONY	6.7	657	9.7	18	1776	19.5 - 32.5	scattered	
ARSENIC	8.79	1,152	17	39	1776	19.5 - 32.5	scattered	Raffinate from concentrated ores, Scrap Recovery Plant sump
BARIUM	99.2	74,549	1,100 CIS	7,100 CIS	07 - 04	0 - 12	scattered	Raffinate from concentrated ores, Pilot Plant Wet Side
BERYLLIUM	0.62	197	2.9 CIS	16 CIS	07 - 04	0 - 12	scattered	
BORON	42.7	2,101	31	48	1776	6.5 - 19.5		
CADIUM	0.59	407	6.0 CIS	35 CIS	07 - 04	0 - 12	scattered	Raffinate from concentrated ores, Pilot Plant Wet Side, Metals Production and Fabrication Plants, Reconditioning Bldg.
CHROMIUM	19	3,727	55	91	1776	19.5 - 32.5	scattered	Raffinate from concentrated ores, refinery, Metals Plants, Pilot Plant Wet Side, Cooling Towers
COBALT	15.7	2,914	43	110	1776	19.5 - 32.5	scattered	
COPPER	16.3	9,488	140	260	1776	6.5 - 19.5	scattered	Plant 1 Storage, Scrap Recovery Plant, production plant, Plant 9 Sump, Pilot Plant Wet Side, Plant 8 W. Pad, Copper Scrap
CYANIDE	0.11	8	0.12	0.21	1777	6.5 - 26		
LEAD	13.4	10,843	160	280	1776	6.5 - 19.5	scattered	Raffinate from concentrated ores
MANGANESE	922	29,820	440	1,700 CIS	07 - 04	0 - 12	scattered	Raffinate from concentrated ores
MERCURY	0.29	39	0.57	1.2	1776	6.5 - 19.5	scattered	
MOLYBDENUM	2.7	1,017	15	210	1776	19.5 - 32.5		
NICKEL	28.5	6,099	90	210	1776	19.5 - 32.5	scattered	Special Products Plant, Plant 9 Sump Treatment Pilot Plant Wet Side

TABLE A-21
METALS PROFILE OF THE BURN PIT

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (mg/kg) [a b]	(3) ESTIMATED METALS QUANTITY IN BURN PIT (kg) [e]	(4) AVERAGE CONCENTRATION IN BURN PIT FROM RI/FS (mg/kg) [f]	(5) HIGHEST HIT IN BURN PIT FROM RI/FS (mg/kg) [f]	(6) LOCATION OF HIGHEST HIT [h]	(7) VERTICAL PROFILE [h] (ft)	(8) HORIZONTAL PROFILE [h]	(9) POSSIBLE SOURCES [i] (Refer to RI Sections 1 and 4.2 for details of sources)
Total waste volume in pit (yard3) [c]		30,300						
Total dry waste quantity in pit (kg) [d]		67,771,624						
Specific gravity of waste [d]		3.7						
Water content (wt. of water/dry wt.) (%) [d]		27.90						
SELENIUM	0.6	88	1.3	2	1777	6.5 - 26	scattered	Raffinate from concentrated ores
SILVER	2.2	5,896	87 CIS	510 CIS	07 - 04	0 - 12	scattered	Ore Refinery Plant Laboratory, Main Maintenance Building
THALLIUM	0.43	17	0.25 CIS	0.5 CIS	07 - 05	0 - 12	scattered	
TIN		0	U	U			scattered	
URANIUM	4.64	0						
VANADIUM	36.9	3,999	59 CIS	290 CIS	07 - 04	0 - 12	scattered	Slag leach filter cake, MgF2 slag.
ZINC	59	18,976	280	510	1776	6.5 - 19.5	scattered	Raffinate from concentrated ores, Pilot Plant Annex, UF6 to UF4.
TOTAL METALS		171,994						

a Waste stream volumes and calculations were based on:
1. Materials Controls and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

b From Table 4.2 Subsurface Soils

c Refer to Sample Calculations 1 and 34 in RI Appendix F

d Refer to RI Appendix A and Sample Calculation 34 in RI Appendix F

e Based on average concentration - refer to Sample Calculation 36 in RI Appendix F

f From RI Tables 4.7 and 4.8

h RI Appendix A

i Refer to RI Sections 1 and 4.2, and Table A.4.0 in Operable Unit 3 Work Plan Addendum, June 1992

U = non detected and is entered as a zero in all calculations

CIS = Characterization Investigation Study (Refer to RI Appendix A)

mg/kg = milligrams/kilogram

TABLE A-22
METALS PROFILE OF THE CLEARWELL

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (mg/kg)[a b]	(3) ESTIMATED METALS QUANTITY IN CLEARWELL (kg)[e]	(4) AVERAGE CONCENTRATION IN CLEARWELL FROM RI/FS (mg/kg)[f]	(5) HIGHEST HIT IN CLEAR WELL FROM RI/FS (mg/kg)[f]	(6) LOCATION OF HIGHEST HIT[h]	(7) VERTICAL PROFILE[h] (ft)	(8) HORIZONTAL PROFILE[h]	(9) POSSIBLE SOURCES[i] (Refer to RI Sections 1 and 4.2 for details of sources)
Total waste volume in pit (yard3)[c]		3,700						
Total dry waste quantity in pit (kg)[d]		2,892,394						
Specific gravity of waste[d]		1.4						
Water content (wt. of water/dry wt.) (%)[d]		40.90						
ANTIMONY	6.7	25	8.7 CIS	32 CIS	08 - 03	11 - 13	stratified	
ARSENIC	8.79	95	33	59	CW - F	11 - 13	stratified	Raffinate from concentrated ores, Scrap Recovery Plant sump.
BARIUM	99.2	8,388	2,900 CIS	6,900 CIS	08 - 03	11 - 13	stratified	Raffinate from concentrated ores, Pilot Plant Wet Side.
BERYLLIUM	0.62	8	2.9 CIS	9.1 CIS	08 - 03	11 - 13	stratified	
BORON	42.7	0	no data	no data				
CADMIUM	0.59	10	3.4 CIS	7.2 CIS	08 - 03	11 - 13	stratified	Raffinate from concentrated ores, Pilot Plant Wet Side, Metals Production and Fabrication Plants, Reconditioning Bldg.
CHROMIUM	19	271	94	200	CW - F	11 - 13	stratified	Raffinate from concentrated ores, refinery, Metals Plants, Pilot Plant Wet Side, Cooling Towers.
COBALT	15.7	43	15	26	CW - F	11 - 13	stratified	
COPPER	16.3	3,760	1,300	3,300	CW - F	11 - 13	stratified	Plant 1 Storage, Scrap Recovery Plant, production plant, Plant 9 Sump, Pilot Plant Wet Side, Plant 8 W. Pad, Copper Scrap.
CYANIDE	0.11	8.38	2.9 CIS	9.2 CIS	08 - 03	11 - 13	stratified	
LEAD	13.4	709	245	590	CW - F	11 - 13	stratified	Raffinate from concentrated ores.
MANGANESE	922	18,222	6,300	20,000	CW - F	11 - 13	stratified	Raffinate from concentrated ores.
MERCURY	0.29	7	2.4 CIS	4.4 CIS	08 - 03	11 - 13	stratified	
MOLYBDENUM	2.7	61	21	41	CW - D	11 - 13	stratified	
NICKEL	28.5	278	96	230	CW - F	11 - 13	stratified	Special Products Plant, Plant 9 Sump Treatment Pilot Plant Wet Side.

TABLE A-22
METALS PROFILE OF THE CLEARWELL

(1) ANALYTE	(2) BACKGROUND CONCENTRATION FOR SOIL (mg/kg)[a b]	(3) ESTIMATED METALS QUANTITY IN CLEARWELL (kg)[e]	(4) AVERAGE CONCENTRATION IN CLEARWELL FROM RI/FS (mg/kg)[f]	(5) HIGHEST HIT IN CLEAR WELL FROM RI/FS (mg/kg)[f]	(6) LOCATION OF HIGHEST HIT[h]	(7) VERTICAL PROFILE[h] (ft)	(8) HORIZONTAL PROFILE[h]	(9) POSSIBLE SOURCES[i] (Refer to RI Sections 1 and 4.2 for details of sources)
Total waste volume in pit (yard3)[c]		3,700						
Total dry waste quantity in pit (kg)[d]		2,892,394						
Specific gravity of waste[d]		1.4						
Water content (wt. of water/dry wt.) (%)[d]		40.90						
SELENIUM	0.6	4	1.3 CIS	3.7 CIS	08 - 03	11 - 13	stratified	Raffinate from concentrated ores.
SILVER	2.2	15	5.3	13	CW - F	11 - 13	stratified	Ore Refinery Plant Laboratory, Main Maintenance Building.
THALLIUM	0.43	3	1.0 CIS	2.1 CIS	08 - 03	11 - 13	stratified	
TIN		32	11	24	CW - F	11 - 13	stratified	
URANIUM	4.64							
VANADIUM	36.9	2,169	750 CIS	2,600 CIS	08 - 03	11 - 13	stratified	Slag leach filter cake, MgF2 slag.
ZINC	59	463	160	310	CW - F	11 - 13	stratified	Raffinate from concentrated ores, Pilot Plant Annex, UF6 to UF4.
TOTAL METALS		34,570						

a Waste stream volumes and calculations were based on:
1. Materials Controls and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

b From RI Table 4.2 Subsurface Soils

c Refer to Sample Calculations 1 and 34 in RI Appendix F

d Refer to RI Appendix A and Sample Calculation 34 in RI Appendix F

e Based on average concentration - refer to Sample Calculation 36 in RI Appendix F

f From RI Tables 4.7 and 4.8

h RI Appendix A

i Refer to RI Sections 1 and 4.2, and Table A.4.0 in Operable Unit 3 Work Plan Addendum, June 1992

U = non detected and is entered as a zero in all calculations

CIS = Characterization Investigation Study (Refer to RI Appendix A)

mg/kg = milligrams/kilogram.

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TABLE A-23
ORGANIC PROFILE OF PIT 1

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 1 (kg)[a e]	(3) AVERAGE CONCENTRATION IN PIT 1 FROM RI/FS (µg/kg)[f]	(4) HIGHEST HIT IN PIT 1 FROM RI/FS (µg/kg)[f]	(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE (ft)[h]	(7) HORIZONTAL PROFILE[h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (cubic yards)[b]		48,500					
Total dry waste quantity in pit (kg)[c]		92,137,858					
Specific gravity of waste[d]		3.04					
Water content (wt. of water/dry wt.) (%)[d]		22.4					
FURANS							
2,3,7,8-TCDF [j]	0.30	3.3	14	1765	7-14	scattered	. Bottom ash from three soild waste incinerators, oil burner, or graphite burner
Dibenzofuran [j]	0.00	U	U				
Heptachlorodibenzofuran	0.08	0.9	2.7	1766	14-20.5	scattered	. Oxidation of PCBs (from PCB-contaminated oil) in high temperature heat transfer operations
Hexachlorodibenzofuran	0.10	1.1	2.9	1765	7-14	scattered	
Octachlorodibenzofuran	0.02	0.23	0.76	1766	14-20.5	scattered	
Pentachlorodibenzofuran	0.20	2.2	7.9	1765	7-14	scattered	. High temperature processes such as copper shredding, hydrometallurgical system
Tetrachlorodibenzofuran [j]	0.92	10	35	1765	7-14	scattered	
TOTAL CHLORINATED DIBENZO FURANS [j]	1.3						
DIOXINS							
2,3,7,8-TCDD	0.00	U	U				
Heptachlorordibenzo-p-dioxin	0.07	0.73	2.3	1766	14-20.5	scattered	. From the same sources as furans
Hexachlorodibenzo-p-dioxin	0.16	1.7	4.9	1766	14-20.5	scattered	
Octachlorodibenzo-p-dioxin	0.03	0.3	0.74	1766	14-20.5	scattered	
Tetrachlorodibenzo-p-dioxin [k]	0.00	U	U				
TOTAL CHLORINATED DIBENZO-P-DIOXINS [k]	0.3						

TABLE A-23
ORGANIC PROFILE OF PIT 1

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 1 (kg)[a,e]	(3) AVERAGE CONCENTRATION IN PIT 1 FROM RI/FS (µg/kg)[f]		(4) HIGHEST HIT IN PIT 1 FROM RI/FS (µg/kg)[f]		(5) LOCATION OF HIGHEST HIT[h]	(6) VERTICAL PROFILE (ft)[h]	(7) HORIZONTAL PROFILE[h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (cubic yards)[b]		48,500							
Total dry waste quantity in pit (kg)[c]		92,137,858							
Specific gravity of waste[d]		3.04							
Water content (wt. of water/dry wt.) (%)[d]		22.4							
POLYNUCLEAR AROMATICS (PNAs)									
2-Methynaphthalene	22	235	CIS	900		1767	6-12	scattered	. Bottom ash from three solid waste incinerators, oil burner, or graphite burner
Acenaphthene	0	U		U					. Coal dust and coal by-products
Acenaphthylene	0	U		U					. Fuel oils, direct or as products of combustion
Anthracene	19	211	CIS	540	CIS	01-02	0-12	scattered	. Oil reclaimer
Benzo(a)anthracene	15	167	CIS	540	CIS	01-02	0-12	scattered	. Asphalt
Benzo(a)pyrene	20	222	CIS	540	CIS	01-02	0-12	scattered	. Main maintenance, solvent extraction, laboratories, stores etc.
Benzo(b)fluoranthene	20	214	CIS	470	CIS	01-05	0-12	scattered	
Benzo(g,h,i)perylene	0	U		U					
Benzo(k)fluoranthene	20	222	CIS	540	CIS	01-02	0-12	scattered	
Chrysene	27	295	CIS	540	CIS	01	0-12	scattered	
Dibenzo(a,h)anthracene	0	U		U					
Fluoranthene	32	345		1,000		1765	7-14	scattered	
Fluorene	0	U		U					
Indeno(1,2,3-cd)pyrene	0	U		U					
Naphthalene	16	179	CIS	540	CIS	01-02	0-12	scattered	
Phenanthrene	92	996	CIS	2,400	CIS	01	0-12	scattered	
Pyrene	26	286		900					
TOTAL PNAs	311								
PCBs									
Aroclor-1221	127	1,380		6,000		1766	14-20.5	scattered	. Used in heat transfer liquids (transformers capacitors, and fluorescent light ballasts)
Aroclor-1242	0	U		U					. In hydraulic fluids and lubricants (for core machining, sludge pickling etc.)
Aroclor-1248	333	3,610		10,000		1765	7-14	scattered	. Fire brigade training
Aroclor-1254	529	5,740	CIS	13,000			0-12	scattered	
Aroclor-1260	320	3,470	CIS	7,800	CIS	01	0-12	scattered	
TOTAL PCBs	1,308								

TABLE A-23
ORGANIC PROFILE OF PIT 1

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 1[a] (kg)[e]	(3) AVERAGE CONCENTRATION IN PIT 1 FROM RI/FS (µg/kg)[f]	(4) HIGHEST HIT IN PIT 1 FROM RI/FS (µg/kg)[f]	(5) LOCATION OF HIGHEST HIT[h]	(6) VERTICAL PROFILE (ft)[h]	(7) HORIZONTAL PROFILE[h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (cubic yards)[b]		48,500					
Total dry waste quantity in pit (kg)[c]		92,137,858					
Specific gravity of waste[d]		3.04					
Water content (wt. of water/dry wt.) (%)[d]		22.4					
OTHER CHEMICALS							
4,4-DDT	42	458 CIS	1,600 CIS	01-04	0-12	scattered	. From application of pesticides and/or herbicides
Pentachlorophenol	0	U	U				. Fire brigade training and application of pesticides and/or herbicides
4-Nitrophenol	0	U	U				
2,4,5-Trichlorophenol	0	U	U				. From application of pesticides and/or herbicides
4-Nitroaniline	0	U	U				. Present in corrosion inhibitors
Benzene	0	U	U				. Hilco oil reclaimer, scrap metal pickling, solvent extraction, heavy equipment storage
Dichlorodifluoromethane	1,373	14,900	29,600	1766	13.5-14	scattered	. Refrigeration oil, fabrication warehouse
Tetrachloroethene	11	120	650	1766	13.5-14	scattered	. Contaminated oil storage drums, liquid waste incinerator, de-zincing Zn-Th metal, casting
Tributyl Phosphate	1,281	13,900	25,000	1765	7-14	scattered	. Charcoal treatment, refinery sump
Vinyl Chloride	0	U	U				. Progeny of parent tetrachloroethene or trichloroethene
TOTAL OTHER CHEMICALS	2,707						

[a] Waste streams, volumes, and calculations are based on:
1. Materials Control and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

[b] Refer to Sample Calculation 1 and 34 in RI Appendix F
[c] Refer to Sample Calculation 34 in RI Appendix F
[d] Refer to RI Appendix A, and Sample Calculation 34 in RI Appendix F
[e] Based on average concentration. Refer to Sample Calculation 37 in RI Appendix F
[f] From RI Tables 4.9 and 4.10. Background concentration of organics in soil is considered to be non-detected.
[h] FromRI Appendix A
[i] Refer to RI Sections 1 & 4.2, RI Appendix F, and Table A.4.0 in Operable Unit 3 Work Plan Addendum, June 1992
[j] 2,3,7,8-TCDF and dibenzofuran are included in tetrachlorodibenzofuran; therefore they are not included in the total value.
[k] 2,3,7,8-TCDD is included in tetrachlorodibenzo-p-dioxin; therefore, it is not included in the total value.

CIS = Characterization Investigation Study (refer to RI Appendix A)
U = Non detected
µg/kg = microgram per kilogram

TABLE A-24
ORGANIC PROFILE OF PIT 2

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 2 (kg) [a c]	(3) AVERAGE CONCENTRATION IN PIT 2 FROM RI/FS (µg/kg) [f]	(4) HIGHEST HIT IN PIT 2 FROM RI/FS (µg/kg) [f]	(5) LOCATION OF HIGHEST HIT[h]	(6) VERTICAL PROFILE[h] (ft)	(7) HORIZONTAL PROFILE[h]	(8) POSSIBLE SOURCES (Refer to RI Section 1,RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]		24,200					
Total dry waste quantity in pit (kg)[f]		17,514,507					
Specific gravity of waste [d]		2.62					
Water content (wt. of water/dry wt.) (%) [d]		176.9					
FURANS							
2,3,7,8-TCDF[j]	0.00	U	U				. Bottom ash from three solid waste incinerators, oil burner, or graphite burner
Dibenzofuran [j]	118	6,730	36,000 CIS	02 - 05	0 - 10	scattered	. In calcined raffinate
Heptachlorodibenzofuran	0.04	2	5.9	1768	7 - 14	scattered	. Oxidation of PCBs (from PCB-contaminated oil) in high temperature heat transfer operations.
Hexachlorodibenzofuran	0.01	0.77	2.7	1768	7 - 14	scattered	. High temperature processes such as copper shredding, hydrometallurigical system.
Octachlorodibenzofuran	0.03	1.8	4.9	1768	7 - 14	scattered	
Pentachlorodibenzofuran	0.00	0.2	0.55	1768	7 - 14	scattered	
Tetrachlorodibenzofuran [j]	0.00	U	U				
TOTAL CHLORINATED DIBENZO FURANS [j]	0.1						
DIOXINS							
2,3,7,8-TCDD	0.00	U	U				
Heptachlorordibenzo-p-dioxin	0.05	2.7	8.1	1768	7 - 14	scattered	. From the same sources as furans
Hexachlorodibenzo-p-dioxin	0.00	0.21	0.65	1769	8 - 16	scattered	
Octachlorodibenzo-p-dioxin	0.30	16.6	45.9	1768	7 - 14	scattered	
Tetrachlorodibenzo-p-dioxin [k]	0.00	U	U				
TOTAL CHLORINATED DIBENZO-P-DIOXINS [k]	0.3						

TABLE A-24
ORGANIC PROFILE OF PIT 2

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 2 (kg) [a e]	(3) AVERAGE CONCENTRATION IN PIT 2 FROM RI/FS (µg/kg) [f]		(4) HIGHEST HIT IN PIT 2 FROM RI/FS (µg/kg) [f]		(5) LOCATION OF HIGHEST HIT[h]	(6) VERTICAL PROFILE[h] (ft)	(7) HORIZONTAL PROFILE[h]	(8) POSSIBLE SOURCES (Refer to RI Section 1,RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]		24,200							
Total dry waste quantity in pit (kg)[f]		17,514,507							
Specific gravity of waste [d]		2.62							
Water content (wt. of water/dry wt.) (%)[d]		176.9							
POLYNUCLEAR AROMATICS (PNAs)									
2-Methynaphthalene	58	2,780		7,800		1769	16 - 22	scattered	. Bottom ash from three solid waste
Acenaphthene	228	9,490		43,000	CIS	02 - 05	0 - 10	scattered	incinerators, oil burner, or graphite burner
Acenaphthylene	14	884		2,900		1,769	15 - 15.5	scattered	. In calcined raffinate
Anthracene	438	24,800	CIS	120,000	CIS	02 - 05	0 - 10	scattered	. Coal dust and coal by-products
Benzo(a)anthracene	666	29,000		130,000	CIS	02 - 05	0 - 10	scattered	. Fuel oils, direct or as products of
Benzo(a)pyrene	473	25,100	CIS	120,000	CIS	02 - 05	0 - 10	scattered	combustion
Benzo(b)fluoranthene	455	23,300	CIS	130,000		1,769	16 - 22	scattered	. Oil reclaimer
Benzo(g,h,i)perylene	298	13,000		42,000		1,769	16 - 22	scattered	. Asphalt
Benzo(k)fluoranthene	280	15,700	CIS	75,000	CIS	02 - 05	0 - 10	scattered	. Main maintenance, solvent extraction,
Chrysene	490	21,500		100,000		1,769	16 - 22	scattered	laboratories, stores etc.
Dibenzo(a,h)anthracene	119	5,390		20,000		1,769	16 - 22	scattered	
Fluoranthene	1,751	102,000	CIS	490,000	CIS	02 - 05	0 - 10	scattered	
Fluorene	245	13,000	CIS	62,000	CIS	02 - 05	0 - 10	scattered	
Indeno(1,2,3-cd)pyrene	263	11,200		46000	CIS	02 - 05	0 - 10	scattered	
Naphthalene	158	6,920		23,000		1,769	0 - 10	scattered	
Phenanthrene	1,646	78,000	CIS	370,00	CIS	02 - 05	16 - 22	scattered	
Pyrene	1,401	60,100		250,000	CIS	02 - 05	16 - 22	scattered	
TOTAL PNAs	8,983								
PCBs									. Used in heat transfer liquids (transformers
Aroclor-1221	0	U		U					capacitors, and fluorescent light ballasts)
Aroclor-1242	0	U		U					. In hydraulic fluids and lubricants (for core
Aroclor-1248	38	2,190		5,200	CIS	02 - 05	0 - 10	scattered	machining, sludge pickling etc.).
Aroclor-1254	25	1,440	CIS	10,000	CIS	02 - 05	0 - 10	scattered	. Fire brigade training
Aroclor-1260	0	U		U					
TOTAL PCBs	64								

TABLE A-24
ORGANIC PROFILE OF PIT 2

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 2 (kg) [a e]	(3) AVERAGE CONCENTRATION IN PIT 2 FROM RI/FS (µg/kg) [f]		(4) HIGHEST HIT IN PIT 2 FROM RI/FS (µg/kg) [f]		(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE [h] (ft)	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1,RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]		24,200							
Total dry waste quantity in pit (kg) [f]		17,514,507							
Specific gravity of waste [d]		2.62							
Water content (wt. of water/dry wt.) (%) [d]		176.9							
OTHER CHEMICALS									
4,4-DDT	9	507	CIS	1,400	CIS	02 - 01	0 - 10	scattered	. From application of pesticides and/or herbicides
Pentachlorophenol	63	3,600		14,000		1,769	15 - 15.5	scattered	. Fire brigade training and application of pesticides and/or herbicides
4-Nitrophenol	72	4,130		14,000		1,769	15 - 15.5	scattered	
2,4,5-Trichlorophenol	0	U		U					. From application of pesticides and/or herbicides
4-Nitroaniline	44	2,520	CIS	7,900	CIS	02 - 03	0 - 10	scattered	. Present in corrosion inhibitors
Benzene	0.13	7.6		21		1769	20 - 20.5	scattered	. Hilco oil reclaimer, scrap metal pickling, solvent extraction, heavy equipment storage
Dichlorodifluoromethane	0	U		U					. Refrigeration oil, fabrication warehouse
Tetrachloroethene	0.20	11.4		45		1768	6 - 6.5	scattered	. Contaminated oil storage drums, liquid waste incinerator, de-zincing Zn-Th metal, casting
Tributyl Phosphate	392	22,400		39,000		1,768	14 - 17.5	scattered	. Charcoal treatment, refinery sump
Vinyl Chloride	7	409		1,900		1,769	15. - 15.5	scattered	. Progeny of parent tetrachloroethene or trichloroethene
TOTAL OTHER CHEMICALS	588								

[a] Waste streams, volumes, and calculations are based on:
1. Materials Control and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

[b] Refer to Sample Calculation 1 and 34 in RI Appendix F
[c] Refer to Sample Calculation 34 in RI Appendix F
[d] Refer to RI Appendix A, and Sample Calculation 34 in RI Appendix F
[e] Based on average concentration. Refer to Sample Calculation 37 in RI Appendix F
[f] From RI Tables 4.9 and 4.10. Background concentration of organics in soil is considered to be non-detected
[h] FromRI Appendix A
[i] Refer to RI Sections 1 & 4.2, RI Appendix F, and Table A.4.0 in Operable Unit 3 Work Plan Addendum, June 1992.
[j] 2,3,7,8-TCDF and bdibenzofuran are included in tetrachlorodibenzofuran; therefore, they are not included in the total value.
[k] 2,3,7,8-TCDD is included in tetrachlorodibenzo-p-dioxin; therefore, it is not included in the total value.

CIS = Characterization Investigation Study (refer to RI Appendix A).
U = Non detected and is entered as a zero in all calculations.
µg/kg = microgram per kilogram

TABLE A-25
ORGANIC PROFILE OF PIT 3

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 3 (kg) [a] [c]	(3) AVERAGE CONCENTRATION IN PIT 3 FROM RI/FS (µg/kg) [f]	(4) HIGHEST HIT IN PIT 3 FROM RI/FS (µg/kg) [f]	(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE [h] (ft)	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	204,100						
Total dry waste quantity in pit (kg) [c]	235,071,108						
Specific gravity of waste [d]	2.62						
Water content (wt. of water/dry wt.) (%) [d]	74						
FURANS							
2,3,7,8-TCDF [j]	0.00	U	U				. From raffinate slurry
Dibenzofuran [j]	0.00	U	U				. Oxidation of PCBs (from PCB-contaminated oil) in high temperature heat transfer operations
Heptachlorodibenzofuran	0.09	0.4	0.95	1770	24 - 39	scattered	
Hexachlorodibenzofuran	0.04	0.16	0.35	1770	24 - 39	scattered	
Octachlorodibenzofuran	0.10	0.43	1.1	1770	24 - 39	scattered	. High temperature processes such as copper shredding, hydrometallurgical system
Pentachlorodibenzofuran	0.00	U	U				
Tetrachlorodibenzofuran [j]	0.01	0.06	0.2	1770	24 - 39	scattered	
TOTAL CHLORINATED DIBENZO FURANS [j]	0.2						
DIOXINS							
2,3,7,8-TCDD	0.00	U	U				
Heptachlorordibenzo-p-dioxin	0.28	1.2	3.2	1770	24 - 39	scattered	. From the same sources as furans
Hexachlorodibenzo-p-dioxin	0.03	0.11	0.28	1770	24 - 39	scattered	
Octachlorodibenzo-p-dioxin	1.86	7.9	19.4	1770	24 - 39	scattered	
Tetrachlorodibenzo-p-dioxin [k]	0.00	U	U				
TOTAL CHLORINATED DIBENZO-P-DIOXINS [k]	2.2						

TABLE A-25
ORGANIC PROFILE OF PIT 3

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 3 (kg) [a] [e]	(3) AVERAGE CONCENTRATION IN PIT 3 FROM RI/FS (µg/kg) [f]		(4) HIGHEST HIT IN PIT 3 FROM RI/FS (µg/kg) [f]	(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE [h] (ft)	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	204,100							
Total dry waste quantity in pit (kg) [c]	235,071,108							
Specific gravity of waste [d]	2.62							
Water content (wt. of water/dry wt.) (%) [d]	74							
POLYNUCLEAR AROMATICS (PNAs)								
2-Methynaphthalene	0	U		U				. From raffinate slurry
Acenaphthene	0	U		U				. Coal dust and coal by-products
Acenaphthylene	83	355		1,000	1770	24 - 39	scattered	. Fuel oils, direct or as products of
Anthracene	87	370		1,000	1770	24 - 39	scattered	combustion
Benzo(a)anthracene	94	402	CIS	1,000	1770	24 - 39	scattered	. Oil reclaimer
Benzo(a)pyrene	92	390		1,000	1770	24 - 39	scattered	. Asphalt
Benzo(b)fluoranthene	101	430	CIS	1,000	1770	24 - 39	scattered	. Main maintenance, solvent extraction,
Benzo(g,h,i)perylene	87	370		1,000	1770	24 - 39		laboratories, stores etc.
Benzo(k)fluoranthene	0	U		U				
Chrysene	94	400	CIS	1,000	1770	24 - 39	scattered	
Dibenzo(a,h)anthracene	0	U		U				
Fluoranthene	99	420	CIS	1,000	1770	24 - 39	scattered	
Fluorene	0	U		U				
Indeno(1,2,3-cd)pyrene	87	370		1,000	1770	24 - 39	scattered	
Naphthalene	0	U		U				
Phenanthrene	92	390	CIS	1,000	1770	24 - 39	scattered	
Pyrene	95	404	CIS	1,000	1770	24 - 39	scattered	
TOTAL PNAs	1,011							
PCBs								. Used in heat transfer liquids (transformers
Aroclor-1221	0	U		U				capacitors, and fluorescent light ballasts)
Aroclor-1242	0	U		U				. In hydraulic fluids and lubricants (for core
Aroclor-1248	291	1,240		4,800	1771	28 - 41	scattered	machining, sludge pickling etc.)
Aroclor-1254	242	1,030		3,400	1771	28 - 41	scattered	. Fire brigade training
Aroclor-1260	0	U		U				
TOTAL PCBs	534							

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TABLE A-25
ORGANIC PROFILE OF PIT 3

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 3 (kg) [a] [c]	(3) AVERAGE CONCENTRATION IN PIT 3 FROM RI/FS (µg/kg) [f]	(4) HIGHEST HIT IN PIT 3 FROM RI/FS (µg/kg) [f]	(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE [h] (ft)	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	204,100						
Total dry waste quantity in pit (kg) [c]	235,071,108						
Specific gravity of waste [d]	2.62						
Water content (wt. of water/dry wt.) (%) [d]	74						
OTHER CHEMICALS							
4,4-DDT	0	U	U				
Pentachlorophenol	287	1,220 CIS	2,900 CIS	03 - 07	0 - 12	scattered	. Fire brigade training
4-Nitrophenol	0	U	U				
2,4,5-Trichlorophenol	0	U	U				
4-Nitroaniline	0	U	U				
Benzene	0	U	U				. Hilco oil reclaimer, Scrap metal pickling, solvent extraction, heavy equipment storage
Dichlorodifluoromethane	0	no data	no data				
Tetrachloroethene	2	7.4	22	1770	22 - 22.5	scattered	. Contaminated oil storage drums, liquid waste incinerator, de-zincing Zn-Th metal, casting
Tributyl Phosphate	0	U	U				. Charcoal treatment, refinery sump.
Vinyl Chloride	0	U	U				
TOTAL OTHER CHEMICALS	289						

[a] Waste streams, volumes, and calculations are based on:
1. Materials Control and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

[b] Refer to Sample Calculation 1 and 34 in RI Appendix F
[c] Refer to Sample Calculation 34 in RI Appendix F
[d] Refer to RI Appendix A, and Sample Calculation 34 in RI Appendix F
[e] Based on average concentration. Refer to Sample Calculation 37 in RI Appendix F.
[f] From RI Tables 4.9 and 4.10. Background concentration of organics in soil is considered to be non-detected.
[h] From RI Appendix A
[i] Refer to RI Sections 1 & 4.2, RI Appendix F, and Table A.4.0 in Operable Unit 3 Work Plan Addendum, June 1992
[j] 2,3,7,8-TCDF and dibenzofuran are included in tetrachlorodibenzofuran; therefore, they are not included in the total value.
[k] 2,3,7,8-TCDD is included in tetrachlorodibenzo-p-dioxin; therefore, it is not included in the total value.

CIS = Characterization Investigation Study (refer to RI Appendix A).
U = Non detected and is entered as a zero in all calculations.
µg/kg = microgram per kilogram

TABLE A-26
ORGANIC PROFILE OF PIT 4

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 4 (kg) [a] [e]	(3) AVERAGE CONCENTRATION IN PIT 1 FROM RI/FS (µg/kg) [f]	(4) HIGHEST HIT IN PIT 4 FROM RI/FS (µg/kg) [f]	(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE (ft) [h]	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	55,100						
Total dry waste quantity in pit (kg) [c]	98,590,826						
Specific gravity of waste [d]	3.02						
Water content (wt. of water/dry wt.) (%) [d]	29.1						
FURANS							
2,3,7,8-TCDF [j]	0.44	4.5	9.9	1774	10 - 20	scattered	. Bottom ash from three soild waste incinerators, oil burner, or graphite burner
Dibenzofuran [j]	75	718 CIS	1700 CIS	04 - 04	0 - 20	scattered	. Oxidation of PCBs (from PCB-contaminated oil) in high temperature heat transfer operations
Heptachlorodibenzofuran	0.22	2.2	4.4	1774	10 - 20	scattered	. High temperature processes such as copper shredding, hydrometallurgical system
Hexachlorodibenzofuran	0.31	3.1	8.5	1774	10 - 20	scattered	
Octachlorodibenzofuran	0.21	2.1	8	1773	9 - 18	scattered	
Pentachlorodibenzofuran	0.51	5.2	15.3	1774	10 - 20	scattered	
Tetrachlorodibenzofuran [j]	1.48	15	34	1774	10 - 20	scattered	
TOTAL CHLORINATED DIBENZO FURANS [j]	2.7						
DIOXINS							
2,3,7,8-TCDD	0.00	U	U	1773	9 - 18	scattered	
Heptachlorordibenzo-p-dioxin	0.21	2.1	4	1773	9 - 18	scattered	. From the same sources as furans
Hexachlorodibenzo-p-dioxin	0.11	1.1	2.7	1774	10 - 20	scattered	
Octachlorodibenzo-p-dioxin	0.40	4.1	9	1775	10 - 19	scattered	
Tetrachlorodibenzo-p-dioxin [k]	0.02	0.2	0.47	1774	10 - 20	scattered	
TOTAL CHLORINATED DIBENZO-P-DIOXINS [k]	0.7						

TABLE A-26
ORGANIC PROFILE OF PIT 4

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 4 (kg) [a] [e]	(3) AVERAGE CONCENTRATION IN PIT 1 FROM RI/FS (µg/kg) [f]		(4) HIGHEST HIT IN PIT 4 FROM RI/FS (µg/kg) [f]		(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE (ft) [h]	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	55,100								
Total dry waste quantity in pit (kg) [c]	98,590,826								
Specific gravity of waste [d]	3.02								
Water content (wt. of water/dry wt.) (%) [d]	29.1								
POLYNUCLEAR AROMATICS (PNAs)									
2-Methynaphthalene	49	501	CIS	1,100	CIS	04 - 04	0 - 20	scattered	. Bottom ash from three solid waste
Acenaphthene	69	700		1,900		1775	10-19	scattered	incinerators, oil burner, or graphite burner
Acenaphthylene	0	U		U					. Coal dust and coal by-products
Anthracene	134	1,360	CIS	3,300	CIS	04 - 04	0 - 20	scattered	. Fuel oils, direct or as products of
Benzo(a)anthracene	185	1,880	CIS	4,700		1775	10-19	scattered	combustion
Benzo(a)pyrene	205	2,080	CIS	4,800	CIS	04 - 04	0 - 20	scattered	. Oil reclaimer
Benzo(b)fluoranthene	209	2120	CIS	5,800	CIS	04 - 04	0 - 20	scattered	. Asphalt
Benzo(g,h,i)perylene	46	470	CIS	2,300		1775	10-19	scattered	. Main maintenance, solvent extraction,
Benzo(k)fluoranthene	168	1,700	CIS	3,700	CIS	04 - 04	0 - 20	scattered	laboratories, stores etc.
Chrysene	194	1,970	CIS	4,500	CIS	04 - 02	0 - 20	scattered	
Dibenzo(a,h)anthracene	26	260	CIS	560	CIS	04 - 04	0 - 20	scattered	
Fluoranthene	616	6,250	CIS	18,000	CIS	04 - 04	0 - 20	scattered	
Fluorene	124	1,260	CIS	3400	CIS	04 - 04	0 - 20	scattered	
Indeno(1,2,3-cd)pyrene	46	470		2,300		1775	10-19	scattered	
Naphthalene	83	840	CIS	2,700	CIS	04 - 04	0 - 20	scattered	
Phenanthrene	564	5,720	CIS	16,000	CIS	04 - 04	0 - 20	scattered	
Pyrene	253	2,570	CIS	9,000		1775	10-19	scattered	
TOTAL PNAs	2,973								
PCBs									
Aroclor-1221	0	U		U					. Used in heat transfer liquids (transformers
Aroclor-1242	52	390	CIS	1,030	CIS	04 - 03	0 - 20	scattered	capacitors, and fluorescent light ballasts)
Aroclor-1248	325	3,330		7,500		1,774	10 - 20	scattered	. In hydraulic fluids and lubricants (for core
Aroclor-1254	227	2,300		6,800		1,775	19 - 30	scattered	machining, sludge pickling etc.).
Aroclor-1260	0	U		U					. Fire brigade training
TOTAL PCBs	604								

TABLE A-26
ORGANIC PROFILE OF PIT 4

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 4 (kg) [a] [e]	(3) AVERAGE CONCENTRATION IN PIT 1 FROM RI/FS (µg/kg) [f]	(4) HIGHEST HIT IN PIT 4 FROM RI/FS (µg/kg) [f]	(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE (ft) [h]	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	55,100						
Total dry waste quantity in pit (kg) [c]	98,590,826						
Specific gravity of waste [d]	3.02						
Water content (wt. of water/dry wt.) (%)	29.1						
OTHER CHEMICALS							
4,4-DDT	0	U	U				. From application of pesticides and/or herbicides
Pentachlorophenol	0	U	U				. Fire brigade training and application of pesticides and/or herbicides
4-Nitrophenol	0	U	U				
2,4,5-Trichlorophenol	0	U	U				. From application of pesticides and/or herbicides
4-Nitroaniline	0	U	U				. Present in corrosion inhibitors
Benzene	0	4.3	14	1773	16 - 16.5	scattered	. Hilco oil reclaimer, scrap metal pickling, solvent extraction, heavy equipment storage
Dichlorodifluoromethane	0	U	U				. Refrigeration oil, fabrication warehouse
Tetrachloroethene	28	283 CIS	530 CIS	04 - 02	0 - 20	scattered	. Contaminated oil storage drums, liquid waste incinerator, de-zincing Zn-Th metal, casting
Tributyl Phosphate	5,915	60,000	72,000	1775	19 - 30	scattered	. Charcoal treatment, refinery sump
Vinyl Chloride	0	7.8	16	1774	9.5 - 10	scattered	. Progeny of parent tetrachloroethene or trichloroethene
TOTAL OTHER CHEMICALS	5,943						

[a] Waste streams, volumes, and calculations are based on:
1. Materials Control and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

[b] Refer to Sample Calculation 1 and 34 in RI Appendix F
[c] Refer to Sample Calculation 34 in RI Appendix F
[d] Refer to RI Appendix A, and Sample Calculation 34 in RI Appendix F
[e] Based on average concentration. Refer to Sample Calculation 37 in RI Appendix F.
[f] From RI Tables 4.9 and 4.10. Background concentration of organics in soil is considered to be non-detected
[h] FromRI Appendix A
[i] Refer to RI Sections 1 & 4.2, RI Appendix F, and Table A.4.0 in Operable Unit 3 Work Plan Addendum, June 1992
[j] 2,3,7,8-TCDF and dibenzofuran are included in tetrachlorodibenzofuran; therefore, they are not included in the total value.
[k] 2,3,7,8-TCDD is included in tetrachlorodibenzo-p-dioxin; therefore, it is not included in the total value.

CIS = Characterization Investigation Study (refer to RI Appendix A)
U = Non detected and is entered as a zero in all calculations
µg/kg = microgram per kilogram

TABLE A-27
ORGANIC PROFILE OF PIT 5

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 5 (kg) [a e]	(3) AVERAGE CONCENTRATION IN PIT 5 FROM RI/FS (µg/kg) [f]	(4) HIGHEST HIT IN PIT 5 FROM RI/FS (µg/kg) [f]	(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE [h] (ft)	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	97,000	Data from RI					
Total dry waste quantity in pit (kg)[c]	117,625,873	were rejected					
Specific gravity of waste [d]	2.43	because of long					
Water content (wt. of water/dry wt.) (%) [d]	54.7	holding times					
FURANS							
2,3,7,8-TCDF [j]		U	U				. From raffinate slurry
Dibenzofuran [j]							. Oxidation of PCBs (from PCB-contaminated oil) in high temperature heat transfer operations
Heptachlorodibenzofuran							. High temperature processes such as copper shredding, hydrometallurgical system
Hexachlorodibenzofuran							
Octachlorodibenzofuran							
Pentachlorodibenzofuran							
Tetrachlorodibenzofuran [j]							
TOTAL CHLORINATED DIBENZO FURANS [j]	0.0						
DIOXINS							
2,3,7,8-TCDD							
Heptachlorordibenzo-p-dioxin							. From the same sources as furans
Hexachlorodibenzo-p-dioxin							
Octachlorodibenzo-p-dioxin							
Tetrachlorodibenzo-p-dioxin [k]							
TOTAL CHLORINATED DIBENZO-P-DIOXINS [k]							

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TABLE A-27
ORGANIC PROFILE OF PIT 5

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 5 (kg) [a c]	(3) AVERAGE CONCENTRATION IN PIT 5 FROM RI/FS (µg/kg) [f]		(4) HIGHEST HIT IN PIT 5 FROM RI/FS (µg/kg) [f]		(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE [h] (ft)	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	97,000	Data from RI							
Total dry waste quantity in pit (kg)[c]	117,625,873	were rejected							
Specific gravity of waste [d]	2.43	because of long							
Water content (wt. of water/dry wt.) (%) [d]	54.7	holding times							
POLYNUCLEAR AROMATICS (PNAs)									
2-Methynaphthalene	0	U		U					. From raffinate slurry
Acenaphthene	0	U		U					. Coal dust, coal fly ash, and coal by-products
Acenaphthylene	0	U		U					. Fuel oils, direct or as products of
Anthracene	0	U		U					combustion
Benzo(a)anthracene	0	U		U					. Oil reclaimer
Benzo(a)pyrene	0	U		U					. Asphalt
Benzo(b)fluoranthene	0	U		U					. Main maintenance, solvent extraction,
Benzo(g,h,i)perylene	0	U		U					laboratories, stores etc.
Benzo(k)fluoranthene	0	U		U					
Chrysene	0	U		U					
Dibenzo(a,h)anthracene	0	U		U					
Fluoranthene	0	U		U					
Fluorene	0	U		U					
Indeno(1,2,3-cd)pyrene	0	U		U					
Naphthalene	0	U		U					
Phenanthrene	0	U		U					
Pyrene	0	U		U					
TOTAL PNAs	0.0								
PCBs									. Used in heat transfer liquids (transformers
Aroclor-1221	0	U		U					capacitors, and fluorescent light ballasts)
Aroclor-1242	0	U		U					. In hydraulic fluids and lubricants (for core
Aroclor-1248	80	683	CIS	3,100	CIS	05 - 02	0 - 14	scattered	machining, sludge pickling, etc.)
Aroclor-1254	135	1,150	CIS	6,200	CIS	05 - 02	0 - 14	scattered	. Fire brigade training
Aroclor-1260	0	U		U					
TOTAL PCBs	216								

TABLE A-27
ORGANIC PROFILE OF PIT 5

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 5 (kg) [a e]	(3) AVERAGE CONCENTRATION IN PIT 5 FROM RI/FS (µg/kg) [f]	(4) HIGHEST HIT IN PIT 5 FROM RI/FS (µg/kg) [f]	(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE [h] (ft)	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	97,000	Data from RI					
Total dry waste quantity in pit (kg)[c]	117,625,873	were rejected					
Specific gravity of waste [d]	2.43	because of long					
Water content (wt. of water/dry wt.) (%) [d]	54.7	holding times					
OTHER CHEMICALS							
4,4-DDT	0	U	U				. From application of pesticides and/or herbicides
Pentachlorophenol	0	U	U				. Fire brigade training and application of pesticides and/or herbicides
4-Nitrophenol	0	U	U				. From application of pesticides and/or herbicides
2,4,5-Trichlorophenol	0	U	U				. Present in corrosion inhibitors
4-Nitroaniline	0	U	U				. Hilco oil reclaimer, scrap metal pickling,
Benzene	0	U	U				solvent extraction, heavy equipment storage
							. Refrigeration oil, fabrication warehouse
Dichlorodifluoromethane	0	U	U				. Contaminated oil storage drums, liquid waste
Tetrachloroethene	0	U	U				incinerator, de-zincing Zn-Th metal, casting
							. Charcoal treatment, refinery sump
Tributyl Phosphate	0	no data	no data				. Progeny of parent tetrachloroethene or
Vinyl Chloride	0	U	U				trichloroethene
TOTAL OTHER CHEMICALS	0						

[a] Waste streams, volumes, and calculations are based on:
1. Materials Control and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

[b] Refer to Sample Calculation 1 and 34 in RI Appendix F
[c] Refer to Sample Calculation 34 in RI Appendix F
[d] Refer to RI Appendix A, and Sample Calculation 34 in RI Appendix F
[e] Based on average concentration. Refer to Sample Calculation 37 in RI Appendix F.
[f] From RI Tables 4.9 and 4.10. Background concentration of organics in soil is considered to be non-detected
[h] From RI Appendix A
[i] Refer to RI Sections 1 & 4.2, RI Appendix F, and Table A.4.0 in Operable Unit 3 Work Plan Addendum, June 1992
[j] 2,3,7,8-TCDF and dibenzofuran are included in tetrachlorodibenzofuran; therefore, they are not included in the total value.
[k] 2,3,7,8-TCDD is included in tetrachlorodibenzo-p-dioxin; therefore, it is not included in the total value.

CIS = Characterization Investigation Study (refer to RI Appendix A)
U = Non detected and is entered as a zero in all calculations
µg/kg = microgram per kilogram

TABLE A-28
ORGANIC PROFILE OF PIT 6

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 6 (kg) [a e]	(3) AVERAGE CONCENTRATION IN PIT 6 FROM RI/FS (µg/kg) [f]	(4) HIGHEST HIT IN PIT 6 FROM RI/FS (µg/kg) [f]	(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE (ft) [h]	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	9,600	Data from RI					
Total dry waste quantity in pit (kg) [c]	16,805,824	were rejected					
Specific gravity of waste [d]	2.87	because of long					
Water content (wt. of water/dry wt.) (%) [d]	25.4	holding time					
FURANS							
2,3,7,8-TCDF [j]		U	U				. Bottom ash from three soild waste incinerators, oil burner, or graphite burner . Oxidation of PCBs (from PCB-contaminated oil) in high temperature heat transfer operations . High temperature processes such as copper shredding, hydrometallurgical system
Dibenzofuran							
Heptachlorodibenzofuran							
Hexachlorodibenzofuran							
Octachlorodibenzofuran							
Pentachlorodibenzofuran							
Tetrachlorodibenzofuran [j]							
TOTAL CHLORINATED DIBENZO FURANS [j]	0.0						
DIOXINS							
2,3,7,8-TCDD							
Heptachlorordibenzo-p-dioxin							. From the same sources as furans
Hexachlorodibenzo-p-dioxin							
Octachlorodibenzo-p-dioxin							
Tetrachlorodibenzo-p-dioxin [k]							
TOTAL CHLORINATED DIBENZO-P-DIOXINS [k]							

TABLE A-28
ORGANIC PROFILE OF PIT 6

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 6 (kg) [a e]	(3) AVERAGE CONCENTRATION IN PIT 6 FROM RI/FS (µg/kg) [f]	(4) HIGHEST HIT IN PIT 6 FROM RI/FS (µg/kg) [f]	(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE (ft) [h]	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	9,600	Data from RI					
Total dry waste quantity in pit (kg) [c]	16,805,824	were rejected					
Specific gravity of waste [d]	2.87	because of long					
Water content (wt. of water/dry wt.) (%) [d]	25.4	holding time					
POLYNUCLEAR AROMATICS (PNAs)							
2-Methynaphthalene	0	U	U				. Bottom ash from three soild waste
Acenaphthene	0	U	U				incinerators, oil burner, or graphite burner
Acenaphthylene	0	U	U				. Coal dust, coal fly ash, and coal by-products
Anthracene	0	U	U				. Fuel oils, direct or as products of
Benzo(a)anthracene	0	U	U				combustion
Benzo(a)pyrene	0	U	U				. Oil reclaimer
Benzo(b)fluoranthene	0	U	U				. Asphalt
Benzo(g,h,i)perylene	0	U	U				. Main maintenance, solvent extraction,
Benzo(k)fluoranthene	0	U	U				laboratories, stores etc.
Chrysene	0	U	U				
Dibenzo(a,h)anthracene	0	U	U				
Fluoranthene	0	U	U				
Fluorene	0	U	U				
Indeno(1,2,3-cd)pyrene	0	U	U				
Naphthalene	0	U	U				
Phenanthrene	0	U	U				
Pyrene	0	U	U				
TOTAL PAHs	0						
PCBs							
Aroclor-1221	0	U	U				. Used in heat transfer liquids (transformers
Aroclor-1242	0	U	U				capacitors, and fluorescent light ballasts)
Aroclor-1248	0	U	U				. In hydraulic fluids and lubricants (for core
Aroclor-1254	6	193 CIS	640 CIS		0 - 15	scattered	machining, sludge pickling etc.)
Aroclor-1260	0	U	U				. Fire brigade training
TOTAL PCBs	6						

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TABLE A-28
ORGANIC PROFILE OF PIT 6

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY IN PIT 6 (kg) [a] [e]	(3) AVERAGE CONCENTRATION IN PIT 6 FROM RI/FS (µg/kg) [f]	(4) HIGHEST HIT IN PIT 6 FROM RI/FS (µg/kg) [f]	(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE (ft) [h]	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	9,600	Data from RI					
Total dry waste quantity in pit (kg) [c]	16,805,824	were rejected					
Specific gravity of waste [d]	2.87	because of long					
Water content (wt. of water/dry wt.) (%) [d]	25.4	holding time					
OTHER CHEMICALS							
4,4-DDT	0	U	U				. From application of pesticides and/or herbicides
Pentachlorophenol	0	U	U				. Fire brigade training and application of pesticides and/or herbicides
4-Nitrophenol	0	U	U				
2,4,5-Trichlorophenol	0	U	U				. From application of pesticides and/or herbicides
4-Nitroaniline	0	U	U				. Present in corrosion inhibitors
Benzene	0	U	U				. Hilco oil reclaimer, scrap metal pickling, solvent extraction, heavy equipment storage
Dichlorodifluoromethane	0	U	U				. Refrigeration oil, fabrication warehouse
Tetrachloroethene	244	14,500 CIS	29,000 CIS	06 - 04	0 - 10	scattered	. Contaminated oil storage drums, liquid waste incinerator, de-zincing Zn-Th metal, casting
Tributyl Phosphate	0	no data	no data				. Charcoal treatment, refinery sump
Vinyl Chloride	0	U	U				. Progeny of parent tetrachloroethene or trichloroethene
TOTAL OTHER CHEMICALS	244						

[a] Waste streams, volumes, and calculations are based on:
1. Materials Control and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

[b] Refer to Sample Calculation 1 and 34 in RI Appendix F
[c] Refer to Sample Calculation 34 in RI Appendix F
[d] Refer to RI Appendix A, and Sample Calculation 34 in RI Appendix F
[e] Based on average concentration. Refer to Sample Calculation 37 in RI Appendix F.
[f] From RI Tables 4.9 and 4.10. Background concentration of organics in soil is considered to be non-detected
[h] FromRI Appendix A
[i] Refer to RI Sections 1 & 4.2, RI Appendix F, and Table A.4.0 in Operable Unit 3 Work Plan Addendum, June 1992
[j] 2,3,7,8-TCDF and dibenzofuran are included in tetrachlorodibenzofuran; therefore, they are not included in the total value.
[k] 2,3,7,8-TCDD is included in tetrachlorodibenzo-p-dioxin; therefore, it is not included in the total value.

CIS = Characterization Investigation Study (refer to RI Appendix A).
U = Non detected and is entered as a zero in all calculations.
µg/kg = microgram per kilogram

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TABLE A-29
ORGANIC PROFILE OF THE BURN PIT

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY BURN PIT (kg) [a e]	(3) AVERAGE CONCENTRATION BURN PIT FROM RI/FS (µg/kg) [f]	(4) HIGHEST HIT BURN PIT FROM RI/FS (µg/kg) [f]	(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE (ft) [h]	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	30,300						
Total dry waste quantity in pit (kg) [c]	67,771,624						
Specific gravity of waste [d]	3.74						
Water content (wt. of water/dry wt.) (%)	27.9						
FURANS							
2,3,7,8-TCDF [j]	0.00	U	U				. Bottom ash from three solid waste incinerators, oil burner, or graphite burner
Dibenzofuran [j]	27.79	410	930	1776	19.5 - 32.5	discreet	
Heptachlorodibenzofuran	0.01	0.13	0.31	1777	0 - 6.5	scattered	. In calcined raffinate
Hexachlorodibenzofuran	0.00	U	U				. Oxidation of PCBs (from PCB-contaminated oil) in high temperature heat transfer operations.
Octachlorodibenzofuran	0.01	0.19	0.37	1777	0 - 6.5	scattered	
Pentachlorodibenzofuran [j]	0.00	U	U				
Tetrachlorodibenzofuran	0.00	U	U				. High temperature processes such as copper shredding, hydrometallurigical system.
TOTAL CHLORINATED DIBENZO FURANS [j]	0.02						
DIOXINS							
2,3,7,8-TCDD	0.00	U	U				
Heptachlorordibenzo-p-dioxin	0.04	0.55	0.98	1776	19.5 - 32.5	scattered	. From the same sources as in case 1
Hexachlorodibenzo-p-dioxin	0.00	U	U				
Octachlorodibenzo-p-dioxin	0.16	2.3	4	1776	19.5 - 32.5	scattered	
Tetrachlorodibenzo-p-dioxin [k]	0.00	U	U				
TOTAL CHLORINATED DIBENZO-P-DIOXINS [k]	0.2						

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TABLE A-29
ORGANIC PROFILE OF THE BURN PIT

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY BURN PIT (kg) [a e]	(3) AVERAGE CONCENTRATION BURN PIT FROM RI/FS (µg/kg) [f]	(4) HIGHEST HIT BURN PIT FROM RI/FS (µg/kg) [f]	(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE (ft) [h]	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	30,300						
Total dry waste quantity in pit (kg) [c]	67,771,624						
Specific gravity of waste [d]	3.74						
Water content (wt. of water/dry wt.) (%)	27.9						
POLYNUCLEAR AROMATICS (PNAs)							
2-Methynaphthalene	25	363	930	1776	19.5 - 32.5	scattered	. Bottom ash from three solid waste incinerators, oil burner, or graphite burner
Acenaphthene	30	450	1,100	1776	19.5 - 32.5	discreet	. In creosote from railroad ties
Acenaphthylene	0	U	U				. Coal dust and coal by-products
Anthracene	58	850	3,100	1776	19.5 - 32.5	scattered	. Fuel oils, direct or as products of combustion
Benzo(a)anthracene	98	1,449	6,300	1776	19.5 - 32.5	scattered	. Oil reclaimer
Benzo(a)pyrene	65	965	3,900	1776	19.5 - 32.5	scattered	. Asphalt
Benzo(b)fluoranthene	146	2,150	9,600	1776	19.5 - 32.5	discreet	. Main maintenance, solvent extraction, laboratories, stores, etc.
Benzo(g,h,i)perylene	51	753	2,900	1776	19.5 - 32.5	scattered	
Benzo(k)fluoranthene	48	705	5,000	1776	19.5 - 32.5	scattered	
Chrysene	107	1,580	7,000	1776	19.5 - 32.5	scattered	
Dibenzo(a,h)anthracene	0	U	U				
Fluoranthene	230	3,400	16,000	1776	19.5 - 32.5	scattered	
Fluorene	36	535	1,700	1776	19.5 - 32.5	scattered	
Indeno(1,2,3-cd)pyrene	41	607	2,200	1776	19.5 - 32.5	scattered	
Naphthalene	49	725	5,000	1776	19.5 - 32.5	scattered	
Phenanthrene	216	3,180	15,000	1776	19.5 - 32.5	scattered	
Pyrene	203	3,000	14,000	1776	19.5 - 32.5	scattered	
TOTAL PNAs	1404						
PCBs							. Used in heat transfer liquids (transformers capacitors, and fluorescent light ballasts)
Aroclor-1221	0	U	U				. In hydraulic fluids and lubricants (for core machining, sludge pickling etc.)
Aroclor-1242	10	144	540 CIS				. Fire brigade training
Aroclor-1248	9	139	540 CIS				
Aroclor-1254	165	2,430	7,700	06 - 03	0 - 15	scattered	
Aroclor-1260	0	U	U				
TOTAL PCBs	184						

TABLE A-29
ORGANIC PROFILE OF THE BURN PIT

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY BURN PIT (kg) [a e]	(3) AVERAGE CONCENTRATION BURN PIT FROM RI/FS (µg/kg) [f]		(4) HIGHEST HIT BURN PIT FROM RI/FS (µg/kg) [f]		(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE (ft) [h]	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	30,300								
Total dry waste quantity in pit (kg) [c]	67,771,624								
Specific gravity of waste [d]	3.74								
Water content (wt. of water/dry wt.) (%)	27.9								
OTHER CHEMICALS									
4,4-DDT	0	U		U					. From application of pesticides and/or herbicides
Pentachlorophenol	94	1,380	CIS	2,600	CIS	07-02	0-12	scattered	. Fire brigade training and application of pesticides and/or herbicides
4-Nitrophenol	0	U		U					
2,4,5-Trichlorophenol	0	U		U					. From application of pesticides and/or herbicides
4-Nitroaniline	0	U		U					. Present in corrosion inhibitors
Benzene	0	U		U					. Hilco oil reclaimer, scrap metal pickling, solvent extraction, heavy equipment storage
Dichlorodifluoromethane	0	no data		no data					. Refrigeration oil, fabrication warehouse
Tetrachloroethene	10	143	CIS	260	CIS	06 - 04	0 - 10	scattered	. Contaminated oil storage drums, liquid waste incinerator, de-zincing Zn-Th metal, casting
Tributyl Phosphate	0	no data		no data					. Charcoal treatment, refinery sump
Vinyl Chloride	0	6.1		U		1776	6-6.5	scattered	. Progeny of parent tetrachloroethene or trichloroethene
TOTAL OTHER CHEMICALS	104								

[a] Waste streams, volumes, and calculations are based on:
1. Materials Control and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

[b] Refer to Sample Calculation 1 and 34 in RI Appendix F
[c] Refer to Sample Calculation 34 in RI Appendix F
[d] Refer to RI Appendix A, and Sample Calculation 34 in RI Appendix F
[e] Based on average concentration. Refer to Sample Calculation 37 in RI Appendix F.
[f] From RI Tables 4.9 and 4.10. Background concentration of organics in soil is considered to be non-detected.
[h] From RI Appendix A
[i] Refer to RI Sections 1 & 4.2, RI Appendix F, and Table A.4.0 in Operable Unit 3 Work Plan Addendum, June 1992
[j] 2,3,7,8-TCDF and dibenzofuran are included in tetrachlorodibenzofuran; therefore, they are not included in the total value.
[k] 2,3,7,8-TCDD is included in tetrachlorodibenzo-p-dioxin; therefore, it is not included in the total value.

CIS = Characterization Investigation Study (refer to RI Appendix A)
U = Non detected
µg/kg = microgram per kilogram

TABLE A-30
ORGANIC PROFILE OF THE CLEARWELL

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY CLEARWELL (kg) [a e]	(3) AVERAGE CONCENTRATION CLEARWELL FROM RI/FS (µg/kg) [f]	(4) HIGHEST HIT CLEARWELL FROM RI/FS (µg/kg) [f]	(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE (ft) [h]	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	3,700	Data from RI					
Total dry waste quantity in pit (kg) [c]	2,892,394	were rejected					
Specific gravity of waste [d]	1.44	because of long					
Water content (wt. of water/dry wt.) (%) [d]	40.9	holding time					
FURANS							
2,3,7,8-TCDF [j]		U	U				. Bottom ash from three soild waste incinerators, oil burner, or graphite burner . Oxidation of PCBs (from PCB-contaminated oil) in high temperature heat transfer operations . High temperature processes such as copper shredding, hydrometallurgical system
Dibenzofuran [j]							
Heptachlorodibenzofuran							
Hexachlorodibenzofuran							
Octachlorodibenzofuran							
Pentachlorodibenzofuran							
Tetrachlorodibenzofuran [j]							
TOTAL CHLORINATED DIBENZO FURANS [j]							
DIOXINS							
2,3,7,8-TCDD							. From the same sources as furans
Heptachlorordibenzo-p-dioxin							
Hexachlorodibenzo-p-dioxin							
Octachlorodibenzo-p-dioxin							
Tetrachlorodibenzo-p-dioxin [k]							
TOTAL CHLORINATED DIBENZO-P-DIOXINS [k]							

TABLE A-30
ORGANIC PROFILE OF THE CLEARWELL

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY CLEARWELL (kg) [a] [e]	(3) AVERAGE CONCENTRATION CLEARWELL FROM RI/FS (µg/kg) [f]		(4) HIGHEST HIT CLEARWELL FROM RI/FS (µg/kg) [f]		(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE (ft) [h]	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	3,700	Data from RI							
Total dry waste quantity in pit (kg) [c]	2,892,394	were rejected							
Specific gravity of waste [d]	1.44	because of long							
Water content (wt. of water/dry wt.) (%) [d]	40.9	holding time							
POLYNUCLEAR AROMATICS (PNAs)									
2-Methynaphthalene	0	U		U					. Bottom ash from three soild waste
Acenaphthene	0	U		U					incinerators, oil burner, or graphite burner
Acenaphthylene	0	U		U					. Coal dust, coal fly ash, and coal by-products
Anthracene	1.5	521	CIS	1,400	CIS	08 - 03	11 - 13	stratified	. Fuel oils, direct or as products of
Benzo(a)anthracene	1.5	516	CIS	1,400	CIS	08 - 03	11 - 13	stratified	combustion
Benzo(a)pyrene	1.7	576	CIS	1,400	CIS	08 - 03	11 - 13	stratified	. Oil reclaimer
Benzo(b)fluoranthene	1.7	586	CIS	1,400	CIS	08 - 03	11 - 13	stratified	. Asphalt
Benzo(g,h,i)perylene	1.3	466	CIS	1,400	CIS	08 - 03	11 - 13	stratified	. Main maintenance, solvent extraction,
Benzo(k)fluoranthene	1.7	596	CIS	1,400	CIS	08 - 03	11 - 13	stratified	laboratories, stores etc.
Chrysene	1.4	481	CIS	1,400	CIS	08 - 03	11 - 13	stratified	
Dibenzo(a,h)anthracene	0	U		U					
Fluoranthene	3.4	1,180	CIS	3,100	CIS	08 - 01	11-13	stratified	
Fluorene	1.4	479	CIS	1,400	CIS	08 - 03	11 - 13	stratified	
Indeno(1,2,3-cd)pyrene	1.4	476	CIS	1,400	CIS	08 - 03	11 - 13	stratified	
Naphthalene	0	U		U					
Phenanthrene	1.9	650	CIS	2,100	CIS	08 - 01	11 - 13	stratified	
Pyrene	1.8	621	CIS	1,400	CIS	08 - 03	11 - 13	stratified	
TOTAL PNAs	21								
PCBs									. Used in heat transfer liquids (transformers
Aroclor-1221	0.0	U		U					capacitors, and fluorescent light ballasts)
Aroclor-1242	0.4	124	CIS	330	CIS	08 - 01	11 - 13	stratified	. In hydraulic fluids and lubricants (for core
Aroclor-1248	0.5	190	CIS	330	CIS	08 - 01	11 - 13	stratified	machining, sludge pickling etc.).
Aroclor-1254	0.9	300	CIS	740	CIS	08 - 02	11 - 13	stratified	. Fire brigade training
Aroclor-1260	0.0	U		U					. In creosote railroad.
TOTAL PCBs	1.8								

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TABLE A-30
ORGANIC PROFILE OF THE CLEARWELL

(1) ANALYTE	(2) ESTIMATED CHEMICAL QUANTITY CLEARWELL (kg) [a e]	(3) AVERAGE CONCENTRATION CLEARWELL FROM RI/FS (µg/kg) [f]	(4) HIGHEST HIT CLEARWELL FROM RI/FS (µg/kg) [f]	(5) LOCATION OF HIGHEST HIT [h]	(6) VERTICAL PROFILE (ft) [h]	(7) HORIZONTAL PROFILE [h]	(8) POSSIBLE SOURCES (Refer to RI Section 1, RI Section 4.2, and RI Appendix F for details of sources)
Total waste volume in pit (yard3) [b]	3,700	Data from RI					
Total dry waste quantity in pit (kg) [c]	2,892,394	were rejected					
Specific gravity of waste [d]	1.44	because of long					
Water content (wt. of water/dry wt.) (%) [d]	40.9	holding time					
OTHER CHEMICALS							
4,4-DDT	0	U	U				. From application of pesticides and/or herbicides
Pentachlorophenol	0	U	U				. Fire brigade training and application of pesticides and/or herbicides
4-Nitrophenol	0	U	U				
2,4,5-Trichlorophenol	11	3,800 CIS	7,600 CIS	08 - 01	11 - 13	stratified	. From application of pesticides and/or herbicides
4-Nitroaniline	0	U	U				. Present in corrosion inhibitors
Benzene	0	U	U				. Hilco oil reclaimer, scrap metal pickling, solvent extraction, heavy equipment storage
Dichlorodifluoromethane	0	no data	no data				. Refrigeration oil, fabrication warehouse
Tetrachloroethene	0	U	U				. Contaminated oil storage drums, liquid waste incinerator, de-zincing Zn-Th metal, casting
Tributyl Phosphate	0	no data	no data				. Charcoal treatment, refinery sump
Vinyl Chloride	0	U	U				. Progeny of parent tetrachloroethene or trichloroethene
TOTAL OTHER CHEMICALS	11						

[a] Waste streams, volumes, and calculations are based on:
1. Materials Control and Accounting (MC&A) records;
2. Operable Unit 3 Work Plan Addendum 1992; and
3. Interviews with knowledgeable plant personnel.

[b] Refer to Sample Calculation 1 and 34 in RI Appendix F
[c] Refer to Sample Calculation 34 in RI Appendix F
[d] Refer to RI Appendix A, and Sample Calculation 34 in RI Appendix F
[e] Based on average concentration. Refer to Sample Calculation 37 in RI Appendix F.
[f] From RI Tables 4.9 and 4.10. Background concentration of organics in soil is considered to be non-detected.
[h] From RI Appendix A
[i] Refer to RI Sections 1 & 4.2, RI Appendix F, and Table A.4.0 in Operable Unit 3 Work Plan Addendum, June 1992
[j] 2,3,7,8-TCDF and dibenzofuran are included in tetrachlorodibenzofuran; therefore, they are not included in the total value.
[k] 2,3,7,8-TCDD is included in tetrachlorodibenzo-p-dioxin; therefore, it is not included in the total value.

CIS = Characterization Investigation Study (refer to RI Appendix A).
U = Non detected
µg/kg = microgram per kilogram

TABLE A-31
SURFACE WATER ANALYTICAL RESULTS

Analyte	Units	DD-07	DD-09
Aluminum	μg/L	456	964
Barium	μg/L	320	209
TOC	mg/L	118	7.6
TOX	μg/L	260	37
TDS	mg/L	1190	414
TSS	mg/L	20.0	148
Chloride	mg/L	28.1	39.3
Fluoride	mg/L	1.2	1.3
Nitrate	mg/L	0.20	2.6
Gross Alpha	pCi/L	850 ± 50	420 ± 30
Gross Beta	pCi/L	560 ± 20	380 ± 10
Thorium-228	pCi/L	NR	0.1 ± 0.3
Thorium-230	pCi/L	NR	1.4 ± 0.5
Thorium-232	pCi/L	NR	0.1 ± 0.2
Uranium-234	pCi/L	160 ± 30	57 ± 30
Uranium-235	pCi/L	5 ± 10	1.0 ± 8.6
Uranium-238	pCi/L	740 ± 60	310 ± 40
Radium-226	pCi/L	NR	NR
Radium-228	pCi/L	NR	NR
Chromium	μg/L	10.0	10.0
Sulfate	mg/L	38.3	89.9

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TABLE A-32

CONCENTRATIONS OF URANIUM IN SURFACE WATER WITHIN OPERABLE UNIT 1

Sample Location	Concentration (mg/L)
RO-3	0.007
RO-4	28.0
RO-5	24.0
RO-6	4.0
RO-7	0.31
RO-8	34.0
RO-9	3.0
RO-12	0.34
RO-13	0.54
RO-14	0.48
RO-15	0.71
RO-16	0.62
RO-17	11.0

Source: Dames and Moore, 1985

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TABLE A-33

SUMMARY OF SURFACE WATER RADIOLOGICAL RESULTS, RI/FS DATA

Sample Location	Sample Date	Ra-226 (pCi/L)	Ra-228 (pCi/L)	Th-230 (pCi/L)	Tc-99 (pCi/L)	U-234 (pCi/L)	U-235/236 (pCi/L)	U-238 (pCi/L)	U-Total mg/L
ASIT-18	7/10/88	1.1 ± 0.1	1.2 ± 0.1	NA	NA	NA	NA	NA	135 ± 4
ASIT-19	7/10/88	1.1 ± 0.1	1.3 ± 0.1	NA	NA	NA	NA	NA	39 ± 3
ASIT-22	7/10/88	1.0 ± 0.1	1.1 ± 0.1	NA	NA	NA	NA	NA	15 ± 2
ASIT-18	2/21/89	< 1.00	< 3.00	< 1.00	< 30.0	54.7 ± 8.7	6.3 ± 1.6	227 ± 34	700 ± 112
ASIT-19	2/21/89	< 1.00	< 3.00	< 1.00	41.3 ± 18.5	65.9 ± 12.1	5.6 ± 1.9	345 ± 58	944 ± 156
ASIT-22	2/21/89	< 1.00	< 3.00	< 1.00	< 30.0	22.7 ± 2.9	1.5 ± 0.4	30.3 ± 3.8	92 ± 15
ASIT-23	2/21/89	< 1.00	< 3.00	< 1.00	34.9 ± 16.5	80.3 ± 12.7	4.9 ± 1.4	165 ± 25	465 ± 82
ASIT-24	2/21/89	< 1.00	< 3.00	< 1.00	< 30.0	86.4 ± 13.8	6.7 ± 1.8	205 ± 32	517 ± 83
ASIT-30	2/21/89	< 1.00	< 3.00	< 1.00	54.3 ± 19.7	514 ± 200	43.8 ± 12	2548 ± 586	7030 ± 1127
ASIT-31	2/21/89	< 1.00	< 3.1	< 1.00	175 ± 30	419 ± 69	41.5 ± 7.8	2378 ± 384	6853 ± 1144
ASIT-29	3/10/89	NA[a]	5.7 ± 2	NA	NA	NA	NA	NA	1228 ± 201
ASIT-38	3/29/89	NA	< 3.00	NA	NA	NA	NA	NA	3000 ± 500
ASIT-27	5/9/89	< 1.00	< 3.00	NA	NA	NA	NA	NA	8148 ± 1360
ASIT-28	5/9/89	< 1.00	< 3.00	NA	NA	NA	NA	NA	5067 ± 835
ASIT-38	5/9/89	< 1.00	3.60 ± 1.5	NA	NA	NA	NA	NA	7069 ± 1126

[a]NA - Not applicable; insufficient sample volume

TABLE A-34

SUMMARY OF FEMP ENVIRONMENTAL MONITORING PROGRAM SURFACE WATER SAMPLING RESULTS

	1992				1991				1990			
Sample Location	Number of Samples	Concentration (pCi/L) Min	Max	Avg	Number of Samples	Concentration (pCi/L) Min	Max	Avg	Number of Samples	Concentration (pCi/L) Min	Max	Avg
Total Uranium[a]												
W5	48	0.47	1.2	0.74	47	0.41	1.6	0.78	52	0.68	1.1	0.75
W9	50	0.68	6.8	2.0	40	0.47	5.3	1.5	51	0.88	2.8	1.5
W10	38	0.81	730	86	25	1.0	1100	3.4[b]	44	1.1	1100	76
W11	21	1.3	12	6.3	24	2.5	11	5.7	38	1.4	81	8.9
W7	21	2.2	11	6.4	22	2.3	9.5	5.0	36	2.6	53	6.5
W8	48	1.2	19	2.8	50	1.1	8.1	3.9	20	1.4	26	4.5
Radium-226												
W5	6	<2.2	<2.2	<2.2	6	<0.1	<0.1	<0.1	6	0.078	0.58	0.25
W7	4	<2.2	<2.2	<2.2	6	<0.1	0.1	<0.1	9	0.00061	0.49	0.15[b]
W8	8	<2.2	2.2	<2.2	6	<0.1	0.1	<0.1	3	0.034	<0.15	0.052
Radium-228												
W5	6	<2.2	2.2	<2.2	6	<0.1	0.1	<0.1	6	0.89	<2.0	<1.5
W7	4	<2.2	2.2	<2.2	6	<0.1	0.2	0.1	9	1.0	<2.0	<1.7
W8	8	<2.2	2.2	<2.2	6	<0.1	0.2	0.1	3	0.77	1.2	0.8

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TABLE A-34
(Continued)

Sample Location	1989 Number of Samples	1989 Concentration (pCi/L) Min	1989 Max	1989 Avg	1988 Number of Samples	1988 Concentration (pCi/L) Min	1988 Max	1988 Avg	1987 Number of Samples	1987 Concentration (pCi/L) Min	1987 Max	1987 Avg
Total Uranium[a]												
W5	50	0.47	2.4	0.86	50	0.34	1.4	0.78	52	0.47	3.6	1.0
W9	47	0.61	4.3	1.5	33	0.27	21	2.6	49	0.68	5.9	1.7
W10	31	1.6	640	70	24	1.4	812	39	32	1.1	88	6.8
W11	24	2.8	28	6.7	16	2.7	13	5.7	18	1.8	15	5.8
W7	28	2.3	36	6.4	50	2.9	1.6	7.0	20	1.5	16	5.8
W8	20	1.4	26	4.5	22	1.0	4.8	2.1	32	0.74	4.7	1.9
Radium-226												
W5	6	<0.001	<0.001	<0.001	6	<0.45	<0.45	<0.45	6	<0.5	<0.5	<0.5
W7	8	<0.001	<0.001	<0.001	5	<0.45	<0.45	<0.45	9	<0.5	<0.5	<0.5
W8	4	<0.001	<0.001	<0.001	6	<0.45	0.90	0.53	3	<0.5	<0.5	<0.5
Radium-228												
W5	6	<0.001	<0.001	<0.001	6	<0.45	0.90	0.60	6	<0.5	<0.9	<0.6
W7	8	<0.001	<0.001	<0.001	5	<0.45	0.90	0.54	9	<0.5	<0.5	<0.5
W8	4	<0.001	<0.001	<0.001	6	<0.45	<0.45	<0.23	3	<0.5	<0.5	<0.5

[a]Units are reported as pCi/L in source text. To convert to μg/l multiply by 1.493.
[b]Results are reported for distribution median due to single outliner.

TABLE A-35

RADIOISOTOPES IN PADDYS RUN CREEK SEDIMENTS
FEMP ENVIRONMENTAL MONITORING PROGRAM

Paddys Run Creek North of the Storm Sewer Outfall Ditch
All Values in pCi/g (dry weight)

	Statistic	Pu--238	Pu--239/240	Ra--224	Ra--226	Ra--228	Tc--99	Th--228	Th--230	Th--232	U--234	U--235/236	U--238	U--Total
1992	Measurements	--[a]	--	--	12	--	--	12	12	12	--	--	--	12
	Minimum	--	--	--	0.32	--	--	0.30	0.27	0.21	--	--	--	0.95
	Maximum	--	--	--	2.30	--	--	1.0	2.0	1.1	--	--	--	4.1
	Average	--	--	--	0.78	--	--	0.67	0.98	0.58	--	--	--	2.3
1991	Measurements	--	--	--	12	--	--	10	10	10	--	--	--	12
	Minimum	--	--	--	0.40	--	--	0.34	0.46	0.34	--	--	--	0.61
	Maximum	--	--	--	0.90	--	--	1.0	1.2	1.0	--	--	--	3.7
	Average	--	--	--	0.63	--	--	0.66	0.73	0.66	--	--	--	1.4
1990	Measurements	70	70	70	70	70	70	70	70	70	70	70	70	--
	Minimum	<0.021	<0.014	0.26	<0.25	<0.18	<0.53	0.28	0.27	0.19	0.41	<0.075	<0.46	--
	Maximum	0.22	0.28	2.3	3.7	2.0	1.2	5.1	9.8	5.4	10	<2.6	8.7	--
	Average	<0.059	<0.060	0.57	0.89	0.54	0.71	1.3	1.1	0.75	0.86	<0.72	1.4	--
1989	Measurements	74	74	74	74	74	74	74	74	74	74	74	74	--
	Minimum	<0.012	<0.012	0.21	<0.21	<0.17	<0.90	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	--
	Maximum	0.46	0.056	0.82	1.1	0.73	<0.90	4.3	2.6	2.1	2.2	<1.0	6.6	--
	Average	<0.024	<0.016	0.44	0.63	0.43	<0.90	<1.1	<1.1	<1.0	<1.1	<1.0	<1.2	--
1988	Measurements	24	24	24	24	24	24	24	24	24	24	24	24	--
	Minimum	<0.002	<0.002	0.26	0.14	0.19	<1.0	0.17	0.32	0.17	0.04	<0.01	0.24	--
	Maximum	<0.003	<0.003	0.80	1.4	1.1	<1.0	0.66	2.5	0.87	1.3	0.10	1.5	--
	Average	<0.003	<0.003	0.45	0.65	0.41	<1.0	0.36	0.63	0.35	0.53	<0.05	0.62	--
1987	Measurements	24	24	24	24	24	24	24	24	24	24	24	24	--
	Minimum	<0.02	<0.02	<0.0792	<0.217	<0.154	<1.0	0.18	0.34	0.17	0.24	<0.02	0.2	--
	Maximum	<0.04	<0.03	<0.511	<1.55	<0.523	<1.3	0.74	1.1	0.54	0.69	<0.14	0.82	--
	Average	<0.02	<0.02	<0.213	<0.573	<0.322	<1.1	0.35	0.63	0.33	0.41	<0.051	0.43	--

TABLE A-35
(Continued)

Paddy's Run South of the Storm Sewer Outfall Ditch
All Values in pCi/g (dry weight)

	Statistic	Pu--238	Pu--239/240	Ra--224	Ra--226	Ra--228	Tc--99	Th--228	Th--230	Th--232	U--234	U--235/236	U--238	U--Total
1992	Measurements	--[a]	--	--	--	--	--	--	--	--	--	--	--	12
	Minimum	--	--	--	--	--	--	--	--	--	--	--	--	0.55
	Maximum	--	--	--	--	--	--	--	--	--	--	--	--	3.8
	Average	--	--	--	--	--	--	--	--	--	--	--	--	2.0
1991	Measurements	--	--	--	--	--	--	--	--	--	--	--	--	12
	Minimum	--	--	--	--	--	--	--	--	--	--	--	--	0.61
	Maximum	--	--	--	--	--	--	--	--	--	--	--	--	2.5
	Average	--	--	--	--	--	--	--	--	--	--	--	--	1.2
1990	Measurements	54	54	54	54	54	54	54	54	54	54	54	54	--
	Minimum	<0.019	<0.019	0.237	0.44	0.25	<0.58	0.27	0.21	0.13	0.49	<0.067	0.41	--
	Maximum	0.090	<0.12	1.1	1.2	0.95	<0.97	1.3	1.8	1.1	29	3.4	30	--
	Average	<0.047	<0.044	0.51	0.70	0.46	<0.77	0.58	0.84	0.44	0.83	<0.26	0.81	--
1989	Measurements	53	53	53	53	53	53	53	53	53	53	53	53	--
	Minimum	<0.012	<0.012	<0.032	<0.038	<0.15	<0.90	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	--
	Maximum	0.032	0.097	0.92	1.3	1.0	0.96	6.6	11	1.3	3.6	<1.0	3.9	--
	Average	<0.015	<0.016	0.41	0.50	0.42	<0.90	<1.2	<1.3	<1.0	<1.1	<1.0	<1.1	--
1988	Measurements	18	18	18	18	18	18	18	18	18	18	18	18	--
	Minimum	<0.01	<0.01	0.19	0.42	0.23	<0.90	0.10	0.21	0.07	0.06	<0.05	0.32	--
	Maximum	<0.05	<0.05	0.90	2.1	0.85	<0.90	0.74	4.8	1.0	2.8	0.23	3.1	--
	Average	<0.01	<0.01	0.44	0.69	0.41	<0.90	0.34	0.67	0.32	0.68	0.06	0.77	--
1987	Measurements	18	18	18	18	18	18	18	18	18	18	18	18	--
	Minimum	<0.02	<0.02	<.10	<0.25	<0.11	<1.1	0.13	0.44	0.16	0.34	0.02	0.04	--
	Maximum	<0.04	<0.02	<0.403	<0.817	<0.486	<1.3	0.45	0.9	0.43	0.59	0.08	0.59	--
	Average	<0.02	<0.02	<0.23	<0.56	<0.28	<1.2	0.32	0.64	0.31	0.45	0.05	0.22	--

[a]Analyte not analyzed.

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TABLE A-36

SUMMARY OF SEDIMENT RADIOLOGICAL RESULTS - CIS
(pCi/g)

Sample ID	Technetium-99	Uranium-234	Thorium-228	Uranium-235	Thorium-230	Uranium-238
SD-21-017	U	2.3	0.1	0.2	0.4	8.6
SD-21-019	U	1.7	0.3	0.1	0.2	6.3
SD-26-001	U	11.0	0.4	0.9	1.3	46.0
SD-26-005	U	3.6	0.3	0.2	1.9	12.0
SD-26-007	U	3.3	0.1	0.2	0.9	12.0
SD-28-002	8.6	19.0	0.3	2.4	0.9	111.0
SD-28-007	10.0	121.0	1.7	12.0	9.0	728.0
SD-28-008	13.0	133.0	0.2	26.0	0.1	761.0
SD-28-010	17.0	62.0	2.6	14.0	7.6	338.0
SD-28-011	16.0	85.0	0.2	18.0	0.9	446.0
SD-36-001	8.6	89.0	1.0	27.0	4.0	480.0
SD-36-002	7.0	131.0	1.1	29.0	5.1	746.0
SD-36-003	8.3	71.0	0.2	9.4	0.5	369.0
SD-36-004	17.0	126.0	1.3	33.0	6.1	696.0
SD-36-006	9.3	126.0	0.7	33.0	4.4	696.0

U = Undetected

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TABLE A-37

SURFACE SOIL CIS RADIOLOGICAL DATA

Sample ID #		SS-46-037	SS-46-045	SS-46-059	SS-46-112	SS-46-136	SS-46-407
N Coordinate		481811.14	481758.43	481565.34	481183.28	481180.54	482006.80
E Coordinate		1379252.93	1379351.52	1379096.15	1378435.44	1378535.41	1379414.34
Parameters	Unit						
Cs-137	pCi/g	0.4	U	0.4	1.6	U	U
Np-237	pCi/g	U[a]	U	U	U	U	U
Pu-238	pCi/g	U	U	U	U	0.6	U
Pu-239/240	pCi/g	U	U	U	U	0.3	U
Ru-106	pCi/g	U	U	U	U	U	U
Sr-90	pCi/g	U	U	U	U	U	U
Tc-99	pCi/g	U	U	U	2.6	6.5	14
Th-228	pCi/g	0.8	0.7	2.4	3.1	7.4	0.2
Th-230	pCi/g	U	1.6	11	74	61	1.1
Th-232	pCi/g	0.8	0.6	1.4	3	5.5	0.3
U-234	pCi/g	28	4.6	55	88	67	130
U-235	pCi/g	2.1	0.4	5.7	6.5	3.9	16
U-238	pCi/g	157	23	280	210	155	710

TABLE A-37
(Continued)

Sample ID		SS-46-427	SS-46-428	SS-46-430	SS-46-432	SS-46-434	SS-46-435
N Coordinate		481724.87	481632.95	481775.21	481841.09	481800.54	481761.85
E Coordinate		1379188.54	1379148.01	1379176.92	1379291.76	1379183.61	1379226.57
Parameters	Unit						
Cs-137	pCi/g	U	2.5	1.5	U	U	0.8
Np-237	pCi/g	U	U	U	U	U	U
Pu-238	pCi/g	0.1	U	U	U	U	0.2
Pu-239/240	pCi/g	0.4	U	U	U	U	0.2
Ru-106	pCi/g	U	U	U	U	U	U
Sr-90	pCi/g	U	U	U	U	U	U
Tc-99	pCi/g	6	U	U	U	U	5.5
Th-228	pCi/g	2.8	2.5	1.3	0.1	0.7	4.8
Th-230	pCi/g	13	24	5.4	0.3	146	18
Th-232	pCi/g	1.6	1.7	1	0.1	0.8	2.3
U-234	pCi/g	127	33	54	57	14	109
U-235	pCi/g	11	2.9	4.2	51	0.6	10
U-238	pCi/g	738	154	287	342	15	639

TABLE A-37
(Continued)

Sample ID		SS-46-444	SS-46-446	SS-46-452	SS-46-456	SS-46-457	SS-46-474
N Coordinate		482008.66	482016.21	481461.26	481456.13	481844.86	481692.20
E Coordinate		1379127.29	1379070.47	1378805.19	1378737.02	1379409.91	1379212.66
Parameters	Unit						
Cs-137	pCi/g	U	U	U	1.8	1.2	U
Np-237	pCi/g	U	U	U	U	U	U
Pu-238	pCi/g	U	U	U	U	U	U
Pu-239/240	pCi/g	U	U	U	U	U	U
Ru-106	pCi/g	U	U	U	U	U	U
Sr-90	pCi/g	U	U	U	U	U	U
Tc-99	pCi/g	U	U	U	U	U	33
Th-228	pCi/g	U	1.4	1.4	U	0.4	0.2
Th-230	pCi/g	0.1	13	25	0.9	0.5	1.4
Th-232	pCi/g	U	1.7	2.1	U	U	0.2
U-234	pCi/g	47	21	22	11	20	43
U-235	pCi/g	5.2	1.6	0.7	0.5	1.8	3.4
U-238	pCi/g	238	95	25	27	113	293

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TABLE A-37
(Continued)

Sample ID		SS-46-478	SS-46-488	SS-46-495	SS-46-500	SS-46-504	SS-46-623
N Coordinate		481355.63	481377.40	481373.98	481306.87	481657.77	482031.59
E Coordinate		1378717.27	1378652.84	1378777.79	1378707.93	1379154.70	1378983.86
Parameters	Unit						
Cs-137	pCi/g	0.7	1.4	U	U	U	6
Np-237	pCi/g	U	U	U	U	U	0.5
Pu-238	pCi/g	U	U	U	U	U	0.7
Pu-239/240	pCi/g	U	U	U	U	U	0.6
Ru-106	pCi/g	U	U	U	U	U	U
Sr-90	pCi/g	U	U	U	U	U	1.5
Tc-99	pCi/g	5.6	U	7ñ	U	7.9	58
Th-228	pCi/g	U	5.4	7.8	0.3	U	48
Th-230	pCi/g	0.1	32	32	4	0.1	972
Th-232	pCi/g	U	3	2.4	0.2	U	31
U-234	pCi/g	73	18	123	12	241	155
U-235	pCi/g	5.8	1	10	0.6	25	11
U-238	pCi/g	406	60	753	28	1500	157

[a]Analyte undetected

TABLE A-38

SURFACE SOIL RI/FS RADIOLOGICAL DATA

Sample ID #		007800	007879	033063	033043	033156	005125	005126	005420	005629	005632	005635	005638	005674
Boring No.		1025	1083	1645	1646	2643								
Parameter	Unit[c]													
Cs-137	pCi/g	U[a]	U	*[b]	U	U	U	U	U	U	U	U	U	U
Np-237	pCi/g	U	U	*	*	U	U	U	U	U	U	U	U	U
Pu-238	pCi/g	U	U	*	*	U	U	U	U	U	U	U	U	U
Pu-239/240	pCi/g	U	U	*	*	U	U	U	U	U	U	U	U	U
Ra-226	pCi/g	2.1	U	1.33	2.24	0.89	U	U	0.8	0.7	0.8	0.9	1	1.2
Ra-228	pCi/g	4.7	U	0.73	2.81	0.71	U	U	0.5	0.9	1	1.1	1.3	1.8
Ru-106	pCi/g	U	U	U	U	U	U	U	U	U	U	U	U	U
Sr-90	pCi/g	U	U	*	*	U	0.6	0.5	U	U	U	U	0.9	U
Tc-99	pCi/g	U	*	0.9	0.9	U	U	U	U	U	U	0.9	U	U
Th-228	pCi/g	4.1	0.7	*	*	1.93	0.9	0.9	0.8	1	0.9	1.7	1.4	2.2
Th-230	pCi/g	1.7	1.6	*	*	1.89	2.1	2	1.5	2.7	1.8	6.1	4.2	2.9
Th-232	pCi/g	1.6	0.6	*	*	0.64	0.7	0.8	0.6	0.9	0.9	1.1	1.4	1.3
Th-Total	ug/g	*	*	*	*	5.8	*	*	*	*	*	*	*	*
U-234	pCi/g	2.3	6.2	15.7	28.5	24.6	2.9	2.6	1	5.3	2.9	3.9	2.4	3.7
U-235/236	pCi/g	U	0.9	1.71	3.91	1.97	U	U	U	0.8	U	U	U	U
U-238	pCi/g	8.3	32	73.4	103.7	76.2	5.2	4.2	1.5	9.7	3.9	16.1	8	12.5
U-Total	μg/g	*	*	238.7	413.5	237.8	*	*	3	29	21	62	30	41

[a]Analyte undetected
[b]Analyte not analyzed
[c]μg = micrograms
pCi/g = picoCuries/gram

TABLE A-39

SURFACE SOIL WPA INORGANIC DATA

Sample ID #		WPA2	WPA3	WPA4	WPA5	WPA6	WPA7	WPA8	WPA9
Lab ID #		61009	61016	61023	61030	61037	61044	61050	61058
Parameters	Unit								
Aluminum	mg/kg	2660	4320	7470	9410	2580	5300	7100	5800
Antimony	mg/kg	22.6	30.8	27.8	21.3	22.7	29.5	19.6	28
Arsenic	mg/kg	4.1	4.7	6.4	4.2	4.2	4.5	3.9	3.9
Barium	mg/kg	31.4	42.6	52.5	64.7	27.2	49.9	52.9	51.9
Beryllium	mg/kg	0.62	0.67	0.75	0.69	0.58	0.76	0.63	0.72
Cadmium	mg/kg	5	7.7	5.7	3.4	4.6	5.9	3.3	5.7
Iron	mg/kg	6670	13200	17800	18900	7180	13100	14900	14000
Magnesium	mg/kg	21200	38900	21900	8650	19900	25800	12000	24800
Mercury	mg/kg	U[a]	U	U	U	U	U	U	U
Manganese	mg/kg	423	317	438	655	426	638	512	556
Zinc	mg/kg	21.9	35.3	42.5	46.7	28.9	32.2	38.6	40.9
Vanadium	mg/kg	11.2	16.4	22.2	23.8	10.9	15.4	18.9	18.9
Thallium	mg/kg	U	U	0.68	U	U	U	U	U
Sodium	mg/kg	137	134	109	92.5	135	165	83.6	161
Silver	mg/kg	7.8	9.4	10.3	7.2	7.6	6.7	7.3	10.3
Selenium	mg/kg	U	U	U	U	U	U	U	U
Potassium	mg/kg	434	880	1210	1060	448	849	1120	951
Nickel	mg/kg	24.8	28.4	27.8	27.9	19.7	26.8	20.3	31.9
Molybdenum	mg/kg	3.7	5.7	4.6	3	3.9	4.1	U	4.4
Lead	mg/kg	34.3	7.9	10.5	12.1	8.4	13.5	12.1	7.9
Calcium	mg/kg	137000	124000	99100	26400	143000	155000	35000	101000
Chromium	mg/kg	7.8	11.3	16.3	17	6.1	7.4	14.4	14.4
Cobalt	mg/kg	6.6	9.6	10.9	11.1	7	9	8.2	10.6
Copper	mg/kg	12.1	15.7	18.3	14.6	11.4	18.5	14.5	14.8
Cyanide	mg/kg	U	U	U	U	U	U	U	U

TABLE A-39
(Continued)

Sample ID		WPA10	WPA11	WPA12	WPA13	WPA14	WPA16	WPA17	WPA38	WPA43
Lab ID		61065	61072	61079	61086	61093	61107	61114	61260	61295
Parameters	Unit									
Aluminum	mg/kg	2880	5330	4170	5240	11700	13500	5340	5410	8820
Antimony	mg/kg	25.1	20.3	22.6	32.5	25.5	32.8	28.3	26.4	25.2
Arsenic	mg/kg	2.8	3.5	3.8	4.3	5.3	11.2	5.4	4.6	5.8
Barium	mg/kg	22.5	48.2	34	37.5	92.3	123	47.9	56.3	73.8
Beryllium	mg/kg	0.63	0.62	0.65	0.73	0.79	0.97	0.64	1	0.8
Cadmium	mg/kg	5.5	4	5.3	7.5	3.2	4.7	5.6	6.6	4.3
Iron	mg/kg	8200	15700	9610	12800	23800	24500	13500	7160	17800
Magnesium	mg/kg	25500	12500	24300	39000	6370	13700	24200	32900	14900
Mercury	mg/kg	U	U	U	0.11	U	U	U	U	U
Manganese	mg/kg	445	707	391	329	759	841	391	694	519
Zinc	mg/kg	23.6	27.7	59.2	79.9	47.8	64.6	37.9	28	51.3
Vanadium	mg/kg	11.8	18	13.9	17.5	26.9	33	18.1	13.5	22.9
Thallium	mg/kg	U	U	U	U	U	U	U	U	U
Sodium	mg/kg	140	U	U	122	54.6	108	111	185	91.7
Silver	mg/kg	6.7	9.4	7.6	8.7	5.8	8.7	9.2	9.3	9.4
Selenium	mg/kg	U	U	U	0.44	U	U	U	0.62	U
Potassium	mg/kg	586	686	692	813	797	1300	674	763	1120
Nickel	mg/kg	19.7	20.8	22.4	26.7	23.1	38.5	25.1	50.2	23.9
Molybdenum	mg/kg	3.9	3.3	4.1	4.7	3.5	4.8	4.6	4.4	3.6
Lead	mg/kg	6.8	7.8	12	7.9	12.6	16.5	8	20.4	21.6
Calcium	mg/kg	152000	73900	130000	123000	21000	41600	85300	104000	59600
Chromium	mg/kg	5.9	13.3	8.8	11.9	18.8	24.5	14.9	12.4	17.9
Cobalt	mg/kg	7.3	8.5	7.4	9	17	15.7	9.4	6.5	9.9
Copper	mg/kg	13.3	13.8	15.4	19.7	17.8	25.9	17.4	16.7	20.1
Cyanide	mg/kg	U	U	0.37	0.6	U	U	U	0.71	0.5

[a]Undetected

TABLE A-40

SURFACE SOIL WPA ORGANIC DATA

Sample ID #		WPA2	WPA4	WPA7	WPA38	WPA43
Lab ID #		61009	61023	61044	61260	61295
Parameters	Unit[b]					
4,4-DDD	µg/kg	U[a]	U	U	U	U
4,4-DDE	µg/kg	18	U	U	U	U
4,4-DDT	µg/kg	U	U	U	U	U
Aldrin	µg/kg	U	U	U	U	U
Aroclor-1016	µg/kg	U	U	U	U	U
Aroclor-1221	µg/kg	U	U	U	U	U
Aroclor-1232	µg/kg	U	U	U	U	U
Aroclor-1242	µg/kg	U	U	U	U	U
Aroclor-1248	µg/kg	U	U	U	U	U
Aroclor-1254	µg/kg	U	U	64	1400	53
Aroclor-1260	µg/kg	U	200	U	U	U
Dieldrin	µg/kg	18	U	U	U	U
Endosulfan II	µg/kg	18	U	U	U	U
Endosulfan sulfate	µg/kg	U	U	U	U	U
Endosulfan-I	µg/kg	U	U	U	U	U
Endrin	µg/kg	U	U	U	U	U
Endrin ketone	µg/kg	U	U	U	U	U
Heptachlor	µg/kg	U	U	U	U	U
Heptachlor epoxide	µg/kg	U	U	U	U	U
Methoxychlor	µg/kg	U	U	U	U	U
Toxaphene	µg/kg	U	U	U	U	U
alpha-BHC	µg/kg	U	U	U	U	U
alpha-Chlordane	µg/kg	U	U	U	U	U
beta-BHC	µg/kg	U	U	U	U	U
delta-BHC	µg/kg	U	U	U	U	U
gamma-BHC (Lindane)	µg/kg	U	U	U	U	U
gamma-Chlordane	µg/kg	U	U	U	U	U

[a]Undetected
[b]µg = micrograms

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TABLE A-41

RI/FS SUBSURFACE SOIL
RESULTS ABOVE RADIOLOGICAL BACKGROUND CONCENTRATION
(pCi/g)

Depth (feet)	Zone	Boring No.	Sample No.	Ra-226	Ra-228	Sr-90	Tc-99	Th-228	Th-230	Th-232	U-234	U-235/236	U-238
3.0	1	1078	007676	-[a]	-	-	-	2.3	3	1.8	97.2	6.1	320.2
3.0	1	1079	007370	-	-	-	-	-	2.3	-	4.4	-	8.9
3.0	1	1644	033092	32.6	12.3	0.784	1.07	4.11	44.6	4.21	4712	278	4682
3.0	1	1944	033025	-	-	0.715	-	-	-	-	158	7.66	178
4.5	1	1028	007819	1.4	1.8	-	-	1.7	2.8	1.5	13.6	2.9	89.4
4.5	1	1643	033221	2.12	1.97	-	-	-	6.46	-	90.1	9.14	128.7
6.0	1	1082	007660	-	-	0.9	-	-	-	-	4.4	0.8	22.5
6.0	1	1943	033009	-	-	1.13	-	1.76	2.59	-	14.9	-	36.7
13.5	1	1073	008487	19.7	18.6	-	6.1	22.9	710	33.1	112	4.7	125
15.0	1	1074	008472	-	-	-	-	-	-	-	-	-	-
15.0	1	2649	033203	-	-	-	-	-	-	-	2.52	-	6.77
16.5	1	1031	008843	-	-	-	1.9	-	4.7	-	6.9	0.8	28
16.5	1	2027	007851	-	-	-	-	-	-	-	-	-	-
18.0	1	1076	008159	1210	160	-	-	-	2.4	-	-	-	-
19.5	1	1080	008792	-	-	-	0.9	-	-	-	-	-	-
19.5	1	3004	007922	-	-	-	-	-	-	-	-	-	-
22.5	1	3084	007526	-	-	-	-	-	-	-	-	-	-
22.5	1	1973	008142	1180	165	8.9	-	581	24.1	761	429	144	1404
24.0	1	1075	008573	-	-	-	-	-	-	-	-	-	-
33.0	1	1081	007655	-	-	-	-	-	-	-	-	-	-
34.5	1	2648	033140	-	-	-	-	-	-	-	1.13	-	-
36.0	1	2643	033179	-	-	-	-	-	-	-	2.21	-	2.12
37.5	1	2648	033142	-	-	-	-	-	-	-	1.64	-	-
37.5	1	3011	007589	-	-	-	-	-	-	-	-	-	-
39.0	2	2028	032684	-	-	0.979	-	-	-	-	-	-	-
27.0	1	2649	033211	-	-	-	-	-	-	-	-	-	-

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TABLE A-41
(Continued)

Depth (feet)	Zone	Boring No.	Sample No.	Ra-226	Ra-228	Sr-90	Tc-99	Th-228	Th-230	Th-232	U-234	U-235/236	U-238
35.0	1	3004	007932	9.5	-	6.9	-	-	-	-	4.1	-	3.8
61.5	2	3084	007546	-	-	-	-	-	3.1	-	-	-	-
66.5	2	2027	007874	-	-	-	-	-	-	-	-	-	-
66.5	2	2028	032700	-	-	1.03	-	-	-	-	1.24	-	-
66.5	2	3011	007595	-	-	-	-	-	-	-	-	-	-
76.5	2	2027	007876	-	-	-	-	-	-	-	-	-	-
116.5	3	3004	008179	-	-	-	-	-	-	-	-	-	-
121.5	3	3084	007558	-	-	-	-	-	-	-	-	-	-
181.5	4	4011	032899	-	-	-	-	-	-	-	-	-	-

[a]Concentrations below background.

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TABLE A-42

SUMMARY OF RADON FLUX MEASUREMENTS

($pCi/m^2/SEC^{-1}$)

Pit Area in m^2	Waste Pit 1 (7430)	Waste Pit 2 (4460)	Waste Pit 3 (22,300)	Waste Pit 4 (7990)
Number of Samples	99	98	199	27[a]
Arithmetic Mean	9.1	6.4	2.6	<0.1
Standard Deviation	13.4	13.4	6.2	<0.1
Standard Error	1.4	1.4	0.6	<0.1
Minimum	0.6	0.2	0.3	<0.1
Maximum	75.2	81.0	48.0	<0.1
99% Confidence Interval of the Mean	5.6 - 12.7	2.9 - 9.9	1.0 - 4.2	<0.1

[a]Includes two duplicate samples.

TABLE A-43

INDIANA CONTROL AREA RADIONUCLIDE CONCENTRATIONS IN GARDEN PRODUCE, AGRICULTURAL CROPS, AND SOIL SAMPLES[a]

		Radionuclide Type and Concentration (pCi/g Dry Weight)					
Sample	Location	Cs-137	Sr-90	U-234	U-235, -236	U-238	Sum of U Activity
Soil (field)	I1	0.3	<0.5[b]	1.1	<0.6	1.0	2.1
Alfalfa	I1	<0.5	0.5	2.4	0.6	1.1	4.1
Field Corn	I1	0.3	<0.5	1.1	<0.6	1.0	2.1
Soil (garden)	I1	0.3	<0.5	1.4	<0.6	1.2	2.6
Okra	I1	<0.4	<0.5	<0.6	<0.6	<0.6	--[c]
Tomato	I1	<0.2	<0.5	2.5	<0.6	0.8	3.3
Green pepper	I1	<0.3	<0.5	<0.6	<0.6	<0.6	--
Potato (flesh)	I1	<0.2	<0.5	<0.6	<0.6	<0.6	--
Potato (peel)	I1	<0.2	<0.5	<0.6	<0.6	<0.6	--
Soil	I2	0.2	<0.5	2.4	<0.6	3.2	5.6
Tomato	I2	<0.2	<0.5	0.8	<0.6	<0.6	0.8
Tomato	I2	<0.4	<0.5	<0.6	<0.6	<0.6	--
Green pepper	I2	<0.3	<0.5	<0.6	<0.6	<0.6	--
Potato (flesh)	I2	<0.2	<0.5	<0.6	<0.6	<0.6	--
Potato (peel)	I2	<0.3	<0.5	2.7	<1.4	<1.4	2.7
Soil	I3	0.3	1.2	1.0	<0.6	1.3	2.3
Soybean	I3	<0.2	<0.5	<0.6	<0.6	<0.6	--
Soybean	I3	<0.2	<0.5	<0.6	<0.6	<0.6	--
Soybean (husk)	I3	<0.2	0.6	0.7	<0.6	<0.6	0.7
Field corn	I3	<0.2	<0.5	<0.6	<0.6	<0.6	--

[a]Source: "Biological Sampling Analysis and Resources Report, Final," ASI/IT 1990.
[b]< = Less than stated detection limit.
[c]-- = No uranium isotopes detected.

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TABLE A-44

RADIONUCLIDE CONCENTRATIONS IN GARDEN PRODUCE FROM ROADSIDE STAND IN THE FEMP VICINITY[a]

		Radionuclide Type and Concentration ([pCi/g] Dry Weight)					
Sample	Site	Cs-137	Sr-90	U-234	U-235, 236	U-238	Sum of U Activity
Sweet corn	Roadside Stand	<0.2[b]	<0.5	<0.6	<0.6	<0.6	--[c]
Sweet corn	Roadside Stand	<0.2	<0.5	<0.6	<0.6	<0.6	--
Tomato	Roadside Stand	<0.5	<0.5	1.9	<0.6	0.7	2.6
Cantaloupe	Roadside Stand	<0.2	<0.5	<0.6	<0.6	<0.6	--

[a]Source: "Biological Sampling Analysis and Resources Report, Final," ASI/IT 1990.
[b]< = Less than stated detection limit.
[c]-- = No uranium isotopes detected.

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TABLE A-45

RADIONUCLIDE CONCENTRATIONS IN FEMP VICINITY GARDEN PRODUCE, AGRICULTURAL CROPS, AND SOIL SAMPLES[a]

		Radionuclide Type and Concentration (pCi/g Dry Weight)					
Sample	Site[b]	Cs-137	Sr-90	U-234	U-235, -236	U-238	Sum of U Activity
Soil	G1	0.2	<0.5[c]	1.7	<0.6	1.6	3.3
Green pepper	G1	<0.2	<0.5	<0.6	<0.6	<0.6	--[d]
Okra	G1	<0.3	<0.5	<0.6	<0.6	<0.6	--
Tomato	G1	<0.3	<0.5	<0.6	<0.6	<0.6	--
Cucumber	G1	<1.1	<0.6	3.0	<0.6	1.8	4.8
Squash	G1	<0.3	<0.5	<0.6	<0.6	<0.6	--
Soil	G2	0.3	0.8	1.3	<0.6	1.5	2.8
Cabbage	G2	<0.2	<0.5	<0.6	<0.6	<0.6	--
Green pepper	G2	<0.2	<0.5	<0.6	<0.6	<0.6	--
Okra	G2	<0.2	<0.5	<0.6	<0.6	<0.6	--
Potato (peel)	G2	<0.2	<0.5	<0.6	<0.6	<0.6	--
Potato (flesh)	G2	<0.2	<0.5	<0.6	<0.6	<0.6	--
Sweet potato	G2	<0.2	<0.5	<0.6	<0.6	<0.6	--
Tomato	G2	<0.2	<0.5	<0.6	<0.6	<0.6	--
Soil	G3	0.3	0.7	0.8	<0.6	<0.6	0.8
Tomato	G3	<0.3	<0.5	0.8	<0.6	<0.6	0.8
Okra	G3	<0.5	<0.5	1.4	<0.6	0.8	2.2
Green pepper	G3	<0.2	<0.5	1.0	<0.6	<0.6	1.0
Soil	G4	0.2	<0.5	2.5	<0.6	2.1	4.6
Alfalfa	G4	<0.4	<0.5	1.2	<0.6	<0.6	1.2
Soil (garden)	G5	<0.2	<0.5	1.3	<0.6	1.3	2.6
Soil (field)	G5	<0.2	2.7	1.3	<0.6	1.7	3.0
Tomato	G5	<0.3	<0.5	<0.6	<0.6	<0.6	--
Field corn	G5	<0.2	<0.5	<0.6	<0.6	<0.6	--
Field corn	G5	<0.2	<0.5	<0.6	<0.6	<0.6	--
Soil (soybean field)	G6	<0.2	<0.5	3.1	<0.6	2.8	5.9
Soybeans	G6	<0.2	<0.5	<0.6	<0.6	<0.6	--

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TABLE A-45
(Continued)

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Sample	Site[b]	Radionuclide Type and Concentration (pCi/g Dry Weight)					
		Cs-137	Sr-90	U-234	U-235, -236	U-238	Sum of U Activity
Soil (pumpkin field)	G6	0.3	1.3	3.7	<0.6	2.9	6.6
Pumpkin	G6	<0.3	<0.5	1.5	<0.6	<0.6	1.5
Pumpkin	G6	<0.4	<0.5	0.9	<0.6	0.8	1.7

[a]Source: "Biological Sampling Analysis and Resources Report, Final," ASI/IT 1990.
[b]See RI Figure 4-42.
[c]< = Less than stated detection limit.
[d]– = No uranium isotopes detected.

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TABLE A-46

TOTAL URANIUM CONCENTRATION RATIOS IN GARDEN PRODUCE AND AGRICULTURAL CROPS FOR SELECTED SITES IN THE FEMP VICINITY[a]

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Sample	Site[b]	Concentration Ratio[c]
Control Sites		
Field alfalfa	I1	1.95
Field corn	I1	1.00
Garden okra	I1	--[d]
Garden tomato	I1	1.27
Garden green pepper	I1	--
Garden potato (flesh)	I1	--
Garden potato (peel)	I1	--
Garden tomato	I2	0.14
Garden tomato	I2	--
Garden green pepper	I2	--
Garden potato (flesh)	I2	--
Garden potato (peel)	I2	0.48
Soybean	I3	--
Soybean	I3	--
Soybean (husk)	I3	0.30
Field corn	I3	--
FEMP Vicinity Sites		
Green pepper	G1	--
Okra	G1	--
Tomato	G1	--
Cucumber	G1	1.46
Squash	G1	--
Cabbage	G2	--
Green pepper	G2	--
Okra	G2	--
Potato peel	G2	--
Potato flesh	G2	--
Sweet potato	G2	--
Tomato	G2	--
Tomato	G3	1.00
Okra	G3	2.75
Green pepper	G3	1.25
Alfalfa	G4	0.26
Tomato	G5	--

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TABLE A-46
(Continued)

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Sample	Site[b]	Concentration Ratio[c]
Field corn	G5	--
Field corn	G5	--
Soybeans	G6	--
Pumpkin	G6	0.23
Pumpkin	G6	0.26

[a]Source: "Biological Sampling Analysis and Resources Report, Final," ASI/IT 1990.
[b]See RI Figure 4-42.
[c]Concentration ratios are calculated as CR = (radionuclide activity per weight of plant)/(radionuclide activity per weight of soil).
[d]-- = Radionuclide concentration below detectable limits; therefore, concentration ratio not calculated.

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TABLE A-47

RADIONUCLIDE CONCENTRATIONS IN WETLAND PLANTS AND SO[illegible] NEAR OPERABLE UNIT 1 ON THE FEMP[a]

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Sample	Site[b]	Radionuclide Type and Concentrations (pCi/g Dry Weight)							
		Cs-137	Sr-90	Tc-99	U-234	U-235,U-236	U-238	Total Isotopic Uranium[c]	Concentration Ratio[d]
Algae[e]	PR-1	<0.2[f]	0.9	<0.9	<0.6	<0.6	<0.6	[g]	[g]
Algae[e]	PR-2A	<0.2	<0.5	<0.9	<0.6	<0.6	<0.6	[g]	[g]
Soil	9A	<0.2	<0.6	[h]	3.9	<0.6	12.4	16.3	[i]
Cattail leaf	9A	<0.3	<0.5	[h]	<0.6	<0.6	<0.6	[g]	[g]
Cattail leaf	9A	<0.2	<0.5	[h]	0.7	<0.6	0.7	1.4	0.09
Cattail root	9A	<0.3	<0.5	[h]	2.6	<0.6	3.8	6.4	0.39
Grass blade	9A	<0.3	<0.6	[h]	<0.6	<0.6	<0.6	[g]	[g]
Grass root	9A	<0.2	<0.5	[h]	7.7	1.3	22.3	31.3	1.92
Grass blades[e]	9A	<0.2	<0.5	1.9	<0.6	<0.6	<0.6	[g]	[g]
Grass roots[e]	9A	<0.2	<0.5	<0.9	0.9	<0.6	4.2	5.1	0.31
Cattail leaf	9B	<0.2	<0.5	[h]	1.4	<0.6	1.9	3.3	0.20
Cattail root	9B	<0.2	<0.5	[h]	<0.6	<0.6	<0.6	[g]	[g]

[a]Source: "Biological Sampling Analysis and Resources Report, Final," ASI/IT 1990.
[b]See RI Figure 4-41.
[c]Total uranium in milligrams per kilogram (ppm).
[d]Concentration ration is determined for total isotopic uranium and is calculated, where possible, as CR= (radionuclide activity per weight of plant)/(radionuclide activity per weight of soil).
[e]1988 sample.
[f]< - Less than stated detection limit.
[g]No uranium isotopes detected.
[h]Technetium-99 analyzed for 1988 samples only.
[i]Not applicable.

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TABLE A-48

CONCENTRATIONS OF RADIOLOGICAL CONSTITUENTS IN SOIL AND TERRESTRIAL VEGETATION NEAR OPERABLE UNIT 1[a]

		Concentrations (pCi/g)				
Analyte	Site[b]	Soil	Grass Blades	Grass Roots	Forb Leaves	Forb Roots
U-234	9	2.9	<0.6[c]	3.9	--[d]	--
	9	2.6	--	--	--	--
	11	1.7	--	--	<0.6	0.6
U-235	9	<0.6	<0.6	<0.6	--	--
U-236	9	<0.6	--	--	--	--
	11	<0.6	--	--	<0.6	<0.6
U-238	9	5.2	<0.6	4.8	--	--
	9	4.2	--	--	--	--
	11	2.6	--	--	<0.6	2.1
U-total[e]	9	8.1	<0.6	8.7	--	--
	9	6.8	--	--	--	--
	11	4.3	--	--	<0.6	2.7
Cs-137	9	<0.2	<0.3	<0.2	--	--
	9	<0.2	--	--	--	--
	11	<0.2	--	--	<0.2	<0.2
Sr-90	9	0.6	<1.5	<0.5	--	--
	9	0.5	--	--	--	--
	11	<0.5	--	--	<0.5	<0.5

[a] Source: "Biological Sampling Analysis and Resources Report, Final," ASI/IT 1990.
[b] See RI Figure 4-41.
[c] < = Isotopes were below presented detection limit.
[d] – = No samples at this site.
[e] Total uranium in milligrams per kilogram (ppm).

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TABLE A-49

CHEMICAL CONCENTRATIONS IN VEGETATION AND WILDLIFE COLLECTED FROM THE FEMP[a]

Sample Type	Site[b]	Anthracene	Butylbenzyl-phthalate	Chrysene	Fluoranthene	Phenanthrene	Pyrene	2-Nitrophenol	4-Nitrophenol
Organics[c]									
Grass blades	9A	10000 U[d]	2000 J[e]	10000 U	10000 U	10000 U	10000 U	10000 U	50000 U
Grass roots	9A	10000 U	1000 J	10000 U	10000 U	10000 U	10000 U	10000 U	50000 U
Minnows	PR-1	20000 U	20000 U	20000 U	20000 U	20000 U	20000 U	20000 U	20000 U
Deer (Kidney)	--	1000 U	1000 U	1000 U	1000 U	1000 U	1000 U	1000 U	1000 U
Deer (Liver)	--	10000 U	10000 U	10000 U	10000 U	10000 U	10000 U	10000 U	10000 U

		PCB						Pesticide	
Sample Type	Site	Aroclor-1260	Aroclor-1254	Aroclor-1221	Aroclor-1016	Aroclor-1232	Aroclor-1242	Chlordane	4,4-DDT
Pesticides and PCBs[c]									
Grass blades	9A	800 U	800 U	800 U	800 U	800 U	800 U	800 U	400 U
Grass roots	9A	800 U	800 U	800 U	800 U	800 U	800 U	800 U	400 U
Minnows	PR-1	800 U	800 U	800 U	800 U	800 U	800 U	800 U	400 U
Deer (Kidney)	--	800 U	800 U	800 U	800 U	800 U	800 U	800 U	400 U
Deer (Liver)	--	800 U	800 U	800 U	800 U	800 U	800 U	800 U	400 U

Sample Type	Site	Aluminum	Arsenic	Barium	Cadmium	Fluoride	Lead	Mercury	Silver	Sulfate	Vanadium	Zinc
Inorganics[c]												
Grass blades	9A	25	13	3.2	0.5 U	210	3 U	0.5	0.5 U	320	1 U	4.4
Grass roots	9A	2160	3 U	17.5	0.5 U	50 U	3 U	2.1	0.5 U	830	3	8.0
Minnows	PR-1	28	6	1.0	4.2	1400	3 U	0.3	0.5 U	830	1 U	33.2
Deer (Kidney)	--	4 U	17	0.2 U	0.5 U	160	3 U	0.1 U	0.5 U	60	1 U	32.3
Deer (Liver)	--	8	20	0.2 U	0.5 U	2400	3 U	0.1 U	0.5 U	140	1 U	51.8

[a]Source: "Biological Sampling Analysis and Resources Report, Final," ASI/IT 1990.
[b]See RI Figure 4-41.
[c]All concentrations in milligrams per kilogram (ppm).
[d]U - Indicates compound was not detected.
[e]J - Indicates estimated level.

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TABLE A-50

RADIONUCLIDE CONCENTRATIONS IN MAMMAL TISSUE SAMPLED NEAR OPERABLE UNIT 1 FROM THE FEMP[a]

			Radionuclide Type and Concentrations (pCi/g Dry Weight)						
Sample	Type	Site[b]	Cs-137	Sr-90	Tc-99	U-234	U-235, U-236	U-238	Total Isotopic Uranium[c]
Opossum	Muscle[d]	Paddys Run Railroad Bridge	<0.3	<0.5	<1.0	<0.6	<0.6	<0.6	[e]
Small mammal[f] (Composite)	Carcasses	Pit 5	<0.2	<0.1	[g]	<0.6	<0.6	<0.6	[e]
Small mammal[f] (Composite)	Organs	Pit 5	<1.1	<2.5	[g]	8.3	1.1	8.6	18.0
Deer[d]	Kidney		<0.2	<0.5	<0.9	<0.6	0.6	<0.6	0.6
Deer[d]	Liver		<0.2	<0.5	<0.9	<0.6	<0.6	<0.6	[e]

[a]Source: "Biological Sampling Analysis and Resources Report, Final," ASI/IT 1990.
[b]See RI Figure 4-41.
[c]Total uranium in milligrams per kilogram (ppm).
[d]1988 sample.
[e]< - Less than stated detection limit.
[f]Composite small samples of deer mouse and short-tailed shrew.
[g]Technetium-99 analyzed for 1988 samples only.

TABLE A-51

RADIONUCLIDE CONCENTRATIONS IN FISH FROM PADDYS RUN CREEK AND POND[a]

Sample	Site[b]	Radionuclide Type and Concentrations ([pCi/g] Dry Weight)						Total Isotopic Uranium[c]
		Cs-137	Sr-90	Tc-99	U-234	U-235, U-236	U-238	
Minnow[d]	PR-1	<0.2[e]	<0.5	<1.6	<0.6	<0.6	<0.6	[f]
Minnow	PR-2	<0.4	<0.5	[g]	<0.6	<0.6	<0.6	[f]
White sucker	PR-2	0.20	<0.5	[g]	--[h]	--[h]	--[h]	[f]
Creek chub	PR-2	<1.90	<0.7	[g]	1.0	<0.6	0.7	1.7
Creek chub	PR-3	<0.17	<0.5	[g]	<0.6	<0.6	<0.6	[f]
White sucker	PR-3	<0.22	<0.5	[g]	<0.6	<0.6	<0.6	[f]
Bluegill	PR-3	<0.19	<0.5	[g]	<0.6	<0.6	<0.6	[f]
White sucker	PR-4	<0.41	<0.5	[g]	0.6	<0.6	<0.6	0.6
Creek chub	PR-4	<0.24	<0.5	[g]	<0.6	<0.6	<0.6	[f]
Bluegill	PR-4	<1.23	<3.32	[g]	2.4	<1.1	1.3	3.7
Bluegill	Pond (9B)	<0.2	<0.5	[g]	<0.6	<0.6	<0.6	[f]
White sucker	Pond (9B)	<0.2	<0.5	[g]	0.7	<0.6	1.0	1.7
Creek chub	Pond (9B)	<0.2	<0.5	[g]	<0.6	<0.6	<0.6	[f]

[a]Source: "Biological Sampling Analysis and Resources Report, Final," ASI/IT 1990.
[b]See RI Figure 4-41.
[c]Total uranium in milligrams per kilogram.
[d]1988 composite sample.
[e]< = Less than stated detection limit.
[f]No isotopes of uranium detected.
[g]Technetium-99 analyzed for 1988 samples only.
[h]Lost in analysis.

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TABLE A-52

RADIONUCLIDE CONCENTRATIONS IN BENTHIC MACROINVERTEBRATES FROM PADDYS RUN CREEK[a]

		Radionuclide Type and Concentration ([pCi/g] Dry Weight)						
Sample	Site[b]	Cs-137	Sr-90	Tc-99	U-234	U-235, U-236	U-238	Total Isotopic Uranium[c]
Benthos composite	PR-1[d]	<0.2[e]	<0.5	1.6	<0.6	<0.6	<0.6	f
Benthos composite	PR-2	<2.0	<3.7	g	3.6	<1.5	2.8	6.4
Crayfish	PR-2	<1.94	<1.2	g	3.5	<0.9	0.9	4.4
Crayfish	PR-3	<4.00	<2.6	g	3.6	<1.1	1.5	5.1
Crayfish	PR-4	<0.24	<1.8	g	1.5	<0.6	<0.6	1.5

[a]Source: "Biological Sampling Analysis and Resources Report, Final," ASI/IT 1990.
[b]See RI Figure 4-41.
[c]Total uranium in milligrams per kilogram (ppm).
[d]1988 sample.
[e]< = Less than stated detection limit.
[f]No isotopes of uranium detected.
[g]Technetium-99 analyzed for 1988 samples only.

APPENDIX B

OPERABLE UNIT 1
TECHNOLOGY AND PROCESS OPTION DESCRIPTIONS

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LIST OF ACRONYMS

AWWT	Advanced Wastewater Treatment
C	centigrade
DOE	United States Department of Energy
DOT	Department of Transportation
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
F	Fahrenheit
FEMP	Fernald Environmental Management Project
gpm	gallons per minute
HDPE	high density polyethylene
ha	hectares
hr	hour
km	kilometer
LC/DS	leachate collection/detection system
NAFB	Nellis Air Force Base
NCP	National Contingency Plan (For Oil and Hazardous Substances)
NEPA	National Environmental Policy Act
NORM	naturally occurring radioactive material
NTS	Nevada Test Site
PVC	Polyvinyl chloride
RCRA	Resource Conservation Recovery Act
VOC	volatile organic compounds

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B.1-1 Process Options and Technologies Included in Operable Unit 1 General Response Action Categories B.1-2

B.1.0 INTRODUCTION

Appendix B describes the potentially applicable technology and process options that were considered in the development of remedial alternatives for Operable Unit 1 at the U.S. Department of Energy (DOE) Fernald Environmental Management Project (FEMP). The discussions in this appendix provide a more detailed explanation of the various process options considered in Section 2.0 of the Operable Unit 1 Feasibility Study.

The technologies and process options described in this appendix are grouped according to general response actions, excluding the "no action" alternative, which is carried for comparative purposes only, as required by the National Contingency Plan for Oil and Hazardous Substances Pollution (NCP). Final remediation of Operable Unit 1 may include a combination of technologies and process options. The process options and technologies, as well as the general response action categories in which they are included, are provided in Table B.1-1.

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TABLE B.1-1
PROCESS OPTIONS AND TECHNOLOGIES INCLUDED IN OPERABLE UNIT 1 GENERAL RESPONSE ACTION CATEGORIES[a]

INSTITUTIONAL CONTROLS (B.2.1)

Monitoring
Air Quality Monitoring
Leachate Collection/Detection System

Access Control
Administrative Controls
Groundwater Monitoring
Physical Barriers
Surface Water/Sediment Monitoring

CONTAINMENT (B.2.2)

Subsurface Flow Control
Grout Curtains
Pumping Wells
Sheet Pilings
Slurry Walls
Subsurface Drains

Capping
Asphalt-Based Cap
Concrete-Based Cap
Multimedia Cap
Soil- or Clay-Based Cap
Synthetic Cover

Run-On/Runoff Control
Diversion/Collection
Grading
Revegetation
Sedimentation Basin/Sediment Trap

REMOVAL (B.2.3)

Mechanical Removal
Backhoe
Conveyor System
Crane with Clamshell System
Dragline System
Loader/Dozer

Hydraulic Removal
Airlift Dredging
Hydraulic Mining Pump
Pneuma/Oozer Dredges

Water Removal
Pumping Wells
Subsurface Drains

TREATMENT (B.2.4)

In Situ Treatment
Dynamic Compaction
In Situ Vitrification
Shallow Soil Mixing
Surcharging
Vacuum Extraction

Waste Stabilization
Cement-Based Solidification
Lime/Flyash Solidification
Thermoplastic Solidification
Vitrification

Physical Treatment
Soil Aeration
Solid/Liquid Separation

Chemical Treatment
Chemical Extraction

Thermal Treatment
Drying
Incineration

Biological Treatment
Biological Treatment

Water Treatment
Advanced Wastewater Treatment Facility

DISPOSAL (B.2.5)

Waste Transportation
Rail Transport
Truck Transport

On-Property Disposal
Above-Grade Concrete Vault
Engineered Disposal Cell

Off-Site Disposal
Nevada Test Site
Representative Permitted Commercial Disposal Facility

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[a]General Response Action categories are identified by the section in Appendix B in which they are discussed.

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B.2.0 DESCRIPTION OF TECHNOLOGIES AND PROCESS OPTIONS

This section provides a discussion of each technology and process option, grouped by general response action.

B.2.1 INSTITUTIONAL CONTROLS

B.2.1.1 Monitoring

Air Quality Monitoring

Air quality monitoring consists of active and passive monitoring equipment that would be used to ascertain air quality in and around Operable Unit 1 during and after remedial activities are complete. Air quality monitoring equipment includes full-flow air sampling devices and carbon adsorption units. Dust generation, contaminant suspension and radon emissions are monitored.

Leachate Collection/Detection System

Resource Conservation and Recovery Act (RCRA) requirements mandate that leachate collection and removal systems be placed immediately above the primary liner in all new hazardous waste landfills. Such systems must be capable of maintaining a leachate depth of 0.3 meters (1 foot) or less above the liner and withstanding clogging, chemical attack, and forces exerted by wastes, equipment, or soil cover.

U.S. Environmental Protection Agency (EPA) guidance documents recommend that the leachate collection system consists of a drainage layer at least 0.3 meters (1 foot) thick, with a hydraulic conductivity greater than or equal to 1×10^{-3} centimeters per second and a minimum slope of 2 percent. When installed over a secondary clay liner with hydraulic conductivity of 1×10^{-7} centimeters per second, such a system provides the four-order-of-magnitude difference in permeability known to significantly increase drainage efficiency. The drainage layer should be covered by a filter (graded sand layer or geotextiles) to prevent infiltration of fines from the waste and subsequent clogging of the drainage layer.

Leachate collection pipe networks should consist of slotted or perforated drain pipe bedded and backfilled with a gravel envelope. Layouts should include base liner slopes greater than or equal to 2 percent and pipe grades greater than or equal to 0.005. Pipe spacing should be determined for the unit. All pipes should be joined and, where appropriate, bonded. Sumps or basins should be installed at low points on the base of the fill to collect leachate discharging from the collection network. A riser pipe extending from the sump to the ground surface enables leachate removal.

B.2.1.2 Access Controls

Administrative Controls

Administrative controls refer to restrictions placed on property access and use. These controls consist of legal deed restrictions, requirements for admission, posted warnings and hazards, and community relations materials to inform the public of the remediation activities and property restrictions. Legal deed restrictions extend beyond the purview of a current site owner or landlord and are, therefore, generally long-lasting.

Groundwater Monitoring

Groundwater monitoring is used as an inventory control method which measures the effectiveness of remedial activities and may be the first indicator of leakage, product migration, and effects of abatement efforts.

The minimum requirements for any groundwater monitoring system involve at least one upgradient well which is capable of yielding representative background samples and at least three downgradient wells with locations and depths to ensure immediate detection of any statistically significant amounts of hazardous wastes or constituents in the upper aquifer. Where these minimum requirements do not allow the overall performance objectives to be met, it must be determined where and how many additional wells are needed. Groundwater samples are generally taken semiannually and analyzed for indicator parameters developed on a site-specific basis. Concentrations of indicator parameters from samples collected at the downgradient wells are individually compared to average background concentrations established from the upgradient well(s).

Physical Barriers

Physical barriers represent any structures placed to inhibit/control public access to contaminated areas. Physical barriers could consist of fences, roadblocks, and/or security posts. Site access will be limited to authorized personnel only. Physical barriers are used in conjunction with administrative controls to prevent public access.

Surface Water/Sediment Monitoring

As discussed previously under groundwater monitoring, surface water and sediment monitoring are used to monitor the effectiveness of remedial activities as well as to provide an indication of contaminant migration or failure of a remedial action. Surface water and sediment samples are collected and analyzed for representative site parameters.

B.2.2 CONTAINMENT

B.2.2.1 Subsurface Flow Control

Grout Curtains

Grout curtains are narrow, vertical walls installed in the ground to divert laterally flowing groundwater. A grout curtain may be used upgradient of a contaminated area to prevent clean water from migrating through wastes, or downgradient to limit migration of contaminants.

This technology is commercially available for use in shallow applications (9-12 meters [30-40 feet] maximum depth). The effectiveness of this technology largely depends on the presence of a confining layer of clay or rock into which the grout curtain is keyed. Without a confining layer, the grout curtain will not form an effective barrier.

Pumping Wells

Pumping wells are used to attract groundwater. Groundwater extraction techniques involve the active manipulation and management of groundwater to contain or remove a plume of contamination or to adjust groundwater levels in order to prevent formation of a plume. Types of wells used in management of contaminated groundwater include wellpoints, suction wells, ejector wells, and deep

wells. The selection of the appropriate well type depends on the depth of contamination and the on hydrological and geological characteristics of the aquifer.

Where plume containment or removal is the objective, either extraction wells or a combination of extraction and injection wells can be used. Use of extraction wells alone is best suited to situations where contaminants are miscible and move readily with water, where the hydraulic gradient is steep and hydraulic conductivity high, and where quick removal is not necessary. Extraction wells are frequently used in combination with slurry walls to prevent groundwater from overtopping the wall and to minimize contact of the leachate with the wall to prevent wall degradation. Slurry walls also reduce the amount of contaminated water that requires removal so that costs and pumping time are reduced.

Extraction or injection wells can be used to adjust groundwater levels; however, this application is not widely used. In this approach, plume development can be controlled at sites where the water table intercepts disposed wastes by lowering the water table with extracting wells. For this pumping technique to be effective, infiltration into the waste pile must be eliminated and liquid wastes must be completely removed. If these conditions are not met, a plume of contaminants may develop. The major drawback to using well systems for lowering water tables is the continued costs associated with system maintenance.

Sheet Pilings

Sheet piles can be used to isolate subsoil contamination by diverting groundwater from the contamination source. Sheet piles can be made of wood, precast concrete, or steel; however, wood is an ineffective water barrier. Concrete is used primarily where great strength is required. Steel is most effective in terms of groundwater cutoff and cost, and is discussed in the following paragraphs.

For construction of a sheet piling cutoff, the pilings are assembled at their edge interlocks before they are driven into the ground. This is to ensure that earth materials and added pressures will not prevent a good lock between piles. The piles are then driven a few feet at a time over the entire length of the wall. This process is repeated until all piles are driven to the desired depth.

Steel sheet piling can be employed as a groundwater barrier much like the other options discussed in this appendix. However, sheet pile walls do not provide a complete barrier against groundwater flow because water may move through the sheet pile joints. Therefore, because of costs and unpredictable wall integrity, sheet piles are seldom used except for temporary dewatering.

One of the largest drawbacks of sheet piling, or any other barrier technology requiring pile driving, is the problem caused by rocky soils. Damage to or deflection of the piles is likely to render any such wall ineffective as a groundwater barrier. There are limitations to the depth to which sheet pilings can be driven. Sheet pilings made of wood, precast concrete, or steel can generally be used to maximum depths of 30, 40 to 50, or 80 to 100 feet, respectively.

Slurry Walls

Slurry walls are the most commonly used subsurface barriers. Slurry walls are constructed in a vertical trench that is excavated under a slurry. The slurry (which is usually a mixture of bentonite and water) assists in shoring the trench to prevent collapse and forms a filter cake on the trench walls that prevents fluid loss to the surrounding ground.

Backfilling, performed by mixing soil materials with a bentonite and water slurry, results in this type of slurry wall. For on-property slurry preparation to be effective, the work area should be located adjacent to the slurry wall installation site.

The use of slurry walls may not be appropriate in areas subject to seismic activity or where heavy equipment operation is to be routine. Vibrations from both sources could result in thixotropy, the liquefaction of the settled slurry mix.

For slurry walls to be effective, it is necessary to use them in conjunction with a suitable cap. The slurry wall should extend to the least permeable underlying layer and go to a predetermined design depth below the bottom of the waste. A detailed predesign investigation characterizing the subsurface conditions and materials is required. Permeabilities of the subsurface layer (to which the slurry wall extends) and the soil-bentonite wall itself are critical elements in the design. The issue of waste/wall

compatibility should be addressed early in the design by permeability testing of the proposed backfill mixture with actual site leachate or groundwater. Based on the investigation results, suitable design and support activities can be recommended.

Subsurface Drains

Subsurface drains include any type of buried conduit used to convey and collect aqueous discharges by gravity flow. Subsurface drains function like an infinite line of extraction wells. They create a continuous zone of influence in which groundwater within this zone flows toward the drain.

The major components of a subsurface drainage system are:

- Gravel bed - conveys flow to a storage tank or wet well. Gravel beds (or french drains) are narrow, vertical trenches lined with slotted, plastic pipe and filled with porous backfill.
- Envelope - conveys flow from the aquifer to the drain pipe or bed
- Filter - prevents fine particles from clogging the system, if necessary
- Backfill - brings the drain to grade and prevents ponding
- Manholes or wet wells - collects flow and pumps the discharge to a treatment plant

Because drains essentially function like an infinite line of extraction wells, they can perform many of the same functions as wells. They can be used to contain or remove a plume or to lower the groundwater table to prevent contact of water with the waste material. The decision to use drains or pumping wells is generally based on a cost-effectiveness analysis.

For shallow contamination problems, drains can be more cost-effective than pumping, particularly in strata with low or variable hydraulic conductivity. Under these conditions, it would be difficult to design and cost-prohibitive to operate a pumping system in order to maintain a continuous hydraulic boundary. Subsurface drains may be also be preferred over pumping where groundwater removal is required for several years, because the operation and maintenance costs of pumping are substantially higher.

One of the biggest drawbacks of using subsurface drains is that they are generally limited to shallow depths. Although it is technically feasible to excavate a trench to almost any depth, the costs of shoring, dewatering, and hard rock excavation can make drains cost-prohibitive at depths of more than 12 meters (40 feet). However, in stable low-permeability soils where little or no rock excavation is required, drains may be cost-effective to depths of 30.4 meters (100 feet).

B.2.2.2 Capping

Asphalt-Based Cap

Bituminous asphalt can be used for the construction of a single-layered cap. Following preparation of the material to be capped (e.g., compaction to ensure that the material can support the cap), a layer of asphalt is placed over the material.

The thickness of an asphalt-based cap will depend on a specified allowable amount of settlement and on local weather conditions. A minimum slope of 2 percent must be maintained to provide runoff of precipitation to minimize generation of leachate from emplaced waste. To improve the life and effectiveness of an asphalt-based cap, periodic application of surface treatments may be required. Generally, a single-layer cap is not acceptable except under certain circumstances, such as:

- The cap is intended for temporary coverage.
- Evapotranspiration substantially exceeds precipitation.
- An acceptable distance exists between the emplaced waste being covered and the nearest source of groundwater.
- Continual maintenance of the cap is ensured for integrity.

Concrete-Based Cap

Similar to the asphalt-based cap, a single-layered cap may be constructed of concrete. A single-layered cap constructed of concrete is subject to the same use limitations as the asphalt-based cap. A minimum slope of two percent is required to ensure precipitation runoff to minimize the generation of leachate. Like the asphalt-based cap, periodic application of special surface treatment may be required to maintain integrity.

Multimedia Cap

The multimedia cap is a preferred cap design because it incorporates the most effective attributes of other designs. The components of a typical multimedia cap include:

- Clay layer - A compacted clay layer with a verified 1 x 10^{-7} centimeter(s) per second permeability placed over fill soils. The clay layer prevents infiltration of water to the underlying waste material, thereby preventing leachate generation.
- Drainage layer - A drainage layer is placed over the clay layer. The upper portion of the drainage layer is a natural-graded natural aggregate, and the lower portion is a narrow graded medium aggregate to provide a minimum permeability of 1 x 10^{-2} centimeter(s) per second. The drainage layer intercepts infiltrating precipitation and rapidly transports the water to a collection system located at the toe of the multimedia cap. A geotextile liner is placed between the top surface of the drainage layer and the overlying vegetative layer to prevent the migration of fines from the vegetative to the drainage layer.
- Vegetative layer - A thick vegetative layer is placed over the drainage layer. This layer is composed of common clean soils, with the upper portion capable of supporting a hardy, persistent growth, shallow-rooted [zero root density at 30.5 centimeters (12 inches)] deep grass crop.

The vegetative layer protects the clay layer against environmental abrasion including desiccation, freeze/thaw damage, erosion, and hydraulic-induced stresses caused by standing or ponding water. The vegetation on the surface should be maintained to preclude both old field succession and erosion. Such maintenance would include, but not be limited to, mowing, reseeding, fertilization, burrow fill material, etc.

A detailed description of the multimedia cap design being considered for Operable Unit 1 is provided in Section 4.3.1.

Soil- or Clay-Based Cap

A natural soil or clay cover having a permeability lower than the waste over which it is placed may be used to construct a single-layered cap much like the asphalt or concrete caps previously discussed. As a cap material, the soil or clay layer must control erosion and minimize generation of leachate

produced by the infiltration of surface precipitation through the emplaced waste. A natural soil/clay cap is more susceptible to freeze/thaw and shrink/swell cycles than asphalt and concrete caps.

Synthetic Cover

A synthetic cover is a single-layered cover made of a material such as high-density polyethylene (HDPE), polyvinyl chloride (PVC), Hypalon, etc. Thin sheets of the material are placed over the area to be covered, overlapped and spliced together. Careful consideration must be given in the selection of the material to ensure compatibility with the covered waste material. As with asphalt- and concrete-based caps, single-layer synthetic covers are limited in their accepted applications.

B.2.2.3 Run-On/Runoff Control

Diversion/Collection

Surface water diversion and collection is an essential part of surface water management and includes dams, dikes/berms, channels (earthen/pipe), waterways, terraces/benches, chutes, downpipes, seepage ditches/basins, levees, and floodwalls. Diversion/collection techniques can be used as temporary or permanent measures for effective surface water control to prevent flooding, to control erosion, and to direct surface runoff.

Grading

Grading is the general term for techniques used to shape or reshape the surface of covered landfills to manage surface water infiltration and runoff control erosion. The spreading and compaction steps used in grading are techniques practiced routinely at sanitary landfills. Grading is often performed in conjunction with capping and revegetation as part of an integrated landfill closure plan.

Surface grading serves several functions:

- Reduces ponding, which minimizes infiltration and reduces subsequent differential settling
- Reduces runoff velocities to reduce soil erosion
- Roughens and loosens soils in preparation for revegetation
- Reduces surface water infiltration, thereby reducing leaching of wastes

Revegetation

The establishment of a vegetative cover is a cost-effective method to stabilize the surface of hazardous waste disposal sites, especially when preceded by capping and grading. Revegetation decreases erosion by wind and water, and contributes to the development of a naturally fertile and stable surface environment. Also, the technique can be used to upgrade the appearance of disposal sites that are being considered for reuse.

A systematic revegetation plan includes: selection of suitable plant species, seedbed preparation, seeding/planting, mulching and/or chemical stabilization, and fertilization and maintenance.

Sedimentation Basin/Sediment Trap

Sedimentation basins are used to control suspended solids entrained in surface flows. A sedimentation basin is constructed by placing an earthen dam across a waterway or natural depression, or by excavation, or by a combination of both. The purpose of installing a sedimentation basin is to impede surface run-off carrying solids, thus allowing sufficient time for the particulate matter to settle.

A typical design for a sedimentation basin includes a principal spillway, an anti-vortex device and the basin. The principal spillway consists of a vertical pipe or riser jointed to a horizontal pipe (barrel) that extends through the dike and outlets beyond the water impoundment. The riser is topped by the anti-vortex device and trash rack which improve the flow of water into the spillway and prevent floating debris from being carried out of the basin. The riser should be watertight and, except for the dewatering opening at the top, should not have any holes, leaks, or perforations. The riser base should be attached to a watertight connection and have sufficient weight to prevent flotation of the riser. The water discharged from the sediment basin through the principal spillway should be conveyed in a erosion-free manner to an existing stable stream.

B.2.3 REMOVAL

B.2.3.1 Mechanical Removal

Backhoe

A backhoe is normally used for trenching and for other subsurface excavation where the excavator remains near the original working level. Backhoes are mechanically or hydraulically operated in a drag and hoist maneuver and are usually crawler-mounted. The lateral and vertical reach of a backhoe is limited by the length of the boom. Conventional backhoes are capable of digging to a depth of approximately 12.2 meters (40 feet). Deeper digging depths (up to 24.3 meters [80 feet]) are achieved by using modified backhoes with extended booms, modified engines, and counterweights. Backhoes are capable of excavating almost any type of material. Material transport and support equipment are required for successful operation.

Conveyor System

A conveyor system is useful in transporting large amounts of material through continuous feed processes. The system consists of a steel or synthetic surface that is carried along a circuit of rollers. The termination point of the system is generally a loading point for another transporting mechanism or a feed input shelter for a treatment plant. The system can be modified to assist in waste removal by the addition of a bucket line or series of steel shelves along the conveyor surface.

Crane with Clamshell System

A clamshell (or grab bucket) is a crane-operated mechanical removal device that could be crawler-mounted for this application. A clamshell is normally used for a reach/depth of up to 30.4 meters (100 feet). Production rates for clamshells are relatively low, typically in the range of 20 to 30 cycles per hour, and vary with depth, working media, and swing angle. Clamshell buckets range in capacity from 0.8 to 9.2 cubic meters (1 to 12 cubic yards). A large-capacity, specially designed bucket could be used for this application. The bucket could be designed so that the probability of losing material during hoisting would be minimized.

Clamshell dredging can excavate most types of material, except highly consolidated sediments and solid rock. The excavation is done at nearly in situ densities. Clamshell dredges can be operated in

confined areas. By using a long boom, operator exposure can be minimized. Major problems are low production, potential of losing material during hoisting operation, and high energy/operational costs.

Dragline System

A dragline is similar to a clamshell. It is also a crane-operated device that would be crawler-mounted for this application. The primary difference is that a dragline bucket is loaded as it is pulled across the material, whereas the clamshell is dropped into the material and hoisted vertically. A dragline can be used to excavate many types of materials. It has a longer reach than a clamshell and better horizontal control.

Loader/Dozer

A front-end loader is a tractor with a bucket for digging, lifting, hauling, and dumping materials. Front-end loaders are generally equipped with a hydraulically controlled bucket lift and can be either crawler- or rubber-tire-mounted. The front-end loader's buckets vary in capacity and design.

Crawler-mounted loaders are excellent excavators for rough, unstable surfaces. They can carry materials as far as 90 meters (300 feet), beyond which the production rate becomes economically unfavorable. Medium-sized crawler-loaders typically have maximum bucket capacities of 3.8 to 4.6 cubic meters (5 to 6 cubic yards). Rubber-tire-mounted loaders for high production operations on stable surfaces have bucket capacities up to 20 cubic meters (26 cubic yards).

Crawler dozers equipped with blades of various sizes and shapes (straight to U-shaped) have tremendous earth-moving power and are excellent graders. In drum excavation work, these dozers can remove miscellaneous fill or soil overburden, or they can push earth and undamaged or empty drums from unstable surface areas to more accessible areas for lifting and loading operations.

B.2.3.2 Hydraulic Removal

Airlift Dredging

Airlift dredges use compressed air to dislodge and transport sediment. Compressed air is introduced into the bottom of an open vertical pipe, usually controlled and supported by a barge-mounted crane. As the air is released, it expands and rises, creating upward currents that carry both water and sediment up through the pipe. The applied air pressure must be sufficient to overcome the hydrostatic pressure at operating depths. Higher air pressures and flow rates result in higher transport capacity. Air can also be introduced through a special transport head that can be vibrated or rotated to further dislodge more cohesive sediment. Slurries of 1:3 solid/liquid ratio can typically be achieved with airlift dredges. The primary advantage of the airlift dredge is that it provides continuous transport of material, maximizing production rate. The primary limitation is that sufficient depth must be available to build up enough air pressure for operation. The minimum dredging depth for economical operation is approximately 6 to 9 meters (20 to 30 feet).

Hydraulic Mining Pump

The hydraulic mining pump is a hydraulic dredge which utilizes a pump to provide suction for removal of slurry. During normal operations, material with solids contents of 10 to 15 percent by weight are drawn through the suction line and discharged to a nearby disposal site. The production rate depends upon the pump size, pump horsepower, and type of material being dredged. During normal working conditions, dredging is performed at 1,000 to 10,000 cubic yards per hour.

Alternatives to this simple hydraulic include cutterhead dredges, which incorporate a rotating cutter apparatus surrounding the intake of the pump to dislodge materials; and dustpan dredges, which use high pressure water jets surrounding a flared dredging head to loosen and agitate the materials to be resolved.

The Pit Hog Dredge is a floating hydraulic dredge with a cutterhead. One is currently located at Waste Pit 5.

Pneuma/Oozer Dredges

Two different dredges - the pneuma dredge and the oozer dredge - are evaluated. The pneuma dredge consists of a pump that is lowered by a crane into the sediment being dredged. The pump is driven by compressed air and operates by positive displacement. The body of the pump contains three cylindrical vessels, each with an intake opening on the bottom and an air port and a discharge outlet on top. The air ports can be opened to the atmosphere through air hoses and valves. The three cylinders operate in parallel, each one-third cycle ahead and behind the other two cylinders, and controlled by an air distributor located on the control vessel.

A pneuma dredge is normally suspended from a crane cable and pulled ahead into the sediment being dredged by a second cable. The dredge head is essentially fixed relative to the vessel so that lateral manipulation of the dredge is limited to the positioning and movement of the vessel.

The oozer dredge, developed in Japan, consists of a pump similar in concept to the pneuma dredge. It uses negative (vacuum) pressure in the filling chambers and atmospheric pressure when dredging in shallow depths. The pump is usually mounted at the end of a ladder. The pump body consists of two cylinders to which a vacuum is applied to increase the differential pressure and flow between the sediment and the cylinders. Sediment thickness detectors, underwater television cameras, and a turbidimeter are attached near the suction mouth for monitoring. Suspended oil can be collected by an attached hood, and cutters can be attached for dislodging hard soils.

An oozer dredge is normally pulled along a straight line fixed by a cable-and-winch arrangement anchored on land or on the bottom of the dredge area. The dredge vessel moves along the line of the cable, and the cable is repositioned to establish a new line as dredging progresses.

B.2.3.3 Water Removal

Pumping Wells

See discussion in Section B.2.2.1.

Subsurface Drains

See discussion in Section B.2.2.1.

B.2.4 TREATMENT

B.2.4.1 In Situ Treatment

Dynamic Compaction

Dynamic compaction involves dropping 5- to 40-ton weights from heights of 20 to 100 feet, resulting in compaction of surface and subsurface soils. A large-capacity crane repeatedly lifts and releases the weight at one location before moving on to the next location. To minimize the potential for contaminant release into the surface environment, a thick soil blanket (approximately four or five feet) is placed over the treatment area. The following support activities would be required before the start of any compaction effort:

- Perform studies to confirm the technology's abilities
- Remove and treat free-standing water
- Evaluate and implement groundwater control measures

In Situ Vitrification

See vitrification discussion in Section B.2.4.2.

Shallow Soil Mixing

Shallow soil mixing is a method of in situ solidification. Shallow soil mixing is designed to provide in situ mixing of ponds, pits, and lagoons to a depth of 9 meters (30 feet) or more using a crane-mounted mixing system. The mixing head is enclosed in a bottom-opened cylinder that allows a closed system for the mixing of waste and treatment chemicals. As the mixing head blades pass up-and-down through the waste, a negative pressure is maintained on the cylinder headspace to pull any vapors or dust to an off-gas treatment system.

Surcharging

This technology typically induces densification and subsidence in incompetent soils by mounding or overburdening the treatment area with large fill soil quantities for a long time. After the compaction goal is achieved, the soil overburden may be removed and discarded or used for surcharging another area (termed "rotating surcharge technique").

This technology is one of the simplest and least expensive methods for large treatment areas. This method can be used most effectively in free-draining soils but can also be applied to fine-grained and cohesive soils by installation of sand drains, collection trenches, or wick drains to decrease the waste consolidation time. Surcharging produces a compact waste/soil matrix suitable for capping.

Vacuum Extraction

Vacuum extraction is typically an in situ process that removes volatile organic compounds (VOCs) from a defined contaminated area. This technology extracts the contaminant through extraction wells by using a vacuum pump or blower to create air flow through the soil. The VOCs enter the air stream, which is passed through a vapor/liquid separator. The off-gases from the separator undergo subsequent treatment, which produces a clarified gas that can be released to the atmosphere.

Important considerations include: volatility of the contaminants, porosity and permeability of the soil, the soil's moisture content, required cleanup level(s), and other chemical and physical properties of the contaminants and soil, respectively.

The essential features of this technology are:

- Manifold piping
- Vapor/liquid separator
- Vacuum pump
- Emission control device (e.g., activated carbon canister)

B.2.4.2 Waste Stabilization

Cement-Based Solidification

Cement-based solidification involves mixing the waste materials directly with portland cement, a very common construction material. The waste is incorporated into the rigid matrix of the hardened concrete. Most solidification is done with Type I Portland cement, but Types II and V can be used for sulfate or sulfite wastes. This method physically or chemically solidifies the wastes, depending on waste characteristics. The end product may be a standing monolithic solid or may have a crumbly, soil-like consistency, depending on the amount of cement added.

Most hazardous wastes slurried in water can be mixed directly with cement, and the suspended solids would be incorporated into the rigid matrix. Although cement can physically incorporate a broad range of waste types, most wastes would not be chemically bound and are subject to leaching.

Cement solidification is most suitable for immobilizing metals because at the pH of the cement mixture, most multivalent cations are converted into insoluble hydroxides or carbonates. However, metal hydroxides and carbonates are insoluble only over a narrow pH range and are subject to leaching in the presence of even mildly acidic leaching solutions (e.g., rain).

Lime/Flyash Solidification

Lime/flyash solidification is similar to cement solidification, but uses siliceous materials such as flyash or slag in combination with setting agents such as lime, cement or gypsum. Reactions between the silicate materials and polyvalent metal ions make this process a chemical stabilization process in addition to a solidification process. The product of lime/flyash solidification varies from a moist clay-like material to a hard material similar in appearances to concrete.

Thermoplastic Solidification

Thermoplastic solidification involves sealing wastes in a matrix such as asphalt bitumen, paraffin, or polyethylene. The waste is dried, heated, and dispersed through a heated plastic matrix. The mixture is then cooled to form a solid-like but deformable material. Bitumen solidification is the most widely used of the thermoplastic techniques.

Thermoplastic encapsulation involving the use of an asphalt binder is most suitable for heavy metal or electroplating wastes. Relative to cement solidification, the increase in volume is significantly less and the rate of leaching is significantly lower. Also, thermoplastics are not greatly affected by either water or microbial attack.

There are a number of waste types that are incompatible with thermoplastic solidification. Oxidizers such as perchlorates or nitrates can react with many of the thermoplastic materials to cause an explosion. Some solvents and decreasing agents can cause asphalt materials to soften and never become rigid. Xylene and toluene diffuse quite rapidly through asphalt. Salts that partially dehydrate at elevated temperatures can be a problem. Sodium sulfate hydrate, for example, will lose some water during asphalt incorporation, and if the waste asphalt mix containing the partially dehydrated salt is soaked in water, the mass will swell and crack due to rehydration. This can be avoided by eliminating easily dehydrated salts or coating the outside of the waste/asphalt mass with pure asphalt.

Vitrification

Vitrification converts contaminated solids into a glass (amorphous) and crystalline mineral matrix that has extremely durable mechanical and chemical properties. Vitrification at melting temperatures between 1,100 and 1,600°C (2,000 and 2,900°F) will destroy organics and fix metals into the nonleachable stabilized melt. The waste mixture must have sufficient mineral content to form the glass matrix. If the waste is low in silica or alumina compounds, these materials may be added in the form of sand or soil.

Glass melting equipment (both continuous and batch) can be used to vitrify wastes. Conventional equipment, including "cold cap" and "drop tube electro" melters, have been studied for vitrifying radioactive waste. A stirred tank melter also has been proposed but not extensively studied. The cold cap, drop tube, and stirred tank melters would be fed a mix of waste, sand, and fluxing agents and would produce a glass melt which could be cast as blocks or frit.

Any vitrification process produces off-gas containing steam, products from combustion of any organics, and some particulates. Some metals may be volatilized but these emissions should be lower

than that produced from other thermal techniques. The off-gas from any vitrification process must be collected and treated.

In situ vitrification is a variation of this process option wherein electrodes are inserted into contaminated materials in place and an electric current is passed through the electrodes to vitrify the waste. Although in principle very similar to vitrification, in situ vitrification is much more difficult to control where the waste material is heterogenous.

B.2.4.3 Physical Treatment

Soil Aeration

Soil aeration involves the injection of a continuous air stream into contaminated soils. The air is used to drive away volatile organics and to assist in drying the soil. This technique is not effective in removing metals or radioactive contaminants, although the air injection may temporarily flush out radon concentrations. The technology is most effective in removing VOCs from contaminated soil.

Solid/Liquid Separation

Solid/liquid separation technology consists of three primary technology subgroups: filtration, sedimentation, and centrifugation. Filtration is primarily used for streams with concentrated slurries of large particles. Filtration is accomplished by introducing a liquid-solid stream onto a filtration medium or screen. The liquid that passes through the screen is called the "filtrate" and the solid deposited on the screen is called the "cake." There are many types of filters; common filter types include filter presses, horizontal belt filters, and vacuum filtration, each having its own advantages and disadvantages.

Filter presses achieve solid/liquid separation by forcing the water from the sludge under high pressure. Two common types of filter presses are recessed plate filter, and plate and frame filter. Advantages of using filter presses include high concentrations of cake solids, good filtrate clarity, high solids capture, and low chemical use. Disadvantages include high labor costs and limitations on filter cloth life.

Horizontal belt filters convey sludge on horizontally mounted continuous belts and use gravity and/or pressure to dewater sludge. Types of horizontal belt filters include moving-screen concentrator, capillary dewatering system, rotating-gravity concentrator, and belt pressure filter. Horizontal belt filters are typically used to dewater sludge with solids in the range of 5 to 10 percent to solids in the 20 to 30 percent range.

Vacuum filtration uses cylindrical drums that have filter media which can be a cloth of natural or synthetic fibers, coil springs, or a wire-mesh fabric. The drum is suspended above and dips into a container of sludge. As the drum slowly rotates, sludge is drawn into a circumference of the filter medium by an internal vacuum. Water is drawn through the porous filter cake for that sector of the circumference. The performance of vacuum filters is affected by the type of sludge, filter medium, and sludge feed temperature. Disadvantages of vacuum filters include highly variable performance and a requirement for chemical conditioning prior to dewatering.

With low concentrations of fine particles, sedimentation may be preferred over filtration for solid/liquid separation. Sedimentation is the process by which suspended particles are allowed to settle out of solution by gravity. Sedimentation requires large amounts of space (but can handle large flow rates) and requires low maintenance. The size of the sedimentation tank or pond depends on the flow rate of the slurry along with the concentration and density of the solids to be removed.

Centrifugation uses an open basket centrifuge to force particles contained in the liquid stream to the wall of the centrifuge where they collect as a cake. The clear liquid leaves the centrifuge via a hollow shaft in the center of the centrifuge. Centrifugal separation is good for low flow rate streams with low concentration of solids. The space requirement for centrifugation is small, but the energy consumption is high.

B.2.4.4 Chemical Treatment

Chemical Extraction

Chemical extraction refers to the use of chemicals to extract contaminants from a waste stream. Chemical extraction includes the following process components:

- Leaching/extraction - Leaching is the extraction of a solute from a solid mixture. It is similar to liquid-liquid extraction in that a liquid solvent is utilized to effect a transfer of the solute, then the solute is recovered from the solvent, usually by evaporation or distillation. The solid usually requires pretreatment such as cutting, grinding, or crushing to increase the surface area. It is important to know the physical characteristics of the carrier solid and the manner the solute is held in the solid to determine the equipment needs and operating parameters. Soil flushing/washing, which uses water and sometimes surfactants to extract contaminants, is a variation of this process.

- Metals precipitation - Metals precipitation is carried out by adding acid or base to a waste solution in order to adjust the pH to a point where the metal(s) of concern have a low solubility. The metals then precipitate out of the solution. Coagulants are often added to the solution to aid in the precipitation process.

  One metals precipitation process that was developed for the precipitation of radionuclides is the TRU/Clear® process. This process was developed at the Los Alamos National Laboratory and is marketed by Analytical Development Corporation. The process uses potassium ferrate as an inorganic coagulant to remove radionuclides (i.e., uranium, thorium, radium) and other priority pollutants from wastewaters.

- Neutralization - Neutralization involves adjusting the pH of a waste stream so that the waste is no longer acidic or basic. Neutralization is used as a treatment for waste acids and alkali solutions following metals precipitations to eliminate or reduce their reactivity and corrosiveness. Neutralization is an inexpensive treatment, especially if a waste acid stream can be used to neutralize a waste alkali stream and vice versa. The constituency of each waste stream must be known to prevent the formation of more hazardous compounds and to ensure that the mixing reaction does not become violent.

B.2.4.5 Thermal Treatment

Drying

Drying is a weight/volume reduction technique that uses heat to remove water from sludges or solids. Drying can be accomplished in indirect heat transfer equipment, through direct contact with hot gas, or in equipment that combines both methods of heat input. In an indirect rotary dryer, waste material is introduced to an inclined rotating cylinder housed in a refractory-built furnace. Drying gases produced in a natural-gas-fueled combustion chamber enter the furnace at 1,000-1,200°F and flow concurrent with the waste material. Heat is transferred to the waste through the inclined cylinder

with no contact between the gases and waste, thus minimizing dust generation. The material itself is heated to approximately 300°F. Volatile organic compounds from the dried waste material must be captured and treated in an off-gas treatment system.

Incineration

A rotary kiln incinerator is a long, inclined tube that is rotated slowly. Wastes and auxiliary fuels are introduced to the high end of the kiln, and the rotation constantly agitates (tumbles) the solid materials. This tumbling causes turbulence and allows for improved combustion. Rotary kilns are intended primarily for solids combustion, but liquids and gases may be co-incinerated with solids. Exhaust gases from the kiln pass to a secondary chamber or afterburner for further oxidation. Ash residue is discharged and collected at the low end of the kiln. Exhaust gases require acid gas and particulate removal through the use of a gas scrubber, and the ash may require stabilization before landfilling.

Most types of solid, liquid, and gaseous organic wastes or a mixture of these wastes can be treated with this technology. Explosive wastes and wastes with high inorganic salt content and/or heavy metals require special evaluation. This operation can create high particulate emissions that require post-combustion control.

B.2.4.6 Biological Treatment

Biological Treatment

Biological treatment is a technique for treating contamination by microbial degradation. The basic concept involves manipulating environmental factors to enhance microbial metabolism of organic compounds, resulting in the degradation of these organic contaminants. The important environmental factors for biological treatment include the concentrations and types of contaminants, oxygen concentration, macro and micro nutrient concentrations, pH, moisture content, and temperature.

Numerous alternatives exist for biological treatment, including: in situ treatment, where contaminated soil or groundwater is treated in place by manipulation of in situ environmental conditions; land farming, where soils are excavated and environmental conditions are controlled in small piles of

contaminated material; and in-vessel systems, where soil, in the form of a slurry, or groundwater is placed in a tank or other vessel and conditions are controlled to stimulate activity. In all instances, indigenous microorganisms may be used or the treatment system may be enhanced with microorganisms specially suited to degrade the contaminants of concern.

B.2.4.7 Water Treatment

Advanced Wastewater Treatment Facility

The FEMP Advanced Wastewater Treatment (AWWT) facility is being built on the FEMP site and will be available for treating wastewater, including contaminated groundwater, surface water, and perched water encountered during remediation. This system will utilize metals precipitation, ion exchange, and other treatment steps so that the effluent will meet all discharge criteria.

The treatment system will consist of two parallel treatment trains. Phase I will treat 700 gallons per minute (gpm) of contaminated storm water runoff from the FEMP storm water retention basin. When capacity is available, the treatment system will also treat uranium-contaminated groundwater to be extracted from the South Groundwater Contamination Plume prior to its discharge to the Great Miami River. The South Plume is located just south of the FEMP in a portion of the Great Miami Aquifer. Phase II will treat 400 gpm of wastewater from cleanup and other activities at the site. This consists of approximately 200 gpm existing wastewater flows and 200 gpm future remediation flows. The AWWT is designed to reduce uranium in the FEMP's wastewater discharges to less than the proposed Safe Drinking Water Standard of 20 parts per billion (ppb).

Each treatment train consists of the following major steps:

- Flow equalization and pH adjustment to 11.5
- TRU/Clear addition and clarification for bulk removal of radionuclides and heavy metals. TRU/Clear is targeted at removal of radionuclides other than uranium; however, uranium will also be removed. The system will have the capacity to use alternate coagulants if TRU/Clear is not required.
- Multitube filtration (solids collected from the clarifiers and filtration will be directed to Plant 8 for filtration) of clarifier effluent
- Carbon adsorption for removal of any organic compounds

- pH adjustment to 8.0 using sulfuric acid (optimum for ion exchange)
- Ion exchange for uranium removal (Dowex 21-K)
- Final pH adjustment to within the National Pollutant Discharge Elimination System permit limits (6.5 - 9.0)
- Final filtration

B.2.5 DISPOSAL

B.2.5.1 Waste Transportation

Rail Transport

Trains could be used to move contaminated materials from the FEMP site to an off-site disposal facility. Waste materials would have to be treated and contained to meet Department of Transportation (DOT) requirements prior to transportation.

Truck Transport

Truck transport can provide portal-to-portal service with the road system available between the FEMP site and the ultimate disposal site. The main disadvantage of truck transport is the size of public roadways near the FEMP site. These two-lane rural roads are heavily traveled with considerable uncontrolled cross traffic and regional commuter traffic. As with rail transport, the waste material must be treated and contained before transporting, to meet DOT requirements.

B.2.5.2 On-Property Disposal

Above-Grade Concrete Vault

This disposal concept places concrete disposal vaults over an engineered liner with a leachate collection/detection system (LC/DS). The waste is placed in the concrete vaults which is covered with a multimedia cap. Each vault has a service opening to allow access for the placement of waste material. The floor of each vault has a minimum slope of two percent to facilitate leachate collection and monitoring. The roof of each vault has a minimum slope of two percent to allow stormwater runoff. As each vault is filled to capacity, all equipment and temporary utilities would be removed and the vault are sealed prior to installation of the multimedia cap.

The LC/DS are composed of alternating composite soil liners and drainage layers to minimize the potential release of contaminated leachate to the groundwater and the Great Miami Aquifer. The liners are constructed of a natural, compacted clay with a maximum permeability of 1×10^{-7} centimeter per second. Each layer is a minimum of 0.9 meters (3 feet) thick. To improve the performance of the clay, a geomembrane of at least 40 mil in thickness is placed over the surface of the clay, which is smooth-rolled to ensure good hydraulic contact. To minimize damage to the geomembrane during construction, a sand layer with a minimum thickness of 20 centimeter (8 inches) is placed over the geomembranes of the LC/DS.

Between the clay layers, drainage layers are installed to intercept any leachate that may be generated. Each drainage layer is a minimum of 0.6 meters (2 feet) each in thickness. The upper 0.3 meters (1 foot) of each layer is a graded natural aggregate, and the lower 0.3 meters (1 foot) is a narrow graded medium aggregate to provide a minimum permeability of 1×10^{-2} centimeters per second. A geotextile membrane is placed on the upper surface of each drainage layer to prevent the migration of granular fines from overlying material.

During placement of the aggregate, 10-centimeters (4-inches) diameter perforated piping is installed within the aggregate to collect and direct any leachate to a series of manholes lined with high density polyethylene (HDPE). Any leachate not captured by the perforated piping that reaches the sand layer travels along the slope of the cap to the manholes. The leachate is then pumped from the manholes for treatment at the FEMP site advanced wastewater treatment facility (AWWT).

A multimedia cap constructed of five distinct layers of media provides final closure of the vaults. The upper layer of the cap is a vegetative layer consisting of topsoil with a hardy, shallow root grass cover. This layer is noncompacted and has a minimum thickness of 0.6 meters (2 feet) to support plant growth. The vegetative layer would inhibit erosion and allow runoff during storm events. A drainage layer beneath the vegetative layer would intercept infiltrating precipitation. The layer would consist of 0.30 meters (1 foot) of compacted pea gravel with a minimum permeability of 1×10^{-2} centimeters per second. A geotextile membrane would be placed between the vegetative layer and the pea gravel.

A layer of cobblestone with a minimum thickness of 0.7 meters (2.3 feet) serves as an intrusion barrier beneath the drainage layer. Beneath the cobblestone is a clay liner to impede downward moisture movement from the drainage layer. This layer consists of natural, compacted clay with a maximum permeability of 1 x 10^{-7} centimeters per second. The layer is 0.9 meters (3 feet) thick to ensure the isolation of the waste material. A geomembrane at least 40 mil in thickness is placed over the surface of the clay, which would be smooth-rolled to ensure good hydraulic contact. Similar to the composite soil liners of the LC/DS, a layer of sand is placed over the geomembrane to minimize damage during construction.

The foundation of the multimedia cap is a layer of clean, compacted soil between 0.15 meters (6 inches) and 0.6 meters (2 feet) in thickness.

Engineered Disposal Cell

The proposed engineered disposal cell concept consists of capping waste that has been placed on an engineered liner system. The liner and cap would be of the general design discussed previously under the Above-Grade Concrete Vault option. The major difference between the options is that the engineered cell does not include concrete vaults for waste disposal. A detailed description of the engineered disposal cell considered for Operable Unit 1 is provided in Section 4.3.1.

B.2.5.3 Off-Site Disposal

Nevada Test Site (NTS)

This process option calls for the disposal of wastes at an existing DOE-owned facility located in an arid western environment. This facility is currently operating and accepting many types of radioactive waste. An Environmental Impact Statement (EIS) for waste disposal activities at the NTS is currently being prepared to satisfy the requirements of the National Environmental Policy Act (NEPA). Several disposal technologies are currently utilized at NTS (e.g., shallow land burial and large-diameter augered shafts). Shallow land burial is the method typically used for low-level waste. Mixed waste is not currently accepted at the facility; however, a permit to accept mixed waste is pending. The facility is highly protective of human health and the environment because it is located far from any population centers in an area with an arid climate and a very large depth to

groundwater. Depths to groundwater beneath the NTS vary from about 157 meters (515 feet) to more than 610 meters (2000 feet). Precipitation levels on the NTS are low, runoff is intermittent, and the majority of the active testing areas on the NTS drain into closed basins on the site.

The NTS is surrounded on the east, north, and west by public access exclusion areas consisting of the Nellis Air Force Base (NAFB) Bombing and Gunnery Range, and the Tonopah Test Range. These two areas comprise the NAFB Range Complex, which provides a buffer zone between the test areas and public lands. The combination of the NAFB Range Complex and the NTS is one of the larger unpopulated land areas in the United States, comprising some 14,200 square kilometers (5,470 square miles).

Excluding Clark County, the major population center (approximately 741,000 in 1990), the population density within a 150-kilometer radius of the NTS is about 0.5 person per square kilometer. In comparison, the 48 contiguous states (1990 census) had a population density of approximately 29 persons per square kilometer. The estimated average population density for Nevada in 1990 (including Clark County) was 2.8 persons per square kilometer.

Representative Permitted Commercial Disposal Facility

This process option calls for disposal of wastes at an existing permitted commercial disposal site located in an arid western environment. The commercial facility evaluated for Operable Unit 1 wastes is representative of a typical permitted commercial disposal site.

The representative facility, located near Clive, Utah, is licensed by the State of Utah for naturally occurring radioactive material (NORM), low-activity radioactive waste, mixed NORM and chemically hazardous waste. The site is located on the eastern edge of the Great Salt Lake Desert in Tooele County, Utah, approximately 129 kilometers (81 miles) west of Salt Lake City. The representative site occupies approximately 220 hectares (540 acres) in an area zoned for radioactive waste disposal and is located approximately 0.62 kilometers (1 mile) south of a rail switch point identified as Clive. Much of the land surrounding the representative site is public domain administered by the U.S. Bureau of Land Management (DOE 1984).

The representative site is situated in an arid desert area rated by the Bureau of Land Management as poor for grazing or forage production. Vegetation at the site is a homogeneous, semidesert low shrubland, composed primarily of shadscale. Plant communities identified in the area are shadscale-gray molly, black greasewood-Gardner saltbrush, and a shadscale-gray molly/black greasewood transitional community; all three communities are low in species diversity. The vegetation forms an important ground cover that provides habitat for wildlife.

No wetlands or other aquatic habitats are present at or in the vicinity of the representative facility. The nearest stream channel ends approximately 3 kilometers (1.9 miles) east of the site, and the nearest body of permanent surface water is Big Spring, about 45 kilometers (28 miles) east of the facility.

REFERENCES

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APPENDIX C

OPERABLE UNIT 1
TREATABILITY STUDY SUMMARY

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LIST OF ACRONYMS

ARAR	Applicable or Relevant and Appropriate Requirements
As	Arsenic
ASTM	American Standard for Testing and Materials
B	Boron
BF	Bulking Factor
BFS	Blast Furnace Slag
CaO	Calcium Oxide
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CPC	Constituent of Potential Concern
CRSP	Cooperative Remedy Screening Program
CRU1	CERCLA/RCRA Unit 1
DOE	United States Department of Energy
EPA	Environmental Protection Agency
ERMC	Environmental Restoration Management Contractor
EVA	Ethyl Vinyl Acetate
FEMP	Fernald Environmental Management Project
HEPA	High-Efficiency Particulate Air
HF	Hydrofluoric Acid
Hg	Mercury
K	Potassium
Li	Lithium
LLD	Lowest Level of Detection
MAWS	Minimum Additive Waste Stabilization
MCC	Materials Characterization Center
MgF_2	Magnesium Fluoride
MgO	Magnesium Oxide
MPCT	Modified Product Consistency Test
MTCLP	Modified Toxicity Characteristic Leaching Procedure
Na	Sodium

LIST OF ACRONYMS
(Continued)

ND	Not Detected
NLR	Normalized Leach Rate
NOX	Nitrogen Oxide
pCi	picoCuries
PCT	Product Consistency Test
pe	Polyethylene
pet	Polyethylene Terephtalate
Pu	Plutonium
Ra	Radium
RCRA	Resource Conservation and Recovery Act
Rn	Radon
RI/FS	Remedial Investigation/Feasibility Study
SOX	Oxides of Sulfur
Sr	Strontium
SRHLWC	Savannah River High Level Waste Criteria
Tc	Technetium
TC	Toxicity Characteristics
TCLP	Toxicity Characteristic Leachate Procedure
Th	Thorium
UCS	Unconfined Compressive Strength
USCS	U.S. Soil Conservation Service
w/w	Wet Weight

LIST OF MEASUREMENTS

cc	cubic centimeter
cm	centimeter
cm/s	centimeters per second
cy/hr	cubic yards per hour
dpm	disintegrations per minute
ft^2	square foot
g	grams
g/cm^3	grams per cubic centimeter
gpm	gallons per minute
kg	kilogram
lb	pound
pCi/g	picoCuries per gram
ppm	parts per million
psi	pounds per square inch
rpm	rotations per minute
tsf	tons per square foot

APPENDIX C

SECTION 1
INTRODUCTION

C.1.0 INTRODUCTION

This appendix summarizes the results of vitrification, cement solidification/stabilization, and thermal treatment and particle agglomeration treatability studies. All treatability work was performed based on work plans prepared in accordance with the U.S. Environmental Protection Agency's (EPA) "Guide for Conducting Treatability Studies Under CERCLA," Interim Final (EPA 1988) and Final (EPA 1992) editions. Additional details on all Operable Unit 1 treatability studies are provided in the work plans referenced for each study and in the Treatability Study Report for Operable Unit 1, Final (DOE 1993).

APPENDIX C

SECTION 2
VITRIFICATION TREATABILITY STUDY

C.2.0 VITRIFICATION TREATABILITY STUDY

C.2.1 INTRODUCTION

Vitrification treatability studies were carried out in support of the Operable Unit 1 remedial investigation feasibility study (RI/FS) process currently underway at the Fernald Environmental Management Project (FEMP). All treatability work was performed based on work plans prepared in accordance with the U.S. Environmental Protection Agency's (EPA) "Guide for Conducting Treatability Studies Under CERCLA," Interim Final (EPA 1988) and Final (EPA 1992). Additional detail on the studies may be found in the referenced work plans and in the Treatability Study Report for Operable Unit 1, Final, (DOE 1993).

C.2.2 TREATABILITY TEST METHODOLOGY

Vitrification studies were performed in a phased approach:

- Vitrification Remedy Screening/Remedy Selection Studies; Work Plan - IT 1990, Treatability Study Work Plan for Operable Unit 1
- Vitrification Remedy Design - Laboratory Scale; Work Plan - GTS Duratek/Catholic University of America 1992, Remedy Design Laboratory Studies, Part I: Vitrification
- Vitrification Remedy Design - Bench Scale (MAWS); Work Plan - R.M. Parsons, 1992, OU1 Minimum Additive Waste Stabilization (MAWS) Remedial Design Bench-Scale Treatability Study Work Plan

C.2.2.1 Vitrification Remedy Screening/Remedy Selection Studies

The remedy screening/remedy selection studies consisted of two phases:

- Preliminary Phase - for Remedy Screening
- Advanced Phase - Stages 1 and 2, and Optional Stage for detailed analysis of alternatives and Remedy Selection

Where possible, experiments were based on a statistically designed matrix to maximize the information gained in the fewest experiments. This work was an iterative process where the results from the experimental matrices were used to determine the course of the next set of experiments. See Figure C.2-1 for the logic of the vitrification screening.

C.2.2.1.1 Preliminary Phase (Composite Samples)

The first step of the vitrification screening process was to determine the glass-forming characteristics of the waste without the addition of vitrifying reagents. In a series of range-finding experiments, various amounts of sodium hydroxide were added to mixtures of waste, flyash, and soil to determine the sodium hydroxide concentration needed to lower the melting point temperature to about 1250°C.

As a target, the reagent waste mixture was to have between 40 and 60 percent combined silicon oxide and aluminum oxide content, and 10 to 20 percent sodium oxide content when dried. It was expected that this range of silicon oxide and aluminum oxide content would produce durable glass. Sodium hydroxide could be added to the mixture before heating to increase the sodium oxide content of the vitrified waste and to cause the mixture to melt at 1250°C in a muffle furnace. This temperature was chosen to give a reasonable compromise among the cost of adding sodium oxide content to lower the melting point, the expected increase in leachability as the melting point of mixture is lowered, and the energy cost to melt and form the vitrified material.

Composite samples were then used in the remedy screening phase. Glass-forming agents such as site flyash (waste being addressed in Operable Unit 2), site soil/sand, and modifiers such as sodium hydroxide were added separately to the waste, and the mix was vitrified to determine the best combination of waste and glass-forming/modifying agents. The two formulations without sodium were deleted because range-finding experiments showed sodium was needed to form a glass product.

C.2.2.1.2 Advanced Phase - Stage 1 (Strata Samples)

The most promising formulas developed during the Preliminary Phase were applied to the top, middle, and bottom strata of each boring from Waste Pits 1 through 4 and the Burn Pit to determine the effect of varying waste composition. It was important to test the individual layers of the waste pits because of the heterogeneous nature of the waste pits. In addition, the one or two most promising formulations were also applied to composite samples from Waste Pits 5 and 6 and the Clearwell. The most promising formulations were those which met the leachability criteria, and minimized both the volume increase of the resultant waste and the cost of reagents.

C.2.2.1.3 Advanced Phase - Stage 2 (Strata Samples)

Advanced Stage 2 and the Optional Stage were not performed because sufficient data had been developed in the Advanced Phase - Stage 1 studies to support remedy selection.

C.2.2.2 Vitrification Remedy Design - Laboratory Scale

The study was intended to delineate the compositional range which met the combined requirements of leach resistance and processibility. FEMP flyash and soils were used as sources of silica in the process to reduce the amounts of chemical additives needed and thereby reduce process costs. Additional chemical additives investigated included (as oxides) sodium oxide, boric acid, and calcium oxide. A flow-diagram illustrating the sequential steps in glass preparation and glass characterization is given in Figure C.2-2.

A series of crucible melts and minimelter runs using Waste Pit 5 sludge were performed to select design and operating parameters. Small crucible melts (400 g) were prepared at temperatures of between 1100-1250°C (typically around 1150°C). The objectives of this study were two-fold: 1) to provide a database on the composition dependence of key process and product parameters to permit selection of the optimum feed composition under a variety of alternative assumptions and 2) to permit an assessment of the tolerance of these parameters to variations in feed stream composition. The key process parameters included sludge loading, melt viscosity, electrical conductivity, development of secondary phases, and processing temperatures. Some of the crucible melts were produced under reducing conditions to determine the effect of redox state on the glass materials as indicated.

Two compositions were selected based on the crucible melts and used for process demonstrations in a small-scale, continuous joule-heated, ceramic melter. These runs provided data on processing rates, cold-cap formation, foaming, and off-gas characteristics. Process parameter measurements taken included temperature readings, current and voltage readings, and feed rates and concentrations of significant species in the off-gas stream. Species in the off-gas included oxides of nitrogen (NOX), hydrofluoric acid (HF), oxides of sulfur (SOX), and volatile metals.

From the data collected, a range of optimal compositions was identified and requirements for additives such as glass formers or fluxing agents were determined. The program made full use of any suitable FEMP waste materials that could be used as additives in the process and which would result in cost savings for the vitrification process. Throughout these efforts, maximum loading of waste per glass volume was considered a critical parameter.

C.2.2.3 Vitrification Remedy Design - Bench Scale (MAWS)

The MAWS (Minimum Additive Waste Stabilization) program will determine if glass can be produced on a remedial scale. The MAWS technology demonstration program is an integrated waste treatment system designed to integrate multiple technologies required to blend multiple waste streams, thus minimizing the need for chemical additives. The bench-scale unit consists of a 0.25 cubic yard per hour (cy/hr) soil washing unit to reduce the contaminated soil volume, a 300 kilogram per day (kg/day) vitrification unit, and a 100 gallon per minute (gpm) wastewater treatment system. This study was originated as an Operable Unit 1 treatability project and is currently ongoing. Responsibility for this project has been reassigned to Operable Unit 4. A separate report on this project will be issued by Operable Unit 4.

C.2.3 TEST OBJECTIVES AND DATA REQUIREMENTS

C.2.3.1 Vitrification Remedy Screening/Remedy Selection Studies

The objective of the remedy screening/remedy selection studies was to develop reagent formulations for vitrification by varying the ratios of waste to binder, thus minimizing the amounts of binder required to produce an acceptable waste form. Acceptable formulations met Toxicity Characteristic Leachate Procedure (TCLP) standards, formed a durable glass, and had a minimum volume increase.

Specific performance objectives were established and used to determine if a particular reagent mixture produced an acceptable waste form. The specific objectives were:

- To develop a database of vitrification reagents, and corresponding hazardous and radioactive materials leachability data for vitrified waste forms

- To determine vitrification reagents and relative quantities required to minimize leachable concentrations of radionuclides and Hazardous Substance List constituents from the final waste form
- To minimize the final volume of treated waste
- To estimate the volumes of treated waste generated by each process
- To provide leaching characteristics for use in fate and transport modeling
- To develop preliminary reagent mixtures for use in future treatability studies
- To develop process parameters, such as percent moisture in the raw waste, for use in future treatability studies
- To provide chemical and radiological data
- To establish the proof of process and applicability of the selected stabilization technology
- To screen a large number of parameters and identify those critical to future bench-scale studies
- To provide data for the detailed evaluation of alternatives in the Feasibility Study

C.2.3.2 Vitrification Remedy Design - Laboratory Scale

The objective of this treatability study was to generate detailed scale-up, design, performance, and cost data to implement and optimize the selected remedy. This study focused on optimizing process parameters which were not developed as a part of the remedy screening and remedy selection studies.

The data generated for this study were of the following types:

- Physical and Chemical Characterization Data
- Process Measurements (Rates, physical parameters such as temperatures)
- Product Characterization Data (such as viscosity, conductivity, leachate analysis)

The acquired data were intended to assess whether the immobilization of the hazardous/radioactive components in the vitrified waste form had been achieved and if the product was processible as, well as, leach resistant.

Process parameters evaluated included sludge loading, processing rate, melt viscosity, electrical conductivity, development of secondary phases, and processing temperatures. Key product parameters included durability, modified Materials Characterization Center Test (MCC-3 Test), microstructure, and overall volume reduction. Results of the Product Consistency Test (PCT) and TCLP tests were used to evaluate the long-term effectiveness of each waste form.

C.2.4 RESULTS AND DISCUSSION

This section includes a discussion of waste stream characteristics and their effects on vitrification for each waste pit. Data from the treatability studies are also summarized and presented by waste pit. Data analysis and interpretation of MAWS studies will appear in a separate report to be issued by Operable Unit 4.

C.2.4.1 Analysis of Waste Stream Characteristics

The heterogeneity of the waste streams is a major factor in analyzing the applicability of vitrification for all or part of the waste pit material. The heterogeneity makes the material difficult to characterize adequately and provides a significant challenge in identifying treatment processes which will be effective for all or most of the material types.

Waste stream characteristics which may affect vitrification include the presence of glass-forming and fluxing agents. The waste pits contain significant quantities of calcium, which is a fluxing agent. The quantity of silica, a glass-former, varies greatly from pit to pit, but quantities are generally low. Large quantities of magnesium fluoride are present in all of the waste pits. The large quantity of fluoride may pose a significant corrosivity problem when waste is heated to temperatures required for vitrification. Waste Pit 2 contains the most significant quantities of organics. These are not expected to have any significant impact on vitrification processing. Metals can cause problems in a vitrification process. If they cannot be successfully incorporated within the glass, they may sink to the bottom of the melter, which can short out the melter if it is not properly designed. The formulas developed will need to be extremely robust and capable of successfully vitrifying material with a wide variety of chemical compositions. The waste pits also contain a large quantity of debris that needs to be segregated and treated separately, or size reduced and incorporated within the melt. The

radionuclides present in the waste pits should be incorporated within the vitrified product without significant problems in off-gas or leaching.

C.2.4.2 Analysis of Treatability Study Data

C.2.4.2.1 Remedy Screening/Remedy Selection

Variables considered for evaluation of vitrification reagent mixtures were leachability, bulking factor, and physical characteristics (e.g., melt viscosity, "glass-like" final product, crystallinity, porosity, opacity, and texture). Initial glass formulations were based on the sodium silicate model with the objectives of greater than 35 percent glass former content with a former to flux ratio of at least 0.5 in each melt. Formulations attempted to maximize waste loading and minimize the sodium/flux addition while maintaining a viscosity of 20 to 100 poise at a melt temperature of 1250°C.

Thirty-four range-finding experiments were carried out to evaluate: 1) the ability of waste material from each pit to vitrify on its own, 2) the need for additional flux (e.g., sodium hydroxide) to produce melts at 1250°C or less, and 3) to show the possible loadings and resulting product character for mixtures of pit waste plus site soil or flyash.

Fifty-eight samples were generated during Remedy Screening. Each waste/soil and waste/flyash mixture chosen was processed at two different sodium/flux levels to vary viscosity, provide observations on glass processibility, and determine the effect of flux concentration on metal leachability during Modified Product Consistency Test (MPCT) and Modified Toxicity Characteristic Leaching Procedure (MTCLP) evaluations. Waste/soil and waste/flyash formulations developed for Remedy Selection testing were chosen based on best glass-like appearance, acceptable melt viscosity, and lowest leaching of radionuclides and anions during MPCT and MTCLP leach testing.

The visual (physical characteristics) parameters that determined if the formulation produced an acceptable waste form were: melt viscosity (pourable), "glass-like" final product, nonporous, color, reactivity with the crucible, and homogeneity of the melt (single phase). Melt viscosities were estimated visually and molten products ranged from very thin pouring liquids to nonpourable monoliths. A scale of five intervals was established as follows:

- V-1: nonpourable at melt temperature; melt remains a uniform monolith within the crucible when removed from furnace and inverted; estimated as > 100 poise
- V-2: near-pourable at melt temperature; melt deforms when removed from furnace and inverted; may be induced to pour by raising temperature; estimated as approximately 100 poise
- V-3: ideal viscosity; pours freely from crucible at melt temperature; estimated as approximately 70 poise
- V-4: low viscosity; very thin liquid; etches crucible surfaces; estimated as around 20 poise
- V-5: very low viscosity; corrosivity causes crucible damage, dissolution, or meltdown

The color of vitrified samples, while not a direct indicator of the quality of a vitrified product, was also noted. The color of vitrified samples and color changes after remelting typically highlighted phase separations or incompleteness of vitrification. The range of colors observed were bright yellow, light beige, amber, green, greenish-brown, brown, and black.

The best preliminary phase formulations were carried forward into Remedy Selection. The 43 samples generated during the advanced phase were subjected to full-scale TCLP, PCT, and radon analysis.

Compositional Analyses

The major glass components of the waste, local soil, and local flyash were determined to assist in the formulation development of the various pit wastes. The dry blend formulations of waste and additives were selected for the initial range-finding experiments based on the compositional analyses. Each dry blend formulation was selected so that enough soil or flyash was added to the waste to form a melt with 30 to 60 percent glass formers. Initial range-finding experiments were crucible melts of pit wastes with no additives. If the solidified product did not look like a glass, or had obvious crystal in it, or if the crucible became damaged or destroyed during the melt, additional soil or flyash was added to the next range-finding experiment. If the mixture did not melt at 1250°C, or if the melt was very viscous, more sodium/flux (e.g., sodium hydroxide or sodium carbonate) was added to the waste.

As a vitrification additive, the flyash, at 94.98 mole percent glass formers and 5.02 mole percent fluxes, is superior to the site soil. While the glass former content of the site soil is significant at 64.20 mole percent, the accompanying 35.80 mole percent fluxes seriously detracts from its usefulness as a vitrification additive. These differences should be kept in mind when reviewing preliminary and advanced phase waste/soil and waste/flyash formulas.

Performing Melts

Generally, addition of flyash or soil, as compared with vitrification of the waste without additives, decreased the leachability of uranium. There is an apparent trend to adding flyash to achieve lower leachability of uranium as compared to adding soil. Increasing the sodium added with the flyash generally increases the leaching of uranium. However, with samples made with soil from Waste Pits 1, 4, and 6, the leachability of uranium decreased for formulations using the higher loadings of sodium. None of the other metals, except barium, leached in sufficient quantities to present a problem. Barium leached in sufficient quantities to provide trends. Barium leaching in Waste Pits 1 through 6 supported the previously stated trend that increased sodium loadings increased leaching of uranium. This trend was true with both flyash and soil additions. In the Burn Pit and Clearwell, no barium leaching trends could be established as a function of formulation.

Leach Testing

TCLP - Full TCLP analysis was performed for the remedy selection phase. Results are included for metals and radionuclides. No organics were detected in any of the TCLP leachates. Results are presented in dilution adjusted concentrations. Results were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample. If the sample dilution factor was less than 1, a dilution factor of 1 was used.

PCT - The Savannah River Product Consistency Test was performed. The PCT is a static seven-day leach test for waste glass, which compares the Normalized Leach Rate (NLR) for glass components to a standard reference glass. The leachate data for the metals of interest to vitrification (aluminum [Al], boron [B], lithium [Li], potassium [K], magnesium [Mg], sodium [Na], silicon [Si] and uranium

[U]) were used to calculate a NLR and are expressed as a percentage of the Savannah River High Level Waste Criteria (SRHLWC). NLRs are presented as averages for the three pit zones.

Radon Emissions - Radon leach testing and radon emanation testing were performed on the vitrified samples. Radon results were multiplied by the reagent dilution factor so the results were expressed relative to the actual amount of pit waste in the vitrified sample. The results in these figures were based on the average result of measurements made on a test specimen from each zone of the pit. It was not possible to draw any conclusions regarding the effectiveness of one vitrification formulation versus the other because irregular pieces of glass were used for the radon emission tests, and the amount of radon released was a function of the surface area of the glass. With smaller pieces, a higher rate per unit weight would result. This factor also explains why the leach rates were lower than the emanation rates. Larger pieces were used in the emanation experiment, so higher rates resulted. Rates for both leaching and emanation in air were lower than calculated rates and rates measured from the raw waste.

Physical Characterization - In the descriptions of the vitrified pit products, a consistent vocabulary was used to describe individual physical texture. The purpose of such descriptions is to locate each product along the scales of increasingly glass-like character and processible viscosity. The following terms are descriptors used for describing physical texture.

- Charred/charcoal-like: appears charred with cracks, holes, or fissures; spongy texture with no significant volume reduction; very porous
- Crystalline: exhibits minute crystals or flakes; friable into powder; rounded edges on fragments; porous
- Granite-like: surface rough to touch; breaks into powder; appears fairly porous
- Porcelain: exhibits smooth surface; fragments into chunks but does not powder; nonporous; may exhibit slag-like features and entrapped gas bubbles
- Glass/Vitreous: exhibits high glossy, smooth surface; fragments into slivers/shards with sharp edges; very nonporous; translucent

C.2.4.2.2 Remedy Design - Laboratory Scale

Additional vitrification laboratory testing was performed by GTS Duratek/Catholic University of America to develop a better database to assess vitrification as a treatment process. Work was performed using material from Waste Pit 5 and included additional crucible melts, analysis of process variables, and small 10 kg melter runs. Work is currently underway to develop the same information database on materials from Waste Pits 3 and 4. Final results of the laboratory studies on Waste Pit 5 material are included in the Waste Pit 5 section of this report. The results available to date on work with Waste Pit 3 and 4 material are presented in the Waste Pit 4 section of this report.

C.2.4.3 Waste Pit 1

C.2.4.3.1 Compositional Analysis

As vitrification feed material, Waste Pit 1 contains 6.76 mole percent glass formers and 93.24 mole percent flux. The former/flux ratio is 0.073, significantly less than the desired 0.5 or greater. Additionally, compositional data reveal the presence of Resource Conservation and Recovery Act (RCRA) metals, uranium, and thorium at levels that might result in significant leaching in poor glass formulations.

C.2.4.3.2 Range-Finding and Remedy Screening Tests

Initial range-finding testing generated five samples that evaluated the performance of Waste Pit 1 composite material to vitrify as-is, with soil, and with site flyash. Remedy Screening generated eight samples that further refined the evaluation of soil, flyash and sodium/flux additives. Table C.2-1 presents formulations and results for these tests.

Four experiments with the waste-only formulation were performed using increasing loadings of sodium/flux to reduce the high melt viscosity. Products ranging from porous to completely vitreous were achieved, all with very low viscosities and all resulting in crucible meltdown. These results reflect the inherent low glass former, high flux content, and the corrosivity such a composition becomes under molten conditions. The melting points of a significant portion of the waste's constituents (e.g., MgF_2, MgO, and CaO) all exceed 1250°C and may not have vitrified even with additional sodium flux. No leach tests were performed on these products.

Two waste/soil formulations also were tested (designated as P1-10 and P1-11), repeating P1-5 formulation in one and in the other reducing the sodium/flux addition by half. The original formulation produced a better appearing glass, single phase, and less brittle. Neither formulation leached uranium or gross alpha/beta in the MPCT and MTCLP tests, but the better appearing glass leached higher sodium and fluorine in the MPCT. P1-10 was deemed an overall better glass and the formulation was developed in the advanced phase testing.

Two waste/flyash formulations (P1-12 and P1-13) were developed to further evaluate the range-finding formulations. The P1-12 formulation produced a pourable melt (V-3/V-4), which cooled to a good quality, black glass with some yellow phase separated inclusions. The P1-13 formulation produced a slightly more viscous melt that cooled to a vitreous, near-crystalline glass with granulated streaks running through it. Both formulations performed well in the leach tests, neither leaching significant radionuclides or RCRA metals. The lower sodium/flux formulation P1-12 was chosen for testing in the advanced phase. The sodium level was lowered for the advanced phase testing; it was theorized that lower sodium levels would further reduce leaching of uranium.

C.2.4.3.3 Remedy Selection Tests

The formulations used on each zone in the advanced phase experiments are given in Tables C.2-2. Table C.2-3 summarizes the bulking factors. The melts had high viscosities that trapped bubbles in them when cooled. The products ranged from granite-like to semi-crystalline, and ranged in color from black to tan. The bulking factors ranged from -2.6 to 84 percent.

Results for the Waste Pit 1 vitrification TCLP radionuclides for the two formulations are shown in Table C.2-4. The metals in the TCLP leachates from untreated characterization samples and the waste treated with the two vitrification formulations, are shown in Table C.2-5, along with the TC criteria for metals. Both formulations pass the TC regulatory criteria. Formula 2 performs better than Formula 1 for inorganic compounds.

The results of the PCT are presented in Table C.2-6 and generally show the flyash formulation was less leachable than the soil formulation. The soil formulation exceeded the SRHLWC for boron. The

majority of metals leached at less than 6 percent. Uniformly the worst performers were sodium and potassium at 14 to 73 percent and 0.2 to 20 percent of the SRHLWC, respectively. The Zone 3 duplicate sample performed at the 73 percent level. The waste/flyash product had the lowest overall NLR for the Pit 1 waste.

C.2.4.3.4 Radon Emissions

Results of radon emissions testing is given in Figures C.2-3 and C.2-4. These figures show that vitrification was effective in reducing the radon emissions.

C.2.4.4 Waste Pit 2

C.2.4.4.1 Compositional Analysis

As vitrification feed material, Waste Pit 2 contains 65.67 mole percent glass formers and 34.33 mole percent flux. The former/flux ratio is 1.913 and satisfies the desired 0.5 or greater target. Additionally, compositional data reveal the presence of chromium (Cr), uranium (U), and thorium (Th) at levels that might result in significant leaching in poor glass formulations.

C.2.4.4.2 Range-Finding and Remedy Screening Tests

Initial testing generated five samples to evaluate the performance of Waste Pit 2 composite material to vitrify as-is, with soil, and with site flyash. Remedy Screening generated seven samples to further refine the evaluation of soil, flyash, and sodium/flux additives. Table C.2-7 presents formulations and results for these tests.

Two waste/soil formulations were tested (P2-7 and P2-8), repeating the P2-3 formulation in P2-7, and in P2-8, reducing the sodium/flux addition by half. Both formulations produced single-phase, vitreous products of low to medium viscosity. Leach test performances of these formulations differed only in leachable uranium, 9.3 ppm for P2-7 and 1.2 ppm for P2-8. Leachable gross alpha/beta, metals, and anions were all at low ppm to nondetectable levels. The low flux formulation (P2-8) was chosen for advanced phase testing due to its reduced leachable uranium performance.

Four experiments were performed with waste/flyash mixtures to refine the P2-5 range-finding formulation. Various sodium/flux additions were tested. At 5.2 percent and 7 percent additions, very high viscosity (V-1) melts were produced that cooled into either a near-vitreous, slag-like material (P2-9) or a glossy, nonporous, single-phase monolith. At 7.7 percent and 8.3 percent flux addition, melt viscosity was reduced to pourable (V-2/V-3) and achieved a glossy black vitreous character. The two glass samples taken through leach testing (P2-11 and P2-12) both leached small amounts of uranium (0.3 to 0.4 ppm) in the MTCLP, but only low to nondetectable gross alpha/beta, metals, and anions. Due to its processible viscosity and satisfactory character as a glass, the 8.3 percent sodium/flux addition formulation (P2-11) was chosen for advanced phase waste/flyash testing.

C.2.4.4.3 Remedy Selection Tests

The advanced phase Waste Pit 2 zone samples used the formulations listed in Table C.2-8. The soil formulation, Formula 1, produced a black, nonporous glass of pourable melt viscosity with the Zone 1 material but was less effective on waste from other zones. With Zones 2 and 3, a high viscosity melt was produced that cooled to a multi-phase, nonporous material, Remelting produced a more homogenous, better quality glass. Apparently, the heterogeneity of zone composition requires a longer processing period to produce the kind of glass observed in the remedy screening tests using this soil formulation. The bulking factor of these glasses was uniformly negative, from -47 to -66 percent, indicating substantial volume reduction after processing. Refer to Table C.2-9.

The flyash formulation, Formulation 2, produced low to high viscosity melts across the three zones, resulting in products of nonporous, semivitreous character. The Zone 3 glass exhibited a slag-like cap with entrapped gas bubbles as was observed during remedy screening tests (e.g., Sample No. 10501902). Resolution of this slag problem might require a higher sodium/flux loading for the Zone 3 material. The bulking factors for these waste/flyash products was uniformly negative, from -20 to -48 percent, which shows less volume reduction than with the waste/soil glasses.

Results for Waste Pit 2 TCLP radionuclides for the two formulations are shown in Table C.2-10. The metals in the TCLP leachates for the waste treated with the two formulations and the TC criteria for metals are shown in Table C.2-11. Both formulations pass the TC regulatory criteria. Formula 1

performs slightly better than Formula 2 for inorganic compounds. The leachability of radionuclides varied greatly. Formula 1 had better results for uranium (except for U-235/236) and Th-total. Formula 2 had better results than Formula 1 for Ra-226, Ra-228, Th-228, and Th-230.

The results of the PCT analysis in Table C.2-12 show the soil formulations prepared for each zone performed very well. Their NLRs were all below 1 percent of the SRHLWC except for sodium (Na), which did not exceed 2 percent of the SRHLWC. The waste/flyash glass average NLRs were all below 1 percent except for Na and B at 34 and 29 percent, respectively, of the SRHLWC. The waste/soil product had the lowest overall NLR for the Pit 2 waste. These very low values for the NLRs lend confidence to the durability of all the Pit 2 vitrified products.

C.2.4.4.4 Radon Emissions

Figures C.2-5 and C.2-6 both show that vitrification was very effective in lowering the radon leach and emanation rates. Even though Formula 1 appeared to be slightly more effective, the highest measured treated rate was approximately 1 percent of the untreated waste.

C.2.4.5 Waste Pit 3

C.2.4.5.1 Compositional Analysis

As vitrification feed material, Waste Pit 3 contains 48.22 mole percent glass formers and 51.78 mole percent flux. The former/flux ratio is 0.931 and satisfies the desired 0.5 or greater target. Additionally, compositional data reveal the presence of RCRA metals, uranium, and thorium at levels that might result in significant leaching in poor glass formulations.

C.2.4.5.2 Range-Finding and Remedy Screening Tests

Initial testing generated five samples that evaluated the performance of Waste Pit 3 composite material to vitrify as-is, with soil, and with site flyash. Remedy Screening generated six samples that further refined the evaluation of soil, flyash, and sodium/flux additives. Table C.2-13 presents formulations and results for these tests.

One as-is vitrified test sample was generated (P3-6) using a 7.4 percent sodium addition. The result was a low viscosity melt that cooled to a black vitreous to slightly porcelain-like material in which green streaks were observed. Slight corrosive attack was observed in the firebrick crucible, which suggests that no higher level of sodium addition would be recommended. Leach testing was performed on this sample and 3.3 ppm uranium and 0.03 ppm cadmium were measured in the MTCLP. Low ppm levels of metals and anions were observed in the MPCT, the highest being 53 ppm sodium and 35 ppm fluorine.

Two waste/soil formulations (P3-7 and P3-8) produced low to medium viscosity melts that cooled to good quality, single-phase glasses. The lower sodium addition P3-8 formulation produced a higher viscosity melt. Leach testing on these samples indicated very similar performances: low to nondetectable levels of gross alpha/beta, metals, and anions. Uranium leachability in the MTCLP was 5.9 ppm for P3-7 and 4.3 ppm for P3-8, while uranium was nondetect in the MPCT for both.

Because both formulations produced satisfactory glasses in Remedy Screening, the sodium/flux addition would be kept the same while the soil loading was increased. It was anticipated that additional glass former from the soil would further improve the quality of glass produced while the additional flux from the soil would help lower the melt viscosity.

Three waste/flyash formulations resulted in medium (V-2/V-3) to high viscosity (V-1/V-2) melts that cooled to products ranging in character from borderline vitreous porcelain to vitreous with potentially crystalline streaks. From visual inspection, P3-12 appears to be the best quality glass although vitrification appears to have occurred nonuniformly through the monolith. Perhaps with increased flux content or increased stirring during processing, a more homogeneous melt could have been achieved. Leach testing was performed for P3-11 and P3-12. Low levels of uranium leaching (0.3 to 0.5 ppm) were observed in the MTCLP and low ppm levels of metals and anions were observed in the MPCT. P3-12, the high sodium/flux level formulation, was chosen for advanced phase testing because it demonstrated the lowest melt viscosity and leachability performance.

C.2.4.5.3 Remedy Selection Tests

The advanced phase Waste Pit 3 zone samples used the formulations listed in Table C.2-14. The soil formulations, Formula 1, produced very different products across the three pit zones. Zone 1 material vitrified with a low viscosity and cooled to a dark amber glass with a bubbled slag-like cap. This zone material would benefit from a higher sodium-flux addition to better process the incompletely vitrified slag phase. Zone 3 produced a nonporous, borderline-crystalline, vitreous material. Apparently, the soil formulation did not provide sufficient glass former. The Zone 3 material probably contained levels and kinds of formers significantly different from the composite material used in the Remedy Screening testing. The bulking factors for the zone waste/soil products were uniformly negative, from -46 to -76 percent, indicating significant volume reduction after processing.

The flyash formulation, Formulation 2, produced low and high viscosity melts among the three pit zones. The cooled products ranged from nonporous, near-vitreous to slag-like with entrapped gas bubbles to granite-like. This trend toward granite-like material is consistent with what was observed in remedy screening tests where no truly vitreous product could be achieved. The bulking factors for these products presented in Table C.2-15 was uniformly negative, -50 percent to -67 percent, indicating a significant volume reduction after processing.

Results for Waste Pit 3 TCLP radionuclides for the two formulations are shown in Table C.2-16. The metals in the TCLP leachates for the waste treated with the two vitrification formulas and the TC criteria for metals are shown in Table C.2-17. Both formulations pass the TC regulatory criteria. Formula 2 performs better than Formula 1 for inorganic compounds. The leachability of the Formula 2 glass was as good as or better than that for Formula 1 for all radiological CPCs, with the exception of Ra-226.

The results of the PCT analysis showing the NLR are presented in Table C.2-18. The NLRs for the three waste/soil zone glasses were all below 1 percent of the SRHLWC except for Na, K, B, and Li, which in the Zone 3 sample reached 18, 7, 61, and 29 percent of the criteria, respectively. The

waste/flyash glass average NLRs were below 1 percent of the SRHLWC except for Na and B, which had 109 and 14 percent, respectively. The leachability of Na exceeded the SRHLWC.

C.2.4.5.4 Radon Emissions

Figures C.2-7 and C.2-8 both show radon leach and emanation rates much lower than the rates for untreated waste or the calculated rate.

C.2.4.5.5 Remedy Design - Laboratory Scale

The preliminary results of the compositional analysis and vitrification testing by GTS Duratek are presented as part of the Waste Pit 4 results.

C.2.4.6 Waste Pit 4

C.2.4.6.1 Compositional Analysis

As vitrification feed material, Waste Pit 4 contains 18.29 mole percent glass formers and 77.07 mole percent flux. The former/flux ratio is 0.237, below the desired 0.5 or greater target. Additionally, compositional data reveal the presence of RCRA metals, uranium, and thorium at levels that might result in significant leaching in poor glass formulations, especially the 4.63 mole percent/UO_3 present.

C.2.4.6.2 Range-Finding and Remedy Screening Tests

Initial testing generated five samples that evaluated the performance of Waste Pit 4 composite material to vitrify as-is, with soil, and with site flyash. Remedy Screening generated nine samples that further refined the evaluation of soil, flyash, and sodium/flux additives. Table C.2-19 presents formulations and results for these tests.

Four experiments with the as-is pit waste were performed with increasing loadings of sodium/flux to reduce the high melt viscosity. Nonporous products ranging from coal-like to glossy black resulted, all with very low viscosities. All but P4-8 resulted in crucible meltdown. These results reflect the inherent low glass former, high flux content of the waste, and the corrosivity of such compositions under molten conditions. The further addition of sodium/flux only exacerbated the problem. The melting points of a significant portion of the waste's constituents (e.g., MgF, MgO, and CaO) all

exceed 1,250°C and may not have vitrified even with additional sodium flux. No leach tests were performed on these products.

Two waste/soil formulations were tested (P4-11 and P4-12), repeating the P4-3 formulation in P4-11 and reducing the sodium/flux addition by half for P4-12. Both formulations produced glossy, nonporous, single-phase vitreous products, but their leachability performance differed significantly. The lower flux formulation (P4-11) leached considerably with 24,000 weight/weight (wt/wt) gross alpha and 5150 wt/wt gross beta), chromium (0.3 ppm), and uranium (U) (67 ppm) in the MTCLP. This poor leachability performance may be related to the observation of corrosive attack on the crucible during melt preparation. Such attack reflects unincorporated flux that can promote leachability. Due to the better quality of its vitrified product and leachability performance (nondetectable gross alpha/beta), formulation P4-12 was developed in the advanced phase testing.

Three waste/flyash formulations were tested during Remedy Screening. The range-finding waste/flyash formulation of choice (P4-5) was repeated with sodium/flux additions at 2.6 percent (P4-13), 5.7 percent (P4-14) and 7 percent (P4-15). The low flux formulation produced a very high viscosity (V-1) melt that cooled to a vitreous mass with slag-like cap, while the high flux formulation produced a pourable melt (V-2/V-3) that cooled to a porous slag with glossy nonporous inclusions. The medium flux formulation was prepared after observing the resulting products from the low and high formulations. The medium flux melt had a pourable viscosity (V-3) and cooled to a glossy black nonporous product streaked with beige crystalline material that had not vitrified. This incomplete vitrification may be due to either composition (e.g., high CaO and MgO), inadequate processing (e.g., insufficient mixing or time at temperature), or both.

The leachability performance of the medium (P4-14) and high (P4-15) flux formulations were evaluated by MPCT and MTCLP and found to be nearly identical: uranium leached from MTCLP (3.6 ppm; 3.6 ppm), gross alpha/beta leached at the lowest level of detection (LLD) for both MTCLP and MPCT, and low ppm levels of metals and sulfate were observed in the MPCT.

The medium flux formulation (P4-14) was taken into the advanced phase testing due to its greater vitreous, although heterogeneous appearance.

C.2.4.6.3 Remedy Selection Tests

The advanced phase Waste Pit 4 zone samples used the formulations listed in Table C.2-20. The soil formulation, Formula 1, produced low viscosity melts across the three zones that cooled to quite different products. Zones 1 and 2 products were nonporous, crystalline to vitreous with streaking of unvitrified material (e.g., yellow cake, green salt) through the interior. Remelts of these products produced darker, more homogeneous and single phase material. The Zone 3 product was light tan with crystalline, porous texture. More extensive furnace processing and sodium/flux addition would be required to improve the quality of these vitrified products. The bulking factors for these zone products shown in Table C.2-21 were positive, from 17 to 32 percent, indicating a slight increase in volume. As with Waste Pit 1, this increase is partially due to incomplete vitrification of waste constituents.

The flyash formulation, Formula 2, produced low to medium viscosity melts and cooled products fairly vitreous in character. Some slag-like coating and crystalline borders and inclusions were apparent, indicating that a longer processing time or higher sodium/flux addition is required. The bulking factors, as with the waste/soil products, were uniformly positive, from 57 to 68 percent.

Results for Waste Pit 4 TCLP radionuclides for the two formulations are shown in Table C.2-22. The metals in the TCLP leachates from the waste treated with the two vitrification formulations and the TC criteria for metals are shown in Table C.2-23. Both formulations pass the TC regulatory criteria. Formula 2 performs better than Formula 1 for inorganic compounds.

The results of the PCT expressed as NLRs are presented in Table C.2-24. For both formulations, boron exceeded the SRHLWC. For the waste/soil product, sodium also exceeded the SRHLWC.

C.2.4.6.4 Waste Pit 4 Vitrification - Radon Emissions

Results of radon emissions testing are given in Figures C.2-9 and C.2-10.

C.2.4.6.5 Remedy Design - Laboratory Scale

Analysis of Waste Pit 3 and Waste Pit 4 Materials

While Waste Pit 4 is mainly MgF_2, a flux for glass-making, Waste Pit 3 is mainly composed of SiO_2, a glass former. This suggests that vitrifiable feeds can be formed by blending these two materials. While Waste Pit 4 contains much more fluoride than Waste Pit 3 (Pit 3 has below the detection limit of 1 wt. percent fluoride), the two materials contain similar amounts of sulfates -- 3.4 weight percent.

The specific gravity of the Waste Pit 4 material, 3.39 g/cm^3 on a dried basis, is consistent with the fact that Waste Pit 4 is mainly composed of MgF_2 (specific gravity of MgF_2 is 3.0 g/cm^3). Likewise, the specific gravity of the Waste Pit 3 material, 2.82 g/cm^3 on a dried basis, is consistent with the fact that Waste Pit 3 is mainly composed of SiO_2 (specific gravity of SiO_2 is 2.5 g/cm^3). Both materials are very similar in weight loss and carbon content, but Waste Pit 4 material has a larger fraction of fine particles than Waste Pit 3 material; 86.4 weight percent passes mesh 200 for Waste Pit 4, while only 49.1 weight percent passes the same mesh for Waste Pit 3 material.

Crucible Melts from Waste Pit 3 and Waste Pit 4 Materials

Table C.2-25 lists the 13 crucible melts completed thus far. Crucible melts were begun to examine the viability of vitrifying Waste Pit 4 and Waste Pit 3 sludges with the F4-5 melt. For that glass, 30 weight percent of Waste Pit 4 and 55 weight percent of Waste Pit 3 were combined, obtaining a total waste loading of 85 weight percent on a dried basis. The glass had undissolved material, most likely due to the high SiO_2 content from the Waste Pit 3 material. More homogeneous glasses were obtained by lowering the amount of Waste Pit 3 and Waste Pit 4. To increase the total waste loading, various amounts of soil wash concentrates from Lockheed Environmental laboratory studies for the MAWS program were added, and some Waste Pit 5 material. Total waste loadings varied from 72 weight percent to 88 weight percent. All of the glasses were opaque, even the ones that showed no signs of crystallization which may be due to the presence of reduced iron in the melt.

One important glass processing requirement is that the glass should have a liquidus temperature significantly below the processing temperature. For formulations suitable for the 10 kg/d Duramelter test runs, the target is a liquidus temperature of below 1050°C. Three out of the eight glasses

examined had a liquidus temperature below 1050°C: F4-7, F4-9 and F4-10. F4-10 produced a heterogeneous crucible melt. Thus, at present, F4-7 and F4-9 are the most viable glass formulations for the 10 kg/day continuous joule-heated melter tests.

Other processing parameters of concern are the melt viscosity and electrical conductivity. The viscosity and conductivity were measured for six of the crucible melts (F4-4 and F4-7 through F4-11). The viscosity and conductivity of all of these crucible melts lie within the working range of the Duramelter joule-heated melter vitrification system. Some of the viscosity measurements are unstable around 1000°C, most likely as a result of the onset of crystallization.

Thus far, F4-7 and F4-9 are the most viable melts based on processing parameters. In addition to examining processing parameters, several of these glasses have been subjected to TCLP leach testing. The results of TCLP tests on five of those crucible melts are presented in Table C.2-26. All of the glasses passed the TCLP test. No data are presently available from PCT leach tests on these glasses, but based on earlier studies with Waste Pit 5 glasses, the performance is expected to be good.

Preliminary Assessment of Waste Pit 3 and Waste Pit 4 Vitrification

From the study thus far, both the F4-7 and F4-9 formulations would be viable candidates for vitrification of Waste Pit 3 and Waste Pit 4 sludges. Both glasses have acceptable viscosity and conductivity, have liquidus temperatures below 1050°C, and pass the TCLP test. Both the F4-7 and F4-9 blends, as prepared in crucible melts, appear to be somewhat reduced (with respect to redox state) after melting at 1150°C for one hour. This is unlikely to be the case for continuous melter operations however, since residence times are much longer and oxygen availability is often greater; this will be confirmed in the 10 kg/day continuous melter test runs. In fact, it was found that heat treatments for an additional three hours at elevated temperatures (1050-1100°C) is enough to produce oxidized glass. The components for F4-7 and F4-9 blends, on both dried and wet (as received) basis, are given in Table C.2-27. These formulations are composed of 74-77 weight percent waste on a dried basis, and 80-83 weight percent waste on a wet (as received) basis.

C.2.4.7 Waste Pit 5

C.2.4.7.1 Compositional Analysis

As vitrification feed material, Waste Pit 5 contains 12.94 mole percent glass formers and 87.06 mole percent flux. The former/flux ratio is 0.149, below the desired 0.5 or greater target. Additionally, compositional data reveal the presence of RCRA metals, uranium, thorium, and anions at levels that might result in significant leaching in poor glass formulations.

C.2.4.7.2 Range-Finding and Remedy Screening Tests

Initial testing generated four samples that evaluated the performance of Waste Pit 5 composite material to vitrify as-is, with soil, and with site flyash. Remedy Screening generated nine samples that further refined the evaluation of soil, flyash, and sodium/flux additives. Table C.2-28 presents formulations and results for these tests.

Two pit waste-only formulations with sodium/flux addition (P5-6 and P5-7) were tested in an attempt to lower the melting point of waste constituents and achieve a more vitreous product. A three percent sodium/flux level for P5-6 resulted in a nonfused, charred black material with an extremely porous texture. Leach testing of this formulation indicated that gross alpha at 2,230 wt/wt and gross beta at 10,200 wt/wt, cadmium (189 ppm), and sodium (354 ppm) leached appreciably in the MPCT, while in the MTCLP the gross beta (1,200 wt/wt) and chromium (1.7 ppm) were detected.

An 18 percent sodium/flux addition to the waste (P5-7) resulted in a pourable (V-3) melt that cooled to a phase-separated product. The outer surface of the monolith was coated with a porous, sulfur-like material through which in some areas a purely vitreous, transparent inner mass was visible. It is hypothesized that the high concentration of anions (fluorine, chlorine, SO_4, and PO_4) formed a separate, nonvitrified phase while, aided by the significant sodium/flux addition, the glass formers vitrified into the glass phase. Leach testing of this formulation revealed aluminum (216 ppm) and sodium (539 ppm) in the MPCT, and chromium (5.5 ppm) and selenium (0.7 ppm) in the MTCLP. Radionuclides (alpha, beta, and uranium) were at LLD in both.

In the as-is Remedy Screening, it appears that high levels of sodium/flux addition cannot bring some of the waste constituents into the vitrifying melt. The addition of soil and flyash helped make some progress towards this, but were unable to totally overcome this limitation.

Three waste/soil formulations were tested involving higher soil and sodium/flux loadings than tested during the range-finding phase. P5-8 at 5.2 percent sodium/flux addition produced a very high viscosity (V-1) melt that cooled to a porous, granite-like mass. No leach testing was done on this sample. P5-11 at 8 percent sodium/flux addition produced a pourable (V-3) melt that cooled to a bi-phasic monolith. Only the outer crucible-contacting surfaces exhibited the vitreous, sulfur-like second phase. The vitreous mass was an excellent glass. Leach testing of this sample indicated some leaching of cadmium (30 ppm), and sodium (33 ppm) in the MPCT and arsenic (1.0 ppm) in the MTCLP. Radionuclides (alpha, beta, and uranium) were at LLD for both. The effect of further raising the sodium/flux addition was investigated in P5-9. At 8.5 percent sodium/flux addition, a good glass was also produced with the same vitreous, sulfur-like second phase. Leach testing of this product revealed an essentially identical level of leaching for gross alpha/beta, metals, and anions.

The problem of a bi-phasic product could not be resolved with sodium/flux or soil addition. Because nothing more seemed to be gained from increasing flux addition from 8 percent to 8.5 percent, the 8 percent formulation (P5-11) was chosen for use in the advanced phase testing.

Four experiments were performed with waste/flyash mixtures to reduce the viscosity of the P5-4 range-finding formulation. Sodium/flux additions at 8.8 percent, 14 percent, 16 percent, and 18 percent were tested. At 8.8 percent and 14 percent additions, very high viscosity (V-1) melts were produced that cooled into slag-like masses with either a spongy-porous (P5-13) or fibrous texture (P5-12). Both products are very heterogeneous in texture and color of constituents. No leach testing was performed on these samples.

At 16 percent and 18 percent flux addition, melt viscosity reduced to pourable (V-2/V-3) and much more complete phase separation was effected. P5-15 exhibited only a small bottom rim of vitreous, sulfur-like second phase, while P5-14 still had layers of the yellow second phase interspersed

throughout it. Leach testing of these two samples detected low levels of metals and anions in the MPCT and MTCLP. P5-15 leached aluminum (31 ppm), silicon (32 ppm), and sodium (126 ppm) in the MPCT, and chromium (0.7 ppm) and uranium (0.3 ppm) in the MTCLP. P5-14 leached cadmium (25 ppm), silicon (24 ppm), and sodium (74 ppm) in the MPCT, and chromium (2.0 ppm) and uranium (0.2 ppm) in the MTCLP. Both were LLD for gross alpha/beta.

From the performance of the four test waste/flyash formulations, it was decided that the waste/flyash ratio was sound and that this formulation should be developed in the advanced phase testing.

C.2.4.7.3 Remedy Selection Tests

The advanced phase Waste Pit 5 composite sample used the soil and flyash formulations listed in Table C.2-29. The soil formulation (Formula 1) produced a low viscosity melt that cooled to a nonporous, dark amber glass that was streaked with yellowish-brown, incompletely vitrified material. This glass product was identical to that produced during Remedy Screening. The bulking factor, Table C.2-30, was -88 percent, indicating a significant volume reduction occurred.

The flyash formulation (Formula 2) produced a low viscosity melt that cooled to a multiphase, semiporous product identical to that produced during Remedy Screening. Its bulking factor was -69 percent.

Results for Waste Pit 5 TCLP radionuclides for the two formulations are shown in Table C.2-31. The metals in the TCLP leachates for the waste treated with the two vitrification formulations and the TC criteria for metals are shown in Table C.2-32. Both formulations pass the TC regulatory criteria. Formula 2 performs better than Formula 1 for inorganic compounds. The concentrations of the radionuclides were compared. Formula 2 had the better results. Specific exceptions where Formula 1 was better were Pu-238, Ra-228, and Sr-90. For all other radiological constituents of concern, Formula 2 had lower concentrations, or both formulas had NDs.

The results of the PCT expressed as NLRs are presented in Table C.2-33. The waste/soil composite glass sample leached at levels typically < 1 percent of the SRHLWC for the metals of interest. The

worst metals were Na and K at 9 and 10 percent of the SRHLWC, respectively.. The waste/flyash composite exceeded the SRHLWC for Na, K, and B.

C.2.4.7.4 Radon Emission

Figures C.2-11 and C.2-12 both show radon leach and emanation rates lower than the untreated waste or the calculated rate.

C.2.4.7.5 Remedy Design - GTS Duratek/Catholic University of America

Glass formulations for FEMP Waste Pit 5 sludges were developed which exhibit high leach resistance, acceptable melt viscosity and electrical conductivity, acceptable liquidus temperatures, and high waste loadings. Volume reduction calculations for Waste Pit 5 sludge (taking into account all additives added to produce a vitrifiable blend) yield a volume reduction of about 80 percent. Results are summarized in Tables C.2-34 through C.2-40.

The processibility of these formulations was demonstrated by test runs on a 10kg Duramelter vitrification system; significantly higher production rates proved possible with these feeds. Fluoride loss from the melt is an important factor which must be carefully addressed by potential vitrification (or any thermal) process technologies. The Duramelter system test runs successfully demonstrated the concept of fluoride capture in the off-gas system and recycle to the feed batch with fluoride emissions below regulatory levels. Measurements show very high intrinsic retention of heavy metals and radionuclides in the glass melt.

Glass formulas were designed to have process viscosities at 1200°C or lower. Vitrification equipment can be made of less costly materials with significantly less maintenance cost if the melt temperature is 1200°C or lower. No noticeable erosion was noticed in the GTS Duratek melter even after 1000+ hours of operation with actual and simulated high-fluoride Pit 5 wastes.

The pit wastes contain high percentages of fluoride as magnesium fluoride. Historically, commercial glasses have been made with fluoride concentrations up to 3 or 5 percent. A new level of fluoride stability was found in making fluoride glass with concentrations between 18 and 22 percent. These

glasses are durable, pass TCLP and PCT tests, and approach the durability of Savannah River highly-radioactive glasses.

To provide a fluoride glass process, some design obstacles had to be overcome. These were:

- Fluoride Off-Gas. During the initial mini-melter runs, it was discovered that the glass melts emit hydrogen fluoride. This was important for two reasons:

  - The glass formulas depends on the fluoride as a flux. If too much fluoride evaporates from the melt the glass becomes too viscous (thick) and the conductivity decreases. Fluoride evaporation can be significant. The amount lost is a function of time and temperature. The loss increased with time and higher temperatures. Up to 1/3 of the fluoride in the melt was lost.

  - The fluoride needs to be recovered. A fluoride recovery system was designed and installed with the MAWS melter. The recovery system uses sodium hydroxide which reacts with the hydrogen fluoride to produce sodium fluoride in a stainless steel reaction vessel. The fluoride is pumped, as a slurry, back to the tanks that feed the melter.

- Fluoride Effect on Glass Viscosity and Conductivity. Fluoride significantly reduces the viscosity of glass. The positive aspect is the lower viscosity means the glasses can be easily made at lower temperatures. The negative aspect is the glass leaks in a conventual melter. This resulted in a special design of the MAWS melter to prevent leaks.

- Fluoride Effect on Glass Conductance. Fluoride makes the glass more conductive. Adjustments to the standard melter design need to be made to melt highly conductive glasses efficiently.

Adjustments were made in the MAWS melter design to handle lower viscous and higher conductivity glasses. Additions to the off-gas system made the vitrification process more robust and capable of processing a wider range of wastes besides fluoride.

Additives used in the MAWS glass development include sodium oxide (from sodium carbonate), calcium oxide (from calcium carbonate), boron oxide (from borax and/or boric acid), and sodium fluoride. The sodium fluoride comes from the reaction of hydrogen fluoride in the off-gas with sodium hydroxide. Fluoride was added to crucible melts and surrogate melter runs to maintain

correct glass viscosity, conductance, and liquidus temperature[1]. The use of boron oxide as a glass additive helps stabilize the glass, reduces the liquidus temperature (by reducing crystallization), and increases waste loading.

Fernald site soils are not as good a source of silica (a glass former) as quartz sand. This is because the soils contain high concentrations of calcium (approximately 1/4 to 1/3 of the total dry weight as calcium carbonate) which forces the silica concentration to be lower. Also, the calcium in the soil is not needed because the pit wastes themselves generally have high concentrations of calcium. The calcium concentration usually ranges between 1/4 to 1/3 of the total dry weight.

Site soils could be used as a glass former for treatment of the waste pits if the soils need to be remediated. The best situation, if site soils need to be treated, is to use soil washing. The soil washing in the MAWS program physically separates the contaminated soil into three size fractions -- fine, middle, and course. The middle fraction is high in silica, and can be sent to the melter without further treatment. The fines and course fractions may be leached to remove the contamination and the contaminated residues may be sent to the melter. Clean soils are released. The middle fraction and the contaminated residues give higher waste loadings than the site soils themselves.

Cooling glass quickly through the liquidus temperature was found to increase the waste loading in some cases. Cooling glass slowly can cause the glass to devitrify. Such glass melts can 1) take on a granite, powdery, crystalline, fractured appearance; 2) change color, and/or 3) form particulate or crystals in the glass. These may or may not affect the leachability of the glass. Forming the glass into frit, marbles, or gems can quickly cool the glass below the liquidus temperature. This can increase waste loading above solid pours even when factoring in the void space between the glass pieces.

[1]The liquidus temperature is the temperature at which the glass will crystalize if maintained at this temperature for prolonged periods of time.

Most large-scale development activities were done on Waste Pit 5, but crucible studies also showed the glass formulations for the other pit sludges exhibit:

- High Leach Resistance, Treatment Effectiveness - The glasses pass the TCLP test and show very good performance in comparison with high-level waste glasses on the PCT test.
- Acceptable melt viscosity and electrical conductivity - The behavior of these properties with temperature makes these wastes suitable for processing in joule-heated melter vitrification system operating at temperatures around 1150°C.
- Acceptable liquidus temperatures - Overall phase stability imposed a major constraint on the formulation of high-waste loading compositions. However, a composition range was identified with sufficiently low liquidus temperature for processing at 1150°C.
- Contaminants are contained by the process - Approximately 99.9 weight percent of the uranium and thorium was contained within the glass before recycling of the off-gas system's scrubber sludge (i.e., volatilization of UF_6 is not a problem). Heavy metals and radionuclides are efficiently retained within the glass melt. The process off-gas passed/met air emission requirements/standards.
- Fluoride problems were overcome - Fluoride was captured in the off-gas system and recycled into the feed batch. Fluoride emissions were below regulatory levels.
- High waste loading - Waste Pit 5 sludges were processed between 77 to 88 weight percent continuously in melters.
- High volume reduction - Overall volume reduction calculations for Waste Pit 5 samples (counting all materials added to produce a vitrified blend, including soil and flyash) yielded a volume reduction of about 80 percent.
- Implementability - The process has been successfully proven on the 100-kg/day system using Waste Pit 5 waste at the Catholic University of America in Washington D.C. The 300-kg/day system has produced surrogate glass gems, but the system has not yet operated at full capacity with actual FEMP wastes.

C.2.4.8 Waste Pit 6

C.2.4.8.1 Compositional Analysis

As vitrification feed material, Waste Pit 6 contains 24.63 mole percent glass formers and 74.07 mole percent flux. The former/flux ratio is 0.333, which is below the desired 0.5 or greater target. Additionally, compositional data reveal the presence of chromium, uranium, and thorium at levels that

might result in significant leaching in poor glass formulations, especially with uranium at 6.69 percent (as UO_3).

C.2.4.8.2 Range-Finding and Remedy Screening Tests

Initial testing generated four samples that evaluated the performance of Waste Pit 6 composite material to vitrify as-is, with soil, and with site flyash. This second round of testing generated five samples which further refined the evaluation of soil, flyash, and sodium/flux additives. Table C.2-41 presents formulations and results for these tests.

The as-is range-finding formulation was modified by the addition of 8.5 percent sodium/flux addition. The resulting formulation (P6-6) produced a low viscosity (V-3/V-4) melt that cooled to a vitreous black-amber mass in which greenish-yellow streaks of a second phase material were still present. Leach testing of this product indicated that some leachability of uranium (15 ppm) in the MTCLP, and silicon (14 ppm), sodium (58 ppm), and fluoride (123 ppm) in the MPCT was evident. Gross alpha/beta was at the lower limit of detection (LLD) in both.

Two waste/soil formulations (P6-7 and P6-8) tested the ability of the P6-3 range-finding formulation to produce a good glass with reduced sodium/flux addition. P6-7 was an unmodified retest of the P6-3 formulation. It produced a low viscosity (V-3) melt that cooled to a transparent glossy black, nonporous glass. Leach testing of this glass indicated leaching of uranium (3.7 ppm) and chromium (0.2 ppm) in the MTCLP, and cadmium (27 ppm), silicon (14 ppm), and fluoride (31 ppm) in the MPCT. Gross alpha/beta were at LLD for both tests. P6-8 reduced the sodium/flux addition to 2.6 percent, which produced a low viscosity (V-3) melt that cooled to a good quality glass. Leach testing of this glass indicated that leaching was occurring for gross alpha (15,800 wt/wt), gross beta (4460 wt/wt), and uranium (1.4 ppm) in the MTCLP, and cadmium (45 ppm), silicon (23 ppm), fluoride (31 ppm), and sulfate (8 ppm) in the MPCT. It appears that increased leachability may parallel reduced sodium/flux content and, because of this, the higher sodium/flux formulation (5.2 percent; P6-7) was chosen for use in the advanced phase testing.

Two waste/flyash tests were designed to increase the flyash loading of the range-finding formulation and test the effect of lower sodium/flux loading. P6-11 raised the flyash to waste loading to 2:1 and kept the flux addition at 5.2 percent. It produced a pourable viscosity (V-2/V-3) melt that cooled to a nonglossy, porous, near-vitreous monolith. Leach testing of this product indicated that leaching of uranium (1.8 ppm) and chromium (0.1 ppm) was occurring in the MTCLP, and aluminum (5 ppm), silicon (11 ppm), and fluoride (3.5 ppm) in the MPCT. Gross alpha/beta were at LLD in both tests. P6-9 maintained the flyash to waste loading at 2:1, but reduced the flux loading to 2.6 percent and produced a good viscosity (V-3) melt that cooled to a glossy black, vitreous mass. Leach testing of this product indicated some leachability, uranium (2.7 ppm) in the MTCLP, and silicon (11 ppm) and aluminum, cadmium, magnesium, and fluoride (all <5 ppm) in the MPCT. Gross alpha/beta were LLD in both tests.

The low flux addition formulation (P6-9) produced a better appearing glass with acceptable leachability performance and was therefore chosen for use in the advanced phase testing.

C.2.4.8.3 Remedy Selection Tests

The advanced phase formulations are given in Table C.2-42. Table C.2-43 gives the bulking factors. The soil formulation, Formula 1, produced a high viscosity melt that cooled to a nonporous, dark amber glass with heavy streaking of incompletely vitrified material. This streaking was not observed during remedy screening. The bulking factor for this glass was 73 percent.

The flyash formulation, Formula 2, produced a low viscosity melt that cooled to a porous, crystalline product. The same material was produced during the Remedy Screening tests. The bulking factor for this material was -50 percent.

Results for Waste Pit 6 TCLP radionuclides for the two formulations are shown in Table C.2-44. The metals in the TCLP leachates for the waste treated with the two vitrification formulations and the TC criteria for metals are shown in Table C.2-45. Both formulations pass the TC regulatory criteria. Formula 1 performs slightly better than Formula 2 for inorganic compounds. The mean dilution adjusted concentrations for Formula 2 were lower for most of the radiological CPCs than Formula 1.

Of particular interest is the uranium concentrations which are an order of magnitude lower for Formula 2. Formula 1 had better results for Pu-238, Ra-226, and Th-230.

The results of the PCT expressed as NLRs are presented in Table C.2-46. The waste/soil glass NLRs were less than 1 percent of the SRHLWC except for the Na and K at 45 percent and 29 percent of the SRHLWC, respectively. Boron exceeded the SRHLWC for the waste/flyash product. Excluding sodium at 59 percent, the remaining metals were less than 4 percent of the SRHLWC.

C.2.4.8.4 Radon Emissions

Figures C.2-13 and C.2-14 show radon leach rates lower than the calculated rate.

C.2.4.9 Burn Pit

C.2.4.9.1 Compositional Analysis

As vitrification feed material, the Burn Pit waste contains 70.58 mole percent glass formers and 29.41 mole percent flux. The former/flux ratio is 2.40, the highest of all the waste pits. In addition, it contains the lowest combined concentration of cadmium and magnesium.

C.2.4.9.2 Range-Finding and Remedy Screening Tests

The as-is waste formulation was tested first and found to be very successful; therefore, waste/soil and waste/flyash formulations tests were unnecessary. Instead, during Remedy Screening, waste/soil and waste/flyash formulations were designed on the basis of past experience with the other waste pits.

The as-is formulation (P7-1) produced a low viscosity (V-4) melt that cooled to an excellent black glass. During Remedy Screening, the effect of sodium/flux addition was evaluated.

Remedy Screening generated eight samples that further refined the evaluation of soil, flyash, and sodium/flux additives. Table C.2-47 presents these formulations. For P7-2, the as-is formulation was supplemented with 7.4 percent sodium/flux and found to produce a good viscosity (V-3) melt and an excellent brownish-black glass. Leach testing of this glass indicated minor leaching of uranium (1.3 ppm) in the MTCLP and silicon (20 ppm) in the MPCT.

Two waste/soil formulations were designed at 0.5:1 soil to waste loading and at two levels of sodium/flux addition: 2.6 percent (P7-2) and 5.2 percent (P7-3). The higher flux formulation produced a fairly low viscosity (V-3/V-4) melt that cooled to a translucent, glossy black glass. Leach testing of this glass indicated leaching of uranium (3.7 ppm) and chromium (0.2 ppm) in the MTCLP, and cadmium (24 ppm) and silicon (24 ppm) in the MPCT. Gross alpha/beta were LLD for both tests. The lower flux formulation produced a medium viscosity melt (V-2/V-3) that cooled to a glossy, dark black glass with a second phase of undissolved specks. These specks appeared to be crystalline in nature and may have been an artifact of too slow a cooling rate or indicative of minor attack or intrusion of the firebrick crucible. Leach testing of this glass indicated minor leaching of uranium (0.3 ppm) in the MTCLP, and cadmium (12 ppm) and silicon (21 ppm) in the MPCT. Gross alpha/beta were LLD for both tests.

Considering the quality of glass produced (e.g., appearance and leachability performance) as compared to sodium/flux addition, it was decided that no significant advantage was gained from a sodium/flux addition beyond 2.6 percent. Therefore the lower flux level formulation (P7-4) was chosen for use in advanced phase testing.

Five waste/flyash formulations were tested, maintaining a 1:1 flyash to waste loading ratio and adjusting the sodium/flux addition from 4.6 percent up through 9.6 percent. The 4.6 percent formulation (P7-5) produced a very high viscosity melt (V-1) and a slag-like monolith with entrapped gas bubbles. The 7 percent formulation (P7-6) produced an equally unpourable monolith with undissolved crystalline inclusions. Due to the very poor quality of these products, no leach testing was performed on them. The 7.7 percent formulation (P7-6) was designed after seeing the results of the other four runs. It produced a pourable (V-2/V-3) melt that cooled into a glossy amber-black glass. Leach testing of this glass indicated slight leaching of uranium (0.6 ppm) in the MTCLP, and aluminum (7 ppm) and silicon (14 ppm) in the MPCT. Gross alpha and beta were at LLD for both tests.

Continuing with the higher flux formulations, the 8.3 percent formulation (P7-7) produced a very high viscosity (V-1) melt that cooled to a glossy, dark amber glass. When broken into thin frag-

ments, it was very homogeneous and completely vitreous. Leach testing of this glass indicated minor leaching of uranium (0.2 ppm) in the MTCLP, and all metals and anions at <3 ppm in the MPCT. Gross alpha/ beta were at LLD for these tests. The highest flux formulation was 9.6 percent; it produced a low viscosity (V-3/V-4) melt and cooled to an excellent amber-black glass. Leachability results indicated trace leaching of uranium (0.4 ppm) in the MTCLP, and aluminum (8 ppm), silicon (17 ppm), and sodium (30 ppm) in the MPCT.

Although some of the waste/flyash formulations produced very good quality glasses with acceptable leachability performance, it was decided that at least one of the FEMP waste pits should be taken into the advanced phase in the as-is formulation. Because the Burn Pit produced such a visually good quality glass, the as-is formulation was carried forward into the advanced phase where individual Burn Pit zone differences might be highlighted.

C.2.4.9.3 Remedy Selection Tests

The advanced phase Burn Pit zone samples used the formulations listed in Table C.2-48. The soil formulation, Formula 1, produced pourable viscosity melts that cooled in two of the three zones, into black, nonporous glasses. The Zone 1 material became very porous, with a granite-like appearance. The remedy screening tests produced glasses like those resulting for Zones 2 and 3. The Zone 1 granite-like product was atypical and suggests that Zone 1 may have higher levels of alumina than the other two. Bulking factors are given in Table C.2-49. The bulking factors for these glasses were from -31 percent to -57 percent.

No waste/flyash formulations were prepared for the Burn Pit in the advanced phase testing. Instead, an as-is formulation, Formula 2, including 7.4 percent sodium/flux addition was tested. The flux-supplemented Zones 1 and 2 material produced low viscosity melts that cooled to slightly different products. Zone 1 product was porous and crystalline, while the Zone 2 material was nonporous and vitreous. The Zone 2 product is consistent with what was observed during remedy screening. The Zone 1 product appears to be incompletely processed and may be due to insufficient flux being present. The bulking factor for both these glasses was -62 percent.

Results for the Burn Pit TCLP radionuclides for the two formulations are shown in Table C.2-50. The metals in the TCLP leachates for the waste treated with the two vitrification formulations and the TC criteria for metals are shown in Table C.2-51. Both formulations pass the TC regulatory criteria. Formula 2 performs better than Formula 1 for inorganic compounds.

The PCT results expressed as NLRs are presented in Table C.2-51. The waste/soil glass NLRs were all less than 6 percent of the SRHLWC. Uranium leached variably, but at very low levels, from 0.005 to 0.1 percent of the SRHLWC. An as-is waste glass formulation was produced instead of a waste/flyash formulation and its NLRs were less than 8 percent of the SRHLWC except for sodium at 26 percent of the SRHLWC. The waste/soil product had the lowest overall NLR for the Burn Pit waste.

C.2.4.9.4 Radon Emissions

Figures C.2-15 and C.2-16 show radon leach rates much lower than the untreated waste or the calculated rate. The unusually high emanation rates for the treated waste (in comparison to raw and calculated rates) may be due to changes in the background. A background measurement was made every day before measurements were started. Any changes occurring during the day would have gone undetected.

C.2.4.10 Clearwell

C.2.4.10.1 Compositional Analysis

As vitrification feed material, the Clearwell waste contains 38.49 mole percent glass formers and 61.51 mole percent flux. The former/flux ratio is 0.626 which satisfies the desired 0.5 or greater target. Additionally, compositional data reveals the presence of barium, chromium, and uranium at levels that might result in significant leaching in poor glass formulations.

C.2.4.10.2 Range-Finding and Remedy Screening Tests

Initial testing generated two samples that evaluated the performance of Clearwell composite material to vitrify as-is and with soil. Remedy Screening generated 6 samples that further refined the

evaluation of soil, flyash, and sodium/flux additives. Table C.2-52 presents formulations and results for these tests.

The as-is formulation (P8-1) was modified with 8.2 percent sodium/flux addition to produce a lower viscosity formulation (P8-3). This formulation produced a good viscosity (V-3) melt that cooled to an excellent amber, vitreous material. However, slight corrosive attack of the crucible was observed. Leach testing of this glass indicated some leaching of uranium (2.0 ppm) in the MTCLP, and cadmium (23 ppm) and silicon (23 ppm) in the MPCT.

Three waste/soil formulations were designed to test the effect of varying sodium/flux levels with a reduced soil-to-waste loading ratio (0.5:1). P8-4 (5.2 percent flux) produced a very high viscosity (V-1) melt that cooled to a glossy black, nonporous monolith. This sample had an asphaltic character to it that suggested homogeneity but incomplete vitrification. No leach testing was performed on this sample. P8-5 (9.8 percent flux) produced a low viscosity (V-3/V-4) melt that cooled to a semi-transparent amber black mass with good vitreous character. Leach testing of this glass indicated leaching of some uranium (1.9 ppm) and chromium (0.1 ppm) in the MTCLP, and cadmium (23 ppm), sodium (27 ppm), and silicon (27 ppm) in the MPCT. Gross alpha/beta were at LLD. The highest flux addition formulation (11 percent; P8-6) produced a pourable viscosity (V-3) melt and cooled to a fully vitreous monolith, but darker and less translucent than P8-5. Leach testing of this glass indicated some leaching in the MPCT of cadmium (28 ppm), silicon (23 ppm), and sodium (30 ppm). Gross alpha/beta were at LLD in the MPCT and MTCLP.

Comparison of these formulations with respect to their appearance and leaching performance led to the conclusion that the mid-level flux formulation (9.8 percent; P8-5) produces a superior glass to P8-4 and justifies the additional sodium/flux. The high level flux (11 percent; P8-6) produces a glass that is not as high quality in appearance as P8-5 and whose leaching performance is not significantly better to warrant the extra flux addition. Therefore, it was decided that the 9.8 percent flux addition formulation (P8-5) would be developed in the advanced phase testing.

As with the waste/soil tests, the fact that the waste vitrifies on its own was relied on to require a minimum of testing waste/flyash formulations. Based on previous experience with the FEMP waste pits, a 1:1 waste to flyash loading ratio was chosen for testing. Two formulations were tested, one at 8.8 percent flux addition (P8-7) and one at 12 percent flux addition (P8-8). The lower flux formulation produced a pourable (V-3) melt that cooled to a black glassy monolith of better than average quality. Leach testing of this glass indicated minor leaching of uranium (0.14 ppm) in the MTCLP, and aluminum (5 ppm), cadmium (4.4 ppm), silicon (14 ppm), and sodium (4.5 ppm) in the MPCT. Gross alpha/beta were at LLD in both tests.

The vitrified product of the higher flux formulation (P8-8) was nearly identical to P8-7. Its leaching performance also paralleled closely that of the lower flux formulation indicating no advantage from the additional sodium/flux; therefore, the lower flux formulation (P8-7) was developed in the advanced phase.

C.2.4.10.3 Remedy Selection Tests

The advanced phase Clearwell composite samples used the soil and flyash formulations listed in Table C.2-53. The soil formulation, Formula 1, produced a pourable viscosity melt that cooled to a fairly homogeneous black glass, which upon remelt in an Inconel 601 crucible became crystalline to near-vitreous. This change in product character is no doubt due to interaction of the melt with the Inconel crucible resulting in a modified glass formulation. The bulking factor for this glass was -58 percent (Refer to Table C.2-54). The flyash formulation, Formula 2, produced a low viscosity melt that cooled to a dark amber, homogeneous glass. Its bulking factor was -15 percent.

Results for Clearwell TCLP radionuclides for the two formulations are shown in Table C.2-55. The TCLP metals in the TCLP leachate are shown in Table C.2-56. Both formulations pass the TC regulatory criteria. Formula 2 performs better than Formula 1 for inorganic compounds. The mean dilution adjusted concentrations for Formula 2 were lower for most of the radiological CPCs. Of particular interest is the uranium concentrations, which are an order of magnitude lower for Formula 2. Formula 1 had better results for Pu-238, Ra-226, Tc-99 and Th-230.

The results of the PCT expressed as NLRs are presented in Table C.2-58. The waste/soil composite glass NLRs did not exceed 3 percent of the SRHLWC, while none of the calculated waste/flyash NLRs exceeded 35 percent of the SRHLWC. Except for the 35 percent for sodium, the waste/flyash product had the lowest overall NLR for the Clearwell waste.

C.2.4.10.4 Radon Emissions

Figures C.2-17 and C.2-18 show radon leach rates much lower than the calculated rate. The unusually high emanation rates for the treated waste (in comparison to raw and calculated rates) may be due to changes in the background. A background measurement was made every day before measurements were started. Any changes occurring during the day would have gone undetected. Also, the relatively low emanation rates from the untreated waste were probably due to the wet, clay-like nature of the waste that was tested. Such material would be expected to have extremely low porosity, reducing the ability of radon to diffuse through it.

C.2.4.11 Comparison to Test Objectives

Performance objectives were established to demonstrate the technology was an effective solution for the treatment of the waste (proof of process), to develop data for various aspects of the Feasibility Study, to develop preliminary process parameters for use in later treatability studies, and to develop a database between treatment variables and process results. All of the performance objectives established in the treatability study work plan were met through the course of the testing program. A glass product was formed for each waste pit which was reduced in volume. All formulations passed the TC regulatory criteria in the TCLP leachate. Although not all waste samples passed the PCT, the results indicated an acceptable formulation could be developed with further testing.

C.2.5 RECOMMENDATIONS AND CONCLUSIONS

The potential robustness of a process is perhaps the most important consideration for evaluation of vitrification because the waste pit contents are extremely heterogeneous in nature. Full characterization prior to excavation is not possible. The treatment process chosen must be robust enough to handle the wide variety of materials to be processed.

Waste from each of the waste pits has been characterized for glass forming constituents. Crucible melts have been performed for a broad range of potential vitrification formulas. More in-depth crucible studies have been performed to evaluate process parameters such as conductivity and viscosity. In addition, several small continuous process melter runs have been made with material from Waste Pit 5, and the vitrified products from these experiments were analyzed and tested for leach resistance. The conclusions reached regarding vitrification as a treatment alternative for the waste pit materials are as follows:

1) Waste Pit material can be vitrified (i.e. a non-crystalline glass product can be formed) with the proper formulation and use of additives. Variations in chemical composition within the waste pit material significantly impact the required formulation and amount of additives required.

2) Vitrification was very effective in reducing the mobility of the contaminants. Leach test results from the TCLP and the PCT demonstrated that the glass matrix effectively prevents uranium, thorium and other contaminants from leaching.

3) A significant reduction in volume of waste was also achieved by vitrification. The amount of volume reduction was greatly dependent on the waste pit material and the required amount of additives to achieve a vitrified product.

4) Preliminary results show that fluoride can be captured in an off-gas system and recycled into the feed batch.

5) Heavy metals and radionuclides appear to be retained in the glass melt minimizing off-gas problems.

Sufficient data have been developed from the treatability work performed to date to evaluate vitrification as a treatment alternative as part of the RI/FS process. Should vitrification be selected as the treatment alternative for all or part of the waste pit material, additional and extensive pilot testing would be required to support design and operations planning. Although fairly extensive laboratory data have been developed for vitrification of the waste pit materials, no body of industrial data or experience is available to support the evaluation of this treatment option. Vitrification has in the past been applied almost exclusively to high level nuclear waste. Processes for producing this glass are generally small melters and highly controlled processes which have undergone intensive testing. Vitrification of large volumes of low-level radioactive waste has not been previously attempted. Since no vitrification processes of this scale have ever been operated for radioactive waste, cost data must be extrapolated from smaller scale studies.

Pretreatment alternatives would also need to be investigated to reduce the impact of the waste heterogeneity if sufficiently robust formulations could not be developed to handle the wide variations in the waste pit's chemical composition.

TABLE C.2-1

WASTE PIT 1 REMEDY SCREENING TESTS

RANGE FINDING TEST						
Formulation[a]	Waste (g)	Soil (g)	Flyash (g)	% Na_2O	Viscosity[b]	Descriptrion of Glass
(As-Is) P1-1 10500301	100	0	0	0	V-1	Multi-phase, granite-like with entrapped gas bubbles
(Soil) P1-2 10501301	100	100	0	5.0	V-3/V-4	Granite-like product
(Soil) P1-3 10501501	100	150	0	5.0	V-3/V-4	Homogeneous, vitreous product
(Flyash) P1-4 10501901	100	0	150	5.0	V-3/V-4	Slag-like material with streaked inner layers
(Flyash) P1-5 10502501	100	0	200	0	V-3/V-4	Low gloss, vitreous product

TABLE C.2-1
(Continued)

PRELIMINARY PHASE TESTS							
Formulation[a]	Waste (g)	Soil (g)	Flyash (g)	% Na_2O	Viscosity[b]	Description of Glass	Leachate Analysis[c]
(As-Is) P1-6 10503001	100	0	0	5.2	V-5 (melt down)	Non-vitreous, porous	NA[d]
(As-Is) P1-7 10502901	100	0	0	8.5	V-5 (melt down)	Vitreous	NA
(As-Is) P1-8 10503201	100	0	0	2.1	V-5 (melt down)	Non-vitreous, tan, porous	NA
(As-Is) P1-9 10503207	100	0	0	0	V-5 (melt down)	Non-vitreous, tan, porous	NA
(Soil) P1-10 10502601	100	150	0	5.0	V-3	Non-porlpous, dual phase	122 F, 148 Na (PCT)
(Soil) P1-11 10502701	100	150	0	2.6	V-3	Non-porous, near-vitreous	51 F, 25 Si (PCT)
(Flyash) P1-12 10502801	100	0	150	3.2	V-3/V-4	Black glass with yellow inclusions	1.0 U (MTCLP)
(Flyash) P1-13 10503002	100	0	200	5.0	V-3/V-4	Non-porous, granular/ crystalline	1.5 U (MTCLP)

[a] Formulations are dry weights given as "part waste"/"part soil or flyash"/% Na_2O addition.
[b] Viscosity designations used here are defined in Section A.1.0 of Appendix B of the Draft Final RI Report for Operable Unit 1, (DOE 1994).
[c] Results are given for MTCLP and PCT leach tests and are reported in ppm (w/w). Analytes not reported were not dectected.
[d] Not analyzed.

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TABLE C.2-2

VITRIFICATION—WASTE PIT 1 ADVANCED PHASE FORMULATIONS[a]

Formulation	Normalized Waste	Normalized Soil	Normalized Flyash	Normalized Sodium Oxide
1	100	150	0	13
2	100	0	199	8

[a] All quantities are normalized to express quantities of reagents in grams used per 100 grams of waste. Waste weights are after drying to remove moisture.

TABLE C.2-3

VITRIFICATION—WASTE PIT 1-ADVANCED PHASE BULKING FACTOR, AVERAGE BULKING FACTOR

Zone	Formulation	Bulking Factor (Percent Volume Increase)	Average Bulking Factor (Percent Volume Increase)
1	1	72	49
1	1	22	
2	1	60	
2	1	-2.6	
3	1	64	
3	1	3	
1	2	51	
1	2	82	
2	2	50	
2	2	84	
3	2	50	
3	2	53	

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TABLE C.2-4

WASTE PIT 1 VITRIFICATION TCLP RADIONUCLIDES DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (pCi/L)	Formula 1 (pCi/L)	Formula 2 (pCi/L)
Cesium-137	ND	27.874	ND
Radium-226	83.500	4.366	5.614
Radium-228	27.300	24.450	ND
Strontium-90	7.290	14.039	ND
Technetium-99	35.350	33.120	ND
Thorium-228	ND	1.610	4.435
Thorium-230	ND	22.312	36.495
Thorium-232	ND	0.567	0.662
Uranium-234	3990.000	707.903	12.659
Uranium-235/236	247.000	43.494	1.766
Uranium-238	4910.000	903.992	210.288
	Raw Waste Characterization (mg/l)	**Formula 1 (mg/l)**	**Formula 2 (mg/l)**
Thorium (Total)	ND	0.006	0.025
Uranium (Total)	7.381	2.710	0.060

[a]Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample. For some vitrification samples, the dilution factor was less than 1. In these cases, a dilution factor of 1 was used.

[b]TCLP results on similar raw waste samples provided for relative comparison for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

TABLE C.2-5

WASTE PIT 1 VITRIFICATION TCLP METALS DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)	TC REG LIMITS (mg/l)
Antimony	0.055	0.007	ND	
Arsenic	0.003	0.048	0.005	5.000
Barium	1.562	0.271	0.320	100.000
Beryllium	0.007	0.009	ND	
Boron	ND	0.799	0.257	
Cadmium	0.008	ND	ND	1.000
Chromium	0.100	0.090	ND	5.000
Cobalt	0.022	0.085	ND	
Copper	0.048	0.158	0.034	
Cyanide	ND	ND	ND	
Lead	0.005	0.006	0.011	5.000
Manganese	0.213	3.448	0.050	
Mercury	ND	ND	ND	0.200
Molybdenum	0.027	0.348	ND	
Nickel	0.121	0.026	ND	
Selenium	0.002	ND	ND	1.000
Silver	0.080	ND	ND	5.000
Thallium	ND	ND	ND	
Vanadium	0.048	0.142	ND	
Zinc	0.086	0.399	9.194	

TABLE C.2-5
(Continued)

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample. For some vitrification samples, the dilution factor was less than 1. In these cases, a dilution factor of 1 was used.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

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TABLE C.2-6

WASTE PIT 1 - NORMALIZED LEACHATE RATES EXPRESSED AS A PERCENTAGE OF SAVANNAH RIVER HIGH LEVEL WASTE CRITERIA

Formulation	Zone	Al	Mg	Na	Si	U	Li[a]	K	B
		Percentages							
1	1	0.4	0.001	37	2.2	0.04	Not Calc'd	6	253
1	2	0.4	0.009	28	2.2	0.07	Not Calc'd	0.5	Not Calc'd
1	3	0.1	0.2	14	0.6	0.09	Not Calc'd	0.2	Not Calc'd
1	3	1.4	0.001	73	3.9	1	Not Calc'd	20.0	>500
2	Average	0.25	0.13	21	0.6	Not Calc'd	Not Calc'd	18	40

[a] Not Calc'd indicates a normalized leach rate was not calculated because the metal was not found in the glass.

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TABLE C.2-7

WASTE PIT 2 REMEDY SCREENING TESTS

RANGE FINDING TEST						
Formulation[a]	Waste (g)	Soil (g)	Flyash (g)	Na_2O	Viscosity[b]	Description of Glass
(As-ls) P2-1 10501201	100	0	0	0	V-3/V-4	Vitreous, slag and porcelain
(Soil) P2-2 10501302	100	100	0	5.0	V-3	Good glass product
(Soil) P2-3 10501502	100	50	0	5.0	V-3	Good glass product
(Flyash) P2-4 10501902	100	0	50	5.0	V-2	Near-vitreous, slag-like
(Soil) P2-5 10502502	100	0	100	0	V-1	Vitreous but non-pourable

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TABLE C.2-7
(Continued)

PRELIMINARY PHASE TESTS							
Formulation[a]	Waste (g)	Soil (g)	Flyash (g)	% Na_2O	Viscosity[b]	Description of Glass	Leachate Analysis[c]
(As-ls) P2-6 10502902	100	0	0	7.7	V-3	Single phase glass	NA[d]
(Soil) P2-7 10502602	100	50	0	5.2	V-3/V-4	Single phase glass	9.3 U (MTCLP)
(Soil) P2-8 10502702	100	50	0	2.6	V-2/V-3	Single phase glass	1.2 U (MTCL)
(Flyash) P2-9 10502802	100	0	100	5.2	V-1	Near-vitreous, slag-like	NA[d]
(Flyash) P2-10 10503003	100	0	100	7.0	V-1	Glossy, vitreous	NA
(Flyash) P2-11 10503004	100	0	100	8.3	V-2/V-3	Good vitreous product	0.3 U (MTCLP)
(Flyash) P2-12 10503202	100	0	100	7.7	V-2/V-3	Good vitreous product	4.0 U (MTCLP)

[a] Formulations are dry weights given as "parts waste"/"parts soil or fly ash"/ % Na_2O addition.
[b] Viscosity designations used here are defined in Section A.1.0 of Appendix B of the Draft Final RI Report for Operable Unit 1, (DOE 1994).
[c] Results are given for MTCLP and PCT leach tests and are reported in ppm (w/w). Analytes not reported were not detected.
[d] Not analyzed.

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TABLE 4 C.2-8

VITRIFICATION WASTE PIT 2
ADVANCED PHASE FORMULATIONS

Formulation	Normalized Waste	Normalized Soil	Normalized Flyash	Normalized Sodium Oxide
1	100	50	0	4
2	100	0	100	18

TABLE C.2-9

VITRIFICATION WASTE PIT 2
ADVANCED PHASE
BULKING FACTOR, AVERAGE BULKING FACTOR

Zone	Formulation	Bulking Factor (Percent Volume Increase)	Average Bulking Factor (Percent Volume Increase)
1	1	-47	-48
2	1	-66	
3	1	-65	
1	2	-20	
2	2	-41	
2	2	-47	
3	2	-48	

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TABLE C.2-10

WASTE PIT 2 VITRIFICATION TCLP RADIONUCLIDES DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (pCi/l)	Formula 1 (pCi/l)	Formula 2 (pCi/l)
Cesium-137	ND	ND	ND
Plutonium-238	ND	0.990	0.510
Plutonium-239/240	ND	1.290	0.990
Radium-226	13.180	171.370	33.620
Radium-228	3.510	35.450	ND
Ruthenium-106	ND	ND	ND
Strontium-90	ND	ND	ND
Technetium-99	67.600	ND	ND
Thorium-228	1.690	3.840	2.390
Thorium-230	1.780	95.840	31.940
Thorium-232	ND	2.750	1.430
Uranium-234	61.710	41.380	42.950
Uranium-235/236	13.500	2.390	1.700
Uranium-238	112.170	45.430	55.250
	Raw Waste Characterization (mg/l)	**Formula 1 (mg/l)**	**Formula 2 (mg/l)**
Thorium (Total)	0.010	0.030	0.010
Uranium (Total)	0.050	0.140	0.170

TABLE C.2-10
(Continued)

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample. For some vitrification samples, the dilution factor was less than 1. In these cases, a dilution factor of 1 was used.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

TABLE C.2-11

WASTE PIT 2 VITRIFICATION TCLP METALS DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)	TC REG LIMITS (mg/l)
Antimony	0.156	ND	0.005	
Arsenic	0.600	0.014	0.024	5.000
Barium	0.048	0.256	0.233	100.000
Beryllium	0.004	ND	0.003	
Boron	0.569	0.184	0.185	
Cadmium	0.028	ND	ND	
Chromium	0.077	0.058	0.016	5.000
Cobalt	1.913	0.043	0.054	
Copper	0.244	0.042	0.041	
Cyanide	ND	ND	ND	
Lead	0.006	0.014	0.008	5.000
Manganese	5.215	0.154	0.309	
Mercury	ND	ND	ND	0.200
Molybdenum	0.235	0.026	0.018	
Nickel	2.181	0.110	0.114	
Selenium	0.025	ND	0.003	1.000
Silicon	29.650	8.099	84.293	
Silver	0.052	ND	ND	5.000
Thallium	0.008	ND	ND	
Vanadium	0.429	0.029	0.028	
Zinc	0.134	0.122	0.148	

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

TABLE C.2-12

PIT 2 - NORMALIZED LEACHATE RATES EXPRESSED AS A PERCENTAGE OF SAVANNAH RIVER HIGH LEVEL WASTE CRITERIA

Formulation	Zone	Al	Mg	Na	Si	U	Li[a]	K	B
		Percentages							
1	1	0.2	0.004	2	0.8	0.05	0	0.8	13
1	2	0.2	0.01	2	0.9	0.2	Not Calc'd	0.6	Not Calc'd
1	3	0.3	0.003	1	0.8	0	Not Calc'd	0.4	Not Calc'd
2	Average	0.5	0.01	34	0.6	Not Calc'd	Not Calc'd	1	29

[a] Not Calc'd indicates a normalized leach rate was not calculated because the metal was not found in the glass.

TABLE C.2-13

WASTE PIT 3 REMEDY SCREENING TESTS

RANGE FINDING TEST						
Formulation[a]	Waste (g)	Soil (g)	Flyash (g)	Na_2O	Viscosity[b]	Description of Glass
(As-ls) P3-1 10500501	100	0	0	0	V-3	Fused, non-vitreous product
(Soil) P3-2 10501303	100	100	0	5.0	V-2/V-3	Good vitreous product
(Soil) P3-3 10501503	100	50	0	5.0	V-2/V-3	Good vitreous product
(Flyash) P3-4 10501903	100	0	50	5.0	V-3	Good vitreous product
(Flyash) P3-5 10502503	100	0	100	0	V-1	Viterous with slage-like cap

TABLE C.2-13
(Continued)

PRELIMINARY PHASE TESTS							
Formulation[a]	Waste (g)	Soil (g)	Flyash (g)	% Na_2O	Viscosity[b]	Description of Glass	Leachate Analysis[c]
(As-ls) P3-6 10502903	100	0	0	7.4	V-3/V-4	Near vitreous, porcelain-like	3.3 U (MTCLP); 53 Na, 35 F (PCT)
(Soil) P3-7 10502603	100	50	0	5.2	V-2/V-3	Good vitreous product	5.9 U (MTCLP)
(Soil) P3-8 10502703	100	50	0	2.6	V-3	Good vitreous product	4.3 U (MTCLP)
(Soil) P3-9 10502803	100	0	100	2.6	V-3/V-4	Near-vitreous porcelain	NA[d]
(Flyash) P3-11 10503005	100	0	100	7.0	V-3/V-4	Vitreous with crystals	0 U (MTCLP)
(Flyash) P3-12 10503006	100	0	100	7.5	V-2/V-3	Good vitreous product	0.5 U (MTCLP)

[a] Formulations are dry weights given as "part waste"/"part soil or flyash"/% Na_2O addition.
[b] Viscosity designations used here are defined in Section A.1.0 of Appendix B of the Draft RI Report for Operable Unit 1, (DOE 1994).
[c] Results are given for MTCLP and PCT leach test and are reported in ppm (w/w). Analytes not reported were not dectected.
[d] Not analyzed.

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TABLE C.2-14

VITRIFICATION WASTE PIT 3
ADVANCED PHASE FORMULATIONS

Formulation	Normalized Waste	Normalized Soil	Normalized Flyash	Normalized Sodium Oxide
1	100	100	0	5
2	100	0	100	16

TABLE C.2-15

VITRIFICATION—ADVANCED PHASE WASTE PIT 3
BULKING FACTOR, AVERAGE BULKING FACTOR

Zone	Formulation	Bulking Factor (Percent Volume Increase)	Average Bulking Factor (Percent Volume Increase)
1	1	-64	-61
2	1	-46	
3	1	-76	
1	2	-50	
2	2	-63	
3	2	-67	

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TABLE C.2-16

WASTE PIT 3 VITRIFICATION TCLP RADIONUCLIDES DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (Pci/l)	Formula 1 (Pci/l)	Formula 2 (Pci/l)
Neptunium-237	ND	5.140	9.020
Plutonium-238	ND	ND	0.920
Plutonium-239/240	ND	1.220	1.340
Radium-226	9.620	2.770	7.240
Radium-228	13.030	ND	ND
Strontium-90	ND	7.090	ND
Technetium-99	867.000	14.540	ND
Thorium-228	6.440	9.520	2.710
Thorium-230	1.070	67.340	73.070
Thorium-232	ND	0.700	0.890
Uranium-234	74.900	127.870	22.980
Uranium-235/236	7.240	27.700	5.790
Uranium-238	181.250	127.610	32.400
	Raw Waste Characterization (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)
Thoruim (Total)	ND	0.010	0.010
Uranium (Total)	0.390	0.380	0.100

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample. For some vitrification samples, the dilution factor was less than 1. In these cases, a dilution factor of 1 was used.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

TABLE C.2-17

WASTE PIT 3 VITRIFICATION TCLP METALS DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)	TC REG LIMITS (mg/l)
Aluminum	3.432	16.071	17.643	
Antimony	0.184	0.014	ND	
Arsenic	0.298	0.056	0.028	5.000
Barium	0.312	2.035	0.460	100.000
Beryllium	0.007	0.009	0.010	
Boron	0.998	0.259	0.150	
Cadmium	0.054	0.015	0.012	1.000
Chromium	0.124	ND	ND	5.000
Cobalt	0.120	0.019	0.017	
Copper	0.475	0.294	0.327	
Cyanide	ND	ND	ND	
Lead	0.007	0.006	0.007	5.000
Manganese	49.812	1.012	0.537	
Mercury	0.001	ND	ND	0.200
Molybdenum	0.370	0.344	0.286	
Nickel	0.709	0.208	0.034	
Selenium	0.218	ND	0.003	1.000
Silver	0.092	ND	ND	5.000
Thallium	0.013	ND	ND	
Vanadium	0.729	0.346	0.510	
Zinc	0.397	0.140	0.175	

TABLE C.2-17
(Continued)

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample. For some vitrification samples, the dilution factor was less than 1. In these cases, a dilution factor of 1 was used.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

TABLE C.2-18

WASTE PIT 3 - NORMALIZED LEACHATE RATES EXPRESSED AS A PERCENTAGE OF SAVANNAH RIVER HIGH LEVEL WASTE CRITERIA

Formulation	Zone	Al	Mg	Na	Si	U	Li[a]	K	B
		Percentages							
1	1	0.7	0.002	9	0.7	0.1	Not Calc'd	0.9	Not Calc'd
1	2	0.3	0.01	1.0	0.6	0.0	Not Calc'd	0.2	Not Calc'd
1	3	0.7	0.1	18	0.4	0.02	29	7	61
2	Average	1	0.03	109	1	Not Calc'd	Not Calc'd	1	14

[a] Not Calc'd indicates a normalized leach rate was not calculated because the metal was not found in the glass.

TABLE C.2-19

REMEDY SCREENING TESTS

RANGE FINDING TESTS						
Formulation[a]	Waste (g)	Soil (g)	Flyash (g)	% Na_2O	Viscosity[b]	Descriptrion of Glass
(As-ls) P4-1 10500401	100	0	0	0	V-3	Non-vitreous, crystalline granite
(Soil) P4-2 10501304	100	100	0	5.0	V-3	Vitreous, crystalline mixture
(Soil) P4-3 10501504	100	50	0	5.0	V-3	Good vitreous product
(Flyash) P4-4 10501904	100	0	150	5.0	V-1	Porous, crystalline granite
(Flyash) P4-5 10502504	100	0	200	0	V-1	Porcelain with slag cap

TABLE C.2-19
(Continued)

PRELIMINARY PHASE TESTS							
Formulation[a]	Waste (g)	Soil (g)	Flyash (g)	% Na_2O	Viscosity[b]	Description of Glass	Leachate Analysis[c]
(As-Is) P4-6 10502904	100	0	0	8.4	V-5 (melt down)	No material recovered	NA[d]
(As-Is) P4-7 10503007	100	0	0	5.2	V-5 (melt down)	Glossy, non-porous product	NA
(As-Is) P4-8 10503203	100	0	0	0	V-3/V-4	Coal-like product	NA
(As-Is) P4-9 10503208	100	0	0	2.1	V-5 (melt down)	Semi-glossy, encapsulated	NA
(Soil) P4-11 10502604	100	150	100	5.2	V-3	Glossy, non-porous glass	2.0 U (MTCLP)
(Soil) P4-12 10502704	100	150	0	2.6	V-3	Vitreous with slag-like cap	24,000 alpha, 5150 beta, 67 U (MTCLP)
(Flyash) P4-13 10502804	100	0	200	2.6	V-1	Porous slag with inclusions	NA
(Flyash) P4-14 10503008	100	0	200	7.0	V-2/V-3	Vitreous with crystal inclusions	3.6 U (MTCLP)
(Flyash) P4-15 10503009	100	0	200	5.7	V-3	Good vitreous product	3.6 U (MTCLP)

[a]Formulations are dry weights given as "part waste"/"part soil or flyash"/% Na_2O addition.
[b]Viscosity designations used here are defined in Section A.1.0 of Appendix B of the Draft Final RI Report for Operable Unit 1 (DOE 1994).
[c]Results are given for MTCLP and PCT leach tests and are reported in ppm (w/w). Analytes not reported were not dectected.
[d]Not analyzed.

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TABLE C.2-20

VITRIFICATION WASTE PIT 4
ADVANCED PHASE FORMULATIONS

Formulation	Normalized Waste	Normalized Soil	Normalized Flyash	Normalized Sodium Oxide
1	100	150	0	13
2	100	0	200	18

TABLE C.2-21

VITRIFICATION—ADVANCED PHASE WASTE PIT 4
BULKING FACTOR, AVERAGE BULKING FACTOR

Zone	Formulation	Bulking Factor (Percent Volume Increase)	Average Bulking Factor (Percent Volume Increase)
1	1	32	37
2	1	20	
2	1	6	
3	1	17	
1	2	60	
2	2	68	
3	2	57	

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TABLE C.2-22

WASTE PIT 4 VITRIFICATION TCLP RADIONUCLIDES DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (pCi/l)	Formula 1 (pCi/l)	Formula 2 (pCi/l)
Neptunium-237	3.630	5.380	9.410
Plutonium-238	ND	ND	1.460
Plutonium-239/240	ND	2.240	2.710
Radium-226	48.960	13.620	12.370
Radium-228	76.900	1108.930	ND
Strontium-90	19.680	8.400	ND
Technetium-99	95.910	34.440	ND
Thorium-228	ND	10.740	5.020
Thorium-230	ND	49.180	42.450
Thorium-232	ND	3.750	2.720
Uranium-234	8515.000	427.590	45.520
Uranium-235/236	1819.500	28.860	5.150
Uranium-238	67550.000	525.740	113.230
	Raw Waste Characterization (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)
Thorium (Total)	ND	0.190	0.020

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample. For some vitrification samples, the dilution factor was less than 1. In these cases, a dilution factor of 1 was used.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

TABLE C.2-23

WASTE PIT 4 VITRIFICATION TCLP METALS DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)	TC REG LIMITS (mg/l)
Antimony	0.400	0.007	ND	
Arsenic	ND	0.015	0.020	5.000
Barium	3.744	1.330	0.402	100.000
Beryllium	0.047	0.005	0.005	
Boron	0.401	0.906	0.425	
Cadmium	0.046	ND	ND	1.000
Chromium	1.276	0.036	0.043	5.000
Cobalt	0.193	0.029	0.038	
Copper	0.439	0.130	0.063	
Cyanide	ND	ND	ND	
Lead	0.007	0.027	0.010	5.000
Manganese	28.344	3.155	0.200	
Mercury	ND	ND	ND	0.200
Molybdenum	0.111	0.022	ND	
Nickel	0.365	0.212	0.110	
Selenium	ND	ND	ND	1.000
Silicon	11.457	201.318	25.978	
Silver	0.706	0.014	ND	5.000
Thallium	ND	ND	ND	
Vanadium	0.508	0.130	0.033	
Zinc	0.484	0.689	0.152	

TABLE C.2-23
(Continued)

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.. For some vitrification samples, the dilution factor was less than 1. In these cases, a dilution factor of 1 was used.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

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TABLE C.2-24

WASTE PIT 4 - NORMALIZED LEACHATE RATES EXPRESSED AS A PERCENTAGE OF SAVANNAH RIVER HIGH LEVEL WASTE CRITERIA

Formulation	Zone	Al	Mg	Na	Si	U	Li[a]	K	B
		Percentages							
1	1	0.4	0.1	4	0.6	0.1	48	4	50
1	2	0.5	0.02	23	1	0.0	50	3	78
1	3	1	0.02	128	2	0.2	Not Calc'd	6	Not Calc'd
1	2	2	0.004	90	1	0.1	14	75	>500
2	Average	0.2	0.05	46	0.7	Not Calc'd	Not Calc'd	10	142

[a] Not Calc'd indicates a normalized leach rate was not calculated because the metal was not found in the glass.

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C.2-25

GLASSES MADE FROM WASTE PIT 3 AND WASTE PIT 4 SLUDGES

Fernald Glass	F4-1	F4-2	F4-3	F4-4	F3-1	F4-5	F4-6	F4-7	F4-8	F4-9	F4-10	F4-11	F4-12	F4-13
Pit 4 (dried @ 450°C)	33	70	50	30	0	30	37	24	29.2	24	24	30.0	26.0	33.0
Pit 3 (dried @ 450°C)	0	0	0	0	76.9	55	45	38	29.2	40	40	30.0	38.0	45.0
Soil Fines (FE30+) (dried at 1150°C)	0	0	0	42	0	0	0	15	12.5	10	15	12.0	15.0	0.0
Pit 5 (FE51) (dried @ 450°C)	0	0	0	0	0	0	0	0	16.7	0	0	0	0	0
Total Waste Loading on Dried Basis	33	70	50	72	76.9	85	82	77	87.6	74	79	72	79	78
SiO_2	0	0	23	0	0	0	0	0	0	0	0	0.0	0.0	0.0
Na_2O	0	10	6	5	7.7	5	7	7	4.2	5	5	5.0	8.0	10
B_2O_3	55	20	8	9	15.4	10	11	11	8.3	11.0	11	11.0	12.0	12.0
Al_2O_3	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0.0
K_2O	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0.0
Fe_2O_3	0	0	0	0	0	0	0	0	0	5	0	0.0	0.0	0.0
CaO	0	0	13	14	0	0	0	5	0	5	5	0.0	1.0	0.0
Li_2O	12	0	0	0	0	0	0	0	0	0	0	0	0	0
Appearance upon cooling	green ceramic	green ceramic	green ceramic	brown opaque glass	opaque black glass/ ceramic	opaque black & green with some undissolved chunks	light green ceramic	phase-separated glass	Opaque black	Opaque black	Some undissolved chunks and crystalized glass	Greenish glass	Black glass	Green brown glass

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TABLE C.2-26

LEACH DATA FOR GLASSES MADE FROM WASTE PIT 3 AND WASTE PIT 4 MATERIALS RCRA METALS (PPM)

	As	Se	Cd	Hg	Ag	Pb	Cr	Ba
F4-4	0.94	0.52	0.01	0.01	0.01	1.63	0.09	0.83
F4-7	0.54	0.43	0.01	0.19[a]	0.00	1.49	0.05	0.48
F4-8	0.11	0.06	0.02	0.07	0.01	1.26	0.06	1.69
F4-9	0.50	0.39	0.01	0.16[b]	0.02	1.09	0.05	0.03
F4-10	0.37	0.02	0.01	0.13	0.02	1.07	0.30	0.13
EPA Limit	5	1	1	0.2	5	5	5	100

[a] Spike of 0.2 ppm Hg gave 0.35 ppm Hg.
[b] Spike of 0.2 ppm Hg gave 0.36 ppm Hg.

TABLE C.2-27

VIABLE GLASSES FOR MELTER RUNS

Components	F4-7 (Dried basis)	F4-7 (Wet basis)	F4-9 (Dried basis)	F4-9 (Wet basis)
Pit 4	24	23.1	24	23.9
Pit 3	38	36.5	40	39.9
Soil Fines (FE30+)	15	23.0	10	15.8
Na_2O	7	5.3	5	3.9
B_2O_3	11	8.3	11	8.6
Fe_2O_3	0	0	5	3.9
CaO	5	3.8	5	3.9
Total	100	100	100	99.9

TABLE C.2-28

WASTE PIT 5 REMEDY SCREENING TESTS

RANGE FINDING TEST						
Formulation[a]	Waste (g)	Soil (g)	Flyash (g)	Na_2O	Viscosity[b]	Description of Glass
(As-ls) P5-1 10500601	100	0	0	0	(did not melt)	Charred chunks, soil-like
(Soil) P5-2 10501305	100	100	0	5.0	V-3	Fused, porcelain with cap
(Soil) P5-3 10501505	100	150	0	5.0	V-1	Fused, granite product
(Flyash) P5-4 10501905	100	0	200	5.0	V-1	Good glass but non-pourable

TABLE C.2-28
(Continued)

PRELIMINARY PHASE TESTS							
Formulation[a]	Waste (g)	Soil (g)	Flyash (g)	% Na_2O	Viscosity[b]	Description of Glass	Leachate Analysis[c]
(As-ls) P5-6 10502905	100	0	0	3.0	(did not melt)	Non-fused, charred solids	2340 alpha, 10,200 beta, 354 Na (PCT); 1.7 Cr (MTCLP)
(As-ls) P5-7 10503010	100	0	0	18.0	V-3	Glass with phase sep.	216 Al, 539 Na (PCT); 5.5 Cr, 0.7 Se (MTCLP)
(Soil) P5-8 10502605	100	200	0	5.2	V-1	Granite-like product	NA[d]
(Soil) P5-9 10502705	100	250	0	8.5	V-3	Bi-phase glass	30 Ca, 33 Na (PCT)
(Soil) P5-11 10503011	100	250	0	8.0	V-3	Bi-phase glass	30 Cd, 33 Na (PCT)
(Flyash) P5-12 10502805	100	0	250	8.8	V-1	Slag-like product	NA
(Flyash) P5-13 10503012	100	0	250	14.0	V.1	Slag-like product	NA
(Flyash) P5-14 10503013	100	0	250	18.0	V-2/V-3	Bi-phase glass	25 Ca, 74 Na, 24 Si (PCT); 0.7 Cr (MTCLP)

TABLE C.2-28
(Continued)

PRELIMINARY PHASE TESTS							
Formulation[a]	Waste (g)	Soil (g)	Flyash (g)	% Na_2O	Viscosity[b]	Description of Glass	Leachate Analysis[c]
(Flyash) P5-15 10503204	100	0	250	16.0	V-2/V-3	Bi-phase glass	31 Al, 126 Na, 32 Si (PCT); 0.7 Cr (MTCLP)
(Flyash) P5-15 10503204	100	0	250	16.0	V-2/V-3	Bi-phase glass	31 Al, 126 Na, 32 Si (PCT); 0.7 Cr (MTCLP)

[a] Formulations are dry weights given as "part waste"/"part soil or flyash"/% Na_2O addition.
[b] Viscosity designations used here are defined in Section A.1.0 of Appendix B.
[c] Results are given for MTCLP and PCT leach test and are reported in ppm (w/w). Analytes not reported were not dectected.
[d] Not analyzed.

TABLE C.2-29

VITRIFICATION--WASTE PIT 5
ADVANCED PHASE FORMULATIONS

Formulation	Normalized Waste	Normalized Soil	Normalized Flyash	Normalized Sodium Oxide
1	100	299	0	35
2	100	0	299	100

TABLE C.2-30

VITRIFICATION--ADVANCED PHASE WASTE PIT 5
BULKING FACTOR, AVERAGE BULKING FACTOR

Zone	Formulation	Bulking Factor (Percent Volume Increase)	Average Bulking Factor (Percent Volume Increase)
Composite	1	-88	-78
Composite	2	-69	

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TABLE C.2-31

WASTE PIT 5 VITRIFICATION TCLP RADIONUCLIDES DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (pCi/l)	Formula 1 (pCi/l)	Formula 2 (pCi/l)
Cesium-137	NA	ND	ND
Neptunium-237	NA	2.690	ND
Plutonium-238	NA	ND	0.490
Plutonium-239/240	NA	1.320	ND
Radium-226	NA	97.700	49.200
Radium-228	NA	ND	7.980
Strontium-90	NA	7.400	10.400
Technetium-99	NA	18.000	ND
Thorium-228	NA	2.760	0.750
Thorium-230	NA	171.000	39.100
Thorium-232	NA	1.140	ND
Uranium-234	NA	106.000	38.900
Uranium-235/236	NA	6.890	1.940
Uranium-238	NA	209.000	74.900
	Raw Waste Characterization (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)
Thorium (Total)	NA	0.010	ND
Uranium (Total)	NA	0.620	0.220

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample. For some vitrification samples, the dilution factor was less than 1. In these cases, a dilution factor of 1 was used.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and some zone as treatability samples but are not identical.

TABLE C.2-32

WASTE PIT 5 VITRIFICATION TCLP METAL DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)	TC REG LIMITS
Antimony	0.082	0.011	0.007	
Arsenic	0.027	0.304	0.039	5.000
Barium	3.904	3.480	1.630	100.000
Beryllium	0.006	0.009	0.010	
Cadmium	0.003	ND	ND	1.000
Chromium	0.014	0.029	0.137	5.000
Cobalt	0.032	0.020	0.083	
Copper	1.916	0.139	ND	
Cyanide	ND	ND	ND	
Lead	0.035	0.038	ND	5.000
Manganese	2.307	1.380	1.000	
Mercury	0.002	ND	ND	0.200
Molybdenum	0.190	1.040	1.350	
Nickel	0.296	0.066	0.299	
Selenium	ND	ND	ND	1.000
Silver	0.099	ND	ND	5.000
Thallium	0.223	ND	ND	
Vanadium	0.815	1.620	0.219	
Zinc	0.326	0.338	0.200	

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample. For some vitrification samples, the dilution factor was less than 1. In these cases, a dilution factor of 1 was used.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

TABLE C.2-33

WASTE PIT 5 - NORMALIZED LEACHATE RATES EXPRESSED AS A PERCENTAGE OF SAVANNAH RIVER HIGH LEVEL WASTE CRITERIA

Formulation	Zone	Al	Mg	Na	Si	U	Li[a]	K	B
		Percentages							
1	Composite	1	0.2	9	0.6	0.1	Not Calc'd	10	Not Calc'd
2	Composite	4	0.5	>500	2	Not Calc'd	Not Calc'd	476	>500

[a] Not Calc'd indicates a normalized leach rate was not calculated because the metal was not found in the glass.

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Table C.2-34

SUMMARY OF CRUCIBLE MELTS MADE FROM FEMP WASTE PIT 5 AND DATA COLLECTED (see notes for key)

Name	Pit 5		Soil	Fly Ash	Additives	Fluoride Analysis	XTAL	Vis	Con	TCLP	PCT	DCP Analysis
F5-1	CL	70	30WS	0	0		*	*	*			*
F5-2	CL	40	40WS	0	20							*
F5-3	CL	70	30WS	0	0		*	*	*			
F5-4	CL	40	40WS	0	20							
F5-5	CL	41.7	41.7	0	16.6		*			*	*	*
F5-6	CL	70	30	0	0							
F5-7	Pt/Au	50	40	0	10		*	*	*	*	*	*
F5-8	Pt/Au	40	40	0	20		*	*	*	*	*	*
F5-10	Pt/Au	45	45	0	10					*	*	*
F5-11	Pt/Au	45	40	0	15			*	*			*
F5-12	Pt/Au	60	14	0	26	*	*	*	*			*
F5-13	Pt/Au	60	14	0	26	*	*	*	*			*
F5-14	Pt/Au	60	14	0	26		*	*	*			*
F5-15	Pt/Au	60	14	0	26		*	*	*			*
F5-16	Pt/Au	60	17	0	23			*	*			*
F5-17	Pt/Au	60	14	0	26			*	*	*	*	*
F5-18	Pt/Au	55	14	0	31			*	*			
F5-19	Pt/Au	55	14	0	31					*	*	*
F5-20	Pt/Au	50	14	0	31	*	*	*	*	*	*	
F5-21	Pt/Au	50	14	0	31							*
F5-22	Pt/Au	40	20	0	40		*	*	*	*	*	*
F5-23	Pt/Au	35	20	0	45	*	*	*	*	*	*	*
F5-24	Pt/Au	30	39	0	31	*		*	*	*	*	*
F5-25	Pt/Au	30.9	40.2	0	28.9	*	*	*	*	*	*	*
F5-26	Pt/Au	28.5	37.1	0	34.4		*	*	*			*

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TABLE C.2-34
(Continued)

Name	Pit 5	Soil	Fly Ash	Additives	Fluoride Analysis	Crystal	Visc	Con	TCLP	PCT	DCP Analysis
F5-27	Pt/Au 28.7	37.3	0	34							*
F5-28	Pt/Au 55	14	0	31		*			*	*	
F5-29	Pt/Au 55	14	0	31					*	*	
F5-30	Pt/Au 55	14	0	31					*	*	
F5-31	Pt/Au 52	0	0	48	*	*	*	*			*
F5-32	Pt/Au 52	0	0	48	*	*	*	*	*	*	*
F5-33	Pt/Au 50	7	0	43	*		*	*			*
F5-34	Pt/AU 49	7	16	28		*	*	*			*
F5-35	IN 49.81	7.11	16.31	26.77	*				*	*	*
F5-36	IN 50	15	0	35	*				*	*	*
F5-37	IN 45.8	13.7	22.2 (wet)	18.3					*	*	*
F5-38	Pt/Au 50	15	15	20							
F5-39	Pt/Au 48	14	15	23			*	*	*	*	
F5-40	Pt/Au 47.1	13.5	14.5	24.9			*	*	*	*	
F5-41	Pt/Au 51	30	0	19	*		*	*			

CL = melted in clay crucibles.
Pt/Au = melted in platinum/gold crucibles.
IN = melted in inconel crucibles
* = analysis completed
WS = Weldon Spring site soil was used
XTAL = Crystallization data
Vis = Melt viscosity data
Con = Electrical conductivity data
DCP = Glass composition analysis by dissolution followed by DCP spectroscopy

The numbers for Pit 5, soil, fly ash, and additives are in weight percent.

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TABLE C.2-35
GLASS BATCH COMPOSITIONS USED FOR CRUCIBLE MELTS AND APPEARANCE UPON COOLING[a].

Fernald Glass	F5-5	F5-7	F5-8	F5-10	F5-11	F5-12	F5-13	F5-14	F5-15	F5-16
Pit 5	41.7	50	40	45	45	60	60	60	60	60
Soil	41.7	40	40	45	40	14	14	14	14	17
Fly Ash	0	0	0	0	0	0	0	0	0	0
SiO_2	0	0	0	0	0	14	14	17	14	14
Na_2O	8.3	5	10	5	5	5	3	0	0	0
B_2O_3	8.3	5	10	5	10	7	6	6	6	6
Al_2O_3	0	0	0	0	0	0	3	3	6	3
K_2O	0	0	0	0	0	0	0	0	0	0
Fe_2O_3	0	0	0	0	0	0	0	0	0	0
CaO	0	0	0	0	0	0	0	0	0	0
Appearance upon cooling	glassy, black	opaque on top, glassy in middle	glassy, brown	green on bottom pores on top	heterogeneous, undissolved chunks	glassy, brown	glassy, brown	opaque green	very glassy	opaque, greenish brown

Fernald Glass	F5-17	F5-18	F5-19	F5-20	F5-21	F5-22	F5-23	F5-24	F5-25	F5-26
Pit 5	60	55	55	50	50	40	35	30	30.9	28.5
Soil	14	14	14	14	14	20	20	39	40.2	37.1
Fly Ash	0	0	0	0	0	0	0	0	0	0
SiO_2	14	14	14	19	14	20	22	11.5	11.9	10.9
Na_2O	0	5	0	5	5	6	6	5.5	5.7	5.2
B_2O_3	3	6	6	6	6	5	7	7	7.2	11.7
Al_2O_3	9	6	6	6	11	5	6	4	4.1	3.8
K_2O	0	0	5	0	0	0	0	0	0	0
Fe_2O_3	0	0	0	0	0	4	4	3	0	2.8
CaO	0	0	0	0	0	0	0	0	0	0
Appearance upon cooling	green on bottom, opaque brown on top	glassy	Not melted at 1150°C. Caramel/ green after heating to 1200°C	dark green & opaque re-melt in clay gives glassy brown	opaque, brown with white chunks	glassy brown	heteroge-neous; green, brown, black, & white; F5-23B still has white pow-der	glassy brown	glassy brown	glassy brown

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TABLE C.2-35
(Continued)

Fernald Glass	F5-27	F5-28	F5-29	F5-30	F5-31	F5-32	F5-33	F5-34	F5-35	F5-36
Pit 5	28.7	55	55	55	52	52	50	49	49.81	50
Soil	37.3	14	14	14	0	0	7	7	7.11	15
Fly Ash	0	0	0	0	0	0	0	16	16.31	0
SiO_2	11	14	14	14	22	22	19	10	10.21	14
Na_2O	7.1 (NaF)	5	8	11	7	7 (NaF)	7	6.5	4.9	6
B_2O_3	6.7	3	3	0	9	9	9	9	9.12	8
Al_2O_3	6.2 (AlF_3)	6	6	6	6	6	5.5	0	0	4
K_2O	0	0	0	0	0	0	0	0	0	0
Fe_2O_3	2.8	3	0	0	1	1	1	1	1.02	3
CaO					3	3	1.5	0.84	1.52	0
Appearance upon cooling	heterogeneous, white,green, and blue	lots of crys	bits of crys in glass	homogeneous rock	glassy brown	opaque green	glassy brown	opaque green	glassy black	shiny black

Fernald Glass	F5-37	F5-38	F5-39	F5-40	F5-41
Pit 5	45.8	50	48	47.1	51
Soil	13.7	15	14	13.5	30
Fly Ash	22.2 (wet)	15	15	14.5	0
SiO_2	5.5	6	6	5.8	7
Na_2O	3.7	4	8 (NaF)	9.6 (NaF)	5 (NaF)
B_2O_3	7.3	8	7.5	8	7
Al_2O_3	0	0	0	0	0
K_2O	0	0	0	0	0
Fe_2O_3	1.8	2	1.5	1.5	0
CaO	0	0	0	0	0
Appearance upon cooling	opaque black	opaque green	opaque blue & green	opaque green	opaque green

* Entries are weight percent on a dry basis.

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TABLE C.2-36

TCLP LEACH DATA FOR FEMP GLASSES - RCRA METALS (PPM)

	As	Se	Cd	Hg	Ag	Pb	Ba	Cr
F5-5	0.57	0.43	0.00	0.01	0.00	0.89	4.06	0.00
F5-7	0.17	0.00	0.00	0.00	0.00	0.86	4.03	0.00
F5-8	0.25	0.17	0.00	0.10	0.00	1.00	4.60	0.03
F5-10	0.64	0.40	0.00	0.07	0.00	1.01	6.02	0.06
F5-17	0.87	0.66	0.00	0.15	0.02	0.99	12.42	0.12
F5-19	0.26	0.23	0.01	0.02	0.01	0.94	2.80	0.01
F5-20	0.54	0.00	0.00	0.06	0.00	0.89	3.70	0.00
F5-22	0.08	0.21	0.00	0.03	0.00	0.90	9.90	0.02
F5-23	0.55	0.16	0.01	0.19	0.01	0.91	9.63	0.04
F5-24	0.34	0.10	0.01	0.03	0.00	0.84	7.52	0.00
F5-25	0.52	0.00	0.02	0.07	0.00	1.12	7.57	0.10
F5-28	0.40	0.31	0.01	0.05	0.01	1.04	4.18	0.02
F5-29	0.10	0.26	0.01	0.10	0.00	0.94	0.69	0.01
F5-30	0.28	0.24	0.01	0.00	0.00	0.69	0.26	0.00
F5-32	0.12	0.38	0.03	0.13	0.02	1.11	5.98	0.03
F5-35	0.56	0.32	0.01	0.06	0.01	0.99	4.62	0.09
F5-36	0.39	0.49	0.00	0.06	0.00	1.05	2.24	0.00
F5-37	0.54	0.11	0.00	0.05	0.00	1.18	1.45	0.01
F5-39	0.31	0.27	0.00	0.00	0.00	0.86	2.11	0.01
F5-40	0.15	0.20	0.03	0.18	0.01	1.04	12.49	0.04
EPA Limit	5	1	1	0.2	5	5	100	5

TABLE C.2-37

TCLP LEACH DATA FOR FEMP GLASSES - RADIONUCLIDE CONCENTRATIONS (PPB)

Radionuclides (ppb)	F5-5	F5-7	F5-8	F5-17	F5-19	F5-20	F5-22	F5-23	F5-24	F5-25
Tc-99	0.16	0.14	0.14	0.10	0.16	0.12	0.15	0.11	0.04	0.03
Th-232	10	8.0	22.7	305	0.52	7.1	94.5	107	30.1	240
U-234	< 0.01	0.05	0.02	0.32	0.31	0.21	0.18	0.17	0.15	0.16
U-233	0.04	0.02	< 0.02	0.91	< 0.02	0.04	0.27	0.22	0.10	< 0.02
U-235	0.64	5.6	3.8	43.7	36	33.7	25	24	18	24
U-236	0.008	0.15	0.09	1.1	0.86	0.83	0.61	0.56	0.49	0.59
U-238	93	891	573	5700	4600	4300	3000	2800	2000	2700

Radionuclides (ppb)	F5-28	F5-29	F5-30	F5-32	F5-35	F5-36	F5-37	F5-39	F5-40
Tc-99	0.03	0.18	0.41	0.09	0.06	0.06	0.09	0.30	0.09
Th-232	7.0	0.75	0.06	0.17	4.1	0.45	0.60	0.54	11
U-234	0.36	0.03	0.02	0.19	0.22	0.34	0.04	0.30	0.23
U-233	0.03	0.03	< 0.02	< 0.02	< 0.02	0.02	< 0.02	0.02	0.05
U-235	49	0.33	0.16	26	33	37	0.93	40	32
U-236	1.2	0.03	< 0.02	0.67	0.74	1.0	< 0.02	1.0	0.79
U-238	5500	38	18	3100	3900	4200	120	4400	9400

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TABLE C.2-38

PCT RESULTS OF FEMP GLASSES (PPM)
(7 DAYS, 90°C, 100-200 MESH)

	F5-5	F5-7	F5-8	F5-10	F5-17	F5-19	F5-20	F5-22	F5-23	F5-24
B	144.5	96.66	239.4	98.43	69.9	47.00	97.7	16.09	28.01	19.16
Si	11.72	6.32	7.43	7.30	1	9.39	8	18.96	21.93	24.29
Na	503.1	296.3	651.4	288.4	5.94	13.95	11.8	54.24	71.95	44.56
pH	11.43	11.19	11.37	11.07	19.3	9.7	3	10.09	9.43	10.04
Al	2.57	0.67	1.22	0.77	7	2.72	217.	1.23	1.02	1.13
Ba	2.12	1.64	1.91	1.10	8.85	3.07	6	1.15	0.58	0.64
Ca	30.20	46.67	52.7	51.34	0.30	68.66	9.58	56.80	47.86	47.20
Fe	0.00	0.00	0.00	0.00	0.91	0.00	0.96	0.00	0.00	0.01
K	46.88	45.92	49.06	47.49	66.2	111.5	1.61	3.62	4.48	5.49
Mg	0.03	0.07	0.00	0.00	5	0.06	40.7	0.01	0.08	0.03
Ti	0.06	0.03	0.09	0.07	0.00	0.00	0	0.03	0.00	0.02
Li	0.89	0.88	1.14	0.65	9.80	0.51	0.00	0.22	0.20	0.19
Mn	0.00	0.02	0.02	0.00	1.40	0.00	14.4	0.01	0.00	0.01
Zr	0.03	0.01	0.15	0.10	0.05	0.00	1	0.19	0.00	0.05
P	0.54	0.59	0.93	0.56	0.55	0.00	0.07	1.03	0.63	0.87
Ni	0.08	0.03	0.22	0.12	0.00	0.10	0.05	0.06	0.00	0.05
Cr	0.25	0.01	0.02	0.30	0.08	0.63	0.37	0.00	0.00	0.00
Sr	0.32	0.45	0.45	0.43	0.37	0.24	0.01	0.09	0.11	0.12
Ag	0.00	0.00	0.00	0.00	0.18	0.16	0.04	0.02	0.00	0.00
As	4.88	2.77	3.78	2.63	0.05	0.00	0.75	0.69	1.24	0.74
Cd	0.00	0.00	0.11	0.00	0.27	0.06	0.22	0.03	0.00	0.09
Hg	0.69	0.08	0.27	1.65	0.00	2.65	0.09	0.97	0.06	0.00
Pb	0.00	0.27	0.30	0.17	0.15	0.23	0.21	0.07	0.00	0.00
Se	7.92	0.00	1.56	1.41	0.10	0.00	0.00	0.82	0.00	0.55
					0.67		0.04			
					0.05		0.10			
					0.00		0.38			
							0.00			
							0.00			

TABLE C.2-38
(Continued)

	F5-25	F5-28	F5-29	F5-30	F5-32	F5-35	F5-36	F5-37	F5-39	F5-40
B	23.40	81.84	135.1	13.48	397.4	296.	369.3	455.7	331.1	315.0
Si	24.44	7.80	18.57	78.71	8.54	7	5.53	6.93	9.42	6.64
Na	54.79	349.5	891.3	4588	477.9	6.92	754.2	713.7	759.3	597
pH	10.14	10.91	11.59	12.25	9.10	464.	10.08	9.62	9.46	9.34
Al	1.16	2.17	5.16	1.00	0.52	5	2.42	1.26	0.35	0.44
Ba	0.89	0.49	0.09	0.09	0.39	9.67	1.35	1.23	0.08	0.25
Ca	60.47	37.22	8.01	0.55	16.36	0.29	60.51	46.03	2.44	4.93
Fe	0.00	0.01	0.00	0.04	0.00	1.25	0.00	0.01	0.03	0.00
K	6.27	9.60	4.85	169.1	4.45	38.1	14.36	44.82	39.14	36.73
Mg	0.05	0.01	0.08	0.08	0.40	4	0.05	0.12	0.26	0.43
Ti	0.02	0.01	0.03	0.06	0.02	0.00	0.03	0.01	0.02	0.08
Li	0.22	0.70	0.45	0.48	0.20	45.9	0.29	0.35	0.59	1.05
Mn	0.00	0.01	0.04	0.00	0.01	0.21	0.02	0.02	0.02	0.03
Zr	0.01	0.09	0.07	0.03	0.01	0.01	0.01	0.04	0.05	0.08
P	1.42	1.01	3.56	0.30	0.06	0.56	0.50	0.74	0.49	3.82
Ni	0.01	0.02	0.03	0.68	0.00	0.05	0.03	0.02	0.23	0.13
Cr	0.00	0.00	0.00	0.28	0.00	0.03	0.14	0.11	0.08	0.00
Sr	0.15	0.15	0.00	0.00	0.12	0.43	0.39	0.40	0.23	0.07
Ag	0.14	0.00	0.01	0.08	0.00	0.06	0.00	0.00	0.08	0.00
As	1.85	4.33	4.08	7.41	7.90	0.39	0.65	0.00	0.03	0.34
Cd	0.01	0.01	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.00
Hg	1.30	1.25	0.34	3.21	1.05	0.00	2.46	1.83	0.77	0.65
Pb	0.01	0.04	0.03	0.00	0.00	2.14	0.00	0.00	0.00	0.09
Se	0.00	0.46	0.00	4.86	0.81	0.00	7.82	2.88	1.06	1.24
						1.68				2.66
						0.00				
						0.28				

TABLE C.2-39

FEEDS USED FOR 10 KG/DAY MELTER RUNS

	Micro-F1		Micro-F2	
	Mass	Wt%	Mass	Wt%
Pit 5 Sludge	6.94 kg	71.8%	6.73 kg	73.2%
Fernald Whole Soil	0.46 kg	4.8%	1.33 kg	14.5%
H_3BO_3	0.59 kg	6.1%	0.50 kg	5.4%
SiO_2	0.60 kg	6.2%	0.30 kg	3.3%
$Fe(OH)_3$ Slurry (88% water)	0.55 kg	5.7%	0	0%
Recovered NaF (40% water)	0.53 kg	5.5%	0.34 kg	3.7%

TABLE C.2-40

TCLP DATA FOR GLASSES PRODUCED FROM 10 KG/DAY CONTINUOUS MELTER RUNS

	As	Se	Cd	Hg	Ag	Pb	Ba	Cr
MIC3-54A	0.39	0.52[a]	0.01	0.15	0.02	1.40	4.47	1.49
MIC3-56A	0.30	0.46[a]	0.02	0.11	0.02	1.37	8.13	0.11
EPA Limit	5	1	1	0.2	5	5	100	5

[a] See data were below the standard deviation of the measurement.

TABLE C.2-41

WASTE PIT 6 REMEDY SCREENING TESTS

RANGE FINDING TEST						
Formulation[a]	Waste (g)	Soil (g)	Flyash (g)	Na_2O	Viscosity[b]	Description of Glass
(As-ls) P6-1 10500801	100	0	0	0	V-3/V-4	Viterous with inclusions
(Soil) P6-2 10501306	100	100	0	5.0	V-3	Excellent glass product
(Soil) P6-3 10501506	100	150	0	5.0	V-3	Excellent glass product
(Flyash) P6-4 10501906	100	0	150	5.0	V-1	Granite-like with crystalline cap

TABLE C.2-41
(Continued)

PRELIMINARY PHASE TESTS							
Formulation[a]	Waste (g)	Soil (g)	Flyash (g)	% Na_2O	Viscosity[b]	Description of Glass	Leachate Analysis[c]
(As-ls) P6-6 10502906	100	0	0	8.5	V-3/V-4	Vitreous, bi-phase glass	19K. 14 Si. 58 Na. 123 F (PCT); 15 U (MTCLP)
(Soil) P6-7 10502606	100	150	0	5.2	V-3	Good vitreous product	3.7 U (MTCLP); 27 Ca. 14 Si. 31 F
(Soil) P6-8 10502706	100	150	0	2.6	V-3	Good vitreous product	15,800 alpha, 4460 beta, 1.4 U (MTCLP); 45 Ca. 23 Si. 31 F. 8 SO_4
(Soil) P6-9 10502806	100	0	200	2.6	V-3	Good vitreous product	1.8 U. 0.1 Cr (MTCLP); 5 Al. 11 Si. 3.5 F (PCT)
(Flyash) P6-11 10503014	100	0	200	5.2	V-2/V-3	Non-vitreous and porous	2.7 U (MTCLP); 11 Si. Al. Cd. Mg and F all <5

[a] Formulations are dry wights given as "part waste"/part soil or flyash"/% Na_2O addition.
[b] Viscosity designations used here are defined in Section A.10 of Appendix B.
[c] Results are given for MTCLP and PCT leach test and are reported in ppm (w/w). Analytes not reported were not detected.

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TABLE C.2-42

VITRIFICATION–WASTE PIT 6
ADVANCED PHASE FORMULATIONS

Formulation	Normalized Waste	Normalized Soil	Normalized Flyash	Normalized Sodium Oxide
1	100	175	0	14
2	100	0	200	20

TABLE C.2-43

VITRIFICATION–ADVANCED PHASE WASTE PIT 6
BULKING FACTOR, AVERAGE BULKING FACTOR

Zone	Formulation	Bulking Factor (Percent Volume Increase)	Average Bulking Factor (Percent Volume Increase)
Composite	1	-73	-62
Composite	2	-50	

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TABLE C.2-44

WASTE PIT 6 VITRIFICATION TCLP RADIONUCLIDES DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (pCi/l)	Formula 1 (pCi/l)	Formula 2 (pCi/l)
Cesium-137	NA	20.000	ND
Neptunium-237	NA	5.000	0.648
Plutonium-238	NA	1.933	
Plutonium-239/240	NA	ND	ND
Radium-226	NA	ND	0.626
Radium-228	NA	ND	ND
Strontium-90	NA	8.060	ND
Technetium-99	NA	236.000	ND
Thorium-228	NA	2.060	1.750
Thorium-230	NA	4.850	5.119
Thorium-232	NA	ND	ND
Uranium-234	NA	1010.000	111.240
Uranium-235/236	NA	104.000	9.428
Uranium-238	NA	5500.000	533.520
	Raw Waste Characterization (mg/l)	**Formula 1 (mg/l)**	**Formula 2 (mg/l)**
Thorium (Total)	NA	ND	ND
Uranium (Total)	NA	16.400	1.588

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample. For some vitrification samples, the dilution factor was less than 1. In these cases, a dilution factor of 1 was used.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

TABLE C.2-45

WASTE PIT 6 VITRIFICATION TCLP
METALS DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)	TC REG LIMITS
Antimony	ND	ND	ND	
Arsenic	0.550	0.004	0.012	5.000
Barium	1.731	ND	0.145	100.000
Beryllium	0.009	ND	0.002	
Cadmium	ND	ND	ND	1.000
Chromium	ND	ND	ND	5.000
Cobalt	ND	ND	ND	
Copper	ND	ND	0.029	
Cyanide	ND	ND	ND	
Lead	0.596	ND	ND	5.000
Manganese	1.255	1.530	0.103	
Mercury	ND	ND	ND	0.200
Molybdenum	ND	ND	ND	
Nickel	0.095	0.035	0.028	
Selenium	ND	ND	ND	1.000
Silver	0.047	ND	ND	5.000
Thallium	0.660	ND	ND	
Vanadium	ND	ND	ND	
Zinc	1.551	0.070	0.080	

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample. For some vitrification samples, the dilution factor was less than 1. In these cases, a dilution factor of 1 was used.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

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TABLE C.2-46

WASTE PIT 6 - NORMALIZED LEACHATE RATES EXPRESSED AS A PERCENTAGE OF SAVANNAH RIVER HIGH LEVEL WASTE CRITERIA

Formulation	Zone	Al	Mg	Na	Si	U	Li[a]	K	B
		Percentages							
1	Composite	0.3	0.009	45	1	0.01	Not Calc'd	29	Not Calc'd
2	Composite	0.3	0.1	59	0.5	Not Calc'd	Not Calc'd	4	271

[a] Not Calc'd indicates a normalized leach rate was not calculated because the metal was not found in the glass.

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TABLE C.2-47

BURN PIT
REMEDY SCREENING TEST

RANGE FINDING TEST						
Formulation[a]	Waste (g)	Soil (g)	Flyash (g)	Na_2O	Viscosity[b]	Description of Glass
(As-ls) P7-1 10500701	100	0	0	0	V-4	Excellent vitreous product
(Soil) No range finding samples were prepared.						
(Flyash) No range finding samples were prepared.						

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TABLE C.2-47
(Continued)

PRELIMINARY PHASE TESTS							
Formulation[a]	Waste (g)	Soil (g)	Flyash (g)	% Na_2O	Viscosity[b]	Description of Glass	Leachate Analysis[c]
(As-ls) P7-2 10502908	100	0	0	7.4	V-3	Excellent vitreous product	1.3 U (MTCLP); 20 Si, (PCT)
(Soil) P7-3 10502607	100	50	0	5.2	V-3/V-4	Translucent vitreous product	3.7 U, 0.2 Cr (MTCLP); 24 Ca, 24 Si (MIPCT)
(Soil) P7-4 10502707	100	50	0	2.6	V-2/V-3	Vitrous with crystal inclusions	0.3 U (MTCL); 12 Ca, 21 Si (MPCT)
(Flyash) P7-5 10502808	100	0	100	4.6	V-1	Slag-like with entrapped gas	NA[d]
(Flyash) P7-6 105030107	100	0	100	7.0	V-1	Slag-like with crystal inclusions	NA
(Flyash) P7-7 10502818	100	0	100	8.3	V-1	Dark amber vitreous product	0.2 U (MTCLP)
(Flyash) P7-8 10503205	100	0	100	7.7	V-2/V-3	Dark amber vitreous product	0.6 U (MTCLP); 7 Al, 14 Si, (MPCT)
(Flyash) P7-9 10503206	100	0	100	9.6	V-3/V-4	Excellent vitreous product	0.2 U (MTCLP)

[a] Formulations are dry weights given as "parts waste"/"parts soil or fly ash"/ % Na_2O addition.
[b] Viscosity designations used here are defined in Section A.1.0 of Appendix B of the RI Report for Operable Unit 1, (DOE1994).
[c] Results are given for MTCLP and PCT leach tests and are reported in ppm (w/w). Analytes not reported were not detected.
[d] Not analyzed.

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TABLE C.2-48

VITRIFICATION-BURN PIT ADVANCED PHASE FORMULATIONS

Formulation	Normalized Waste	Normalized Soil	Normalized Flyash	Normalized Sodium Oxide
1	100	50	0	4
2	100	0	0	8

TABLE C.2-49

VITRIFICATION--ADVANCED PHASE BURN PIT BULKING FACTOR, AVERAGE BULKING FACTOR

Zone	Formulation	Bulking Factor (Percent Volume Increase)	Average Bulking Factor (Percent Volume Increase)
1	1	-50	-52
2	1	-31	
3	1	-57	
1	2	-62	
2	2	-62	

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TABLE C.2-50

BURN PIT VITRIFICATION TCLP RADIONUCLIDES DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (pCi/l)	Formula 1 (pCi/l)	Formula 2 (pCi/l)
Neptunium-237	ND	0.585	0.410
Plutonium-238	ND	0.633	0.620
Plutonium-239/240	ND	0.227	ND
Radium-226	23.600	2.377	2.140
Radium-228	4.500	ND	ND
Strontium-90	ND	4.030	ND
Technetium-99	25.000	ND	ND
Thorium-228	2.010	4.936	2.260
Thorium-230	2.160	22.073	8.450
Thorium-232	ND	2.904	1.090
Uranium-234	10200.000	240.570	96.400
Uranium-235/236	643.000	11.771	4.870
Uranium-238	11000.000	465.590	112.000
	Raw Waste Characterization (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)
Thorium (Total)	ND	0.019	0.010
Uranium (Total)	23.920	1.389	0.336

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

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TABLE C.2-51

BURN PIT VITRIFICATION TCLP METALS DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)	TC REG LIMITS (mg/l)
Antimony	0.095	0.008	ND	
Arsenic	0.078	0.012	0.003	5.000
Barium	1.395	0.173	0.147	100.000
Beryllium	0.005	0.018	ND	
Boron	0.368	ND	ND	
Cadmium	0.017	ND	ND	1.000
Chromium	0.176	0.043	0.055	5.000
Cobalt	0.050	0.038	ND	
Copper	0.053	0.033	0.044	
Cyanide	ND	ND	ND	
Lead	0.065	0.010	0.056	5.000
Manganese	3.820	0.940	0.173	
Mercury	ND	ND	ND	0.200
Molybdenum	0.025	0.033	ND	
Nickel	0.081	0.051	0.040	
Selenium	0.190	ND	ND	1.000
Silicon	4.760	44.950	16.900	
Silver	0.121	ND	ND	5.000
Thallium	ND	ND	ND	
Vanadium	0.070	0.012	ND	
Zinc	0.513	0.201	0.127	

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample. For some vitrification samples, the dilution factor was less than 1. In these cases, a dilution factor of 1 was used.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

TABLE C.2-52

BURN PIT - NORMALIZED LEACHATE RATES EXPRESSED AS A PERCENTAGE OF SAVANNAH RIVER HIGH LEVEL WASTE CRITERIA

Formulation	Zone	Al	Mg	Na	Si	U	Li[a]	K	B
		Percentages							
1	1	0.3	0.01	4	2	0.005	Not Calc'd	0.1	Not Calc'd
1	2	0.1	1.2	4	0.9	0.01	Not Calc'd	2	6
1	3	0.3	0.01	5	0.9	0.07	Not Calc'd	0.6	Not Calc'd
2	Composite	0.4	0.6	26	0.4	Not Calc'd	Not Calc'd	0.7	8

[a] Not Calc'd indicates a normalized leach rate was not calculated because the metal was not found in the glass.

TABLE C.2-53

CLEARWELL REMEDY SCREENING TESTS

RANGE FINDING TEST						
Formulation[a]	Waste (g)	Soil (g)	Flyash (g)	Na_2O	Viscosity[b]	Description of Glass
(As-ls) P8-1 10501907	100	100	0	5.0	V-2/V-3	Viterous with slag-like skin
(Soil) P8-2 10501507	100	0	0	0	V-3	Excellent viterous product
(Flyash) No range finding samples were prepared						

TABLE C.2-53
(Continued)

PRELIMINARY PHASE TESTS							
Formulation[a]	Waste (g)	Soil (g)	Flyash (g)	% Na_2O	Viscosity[b]	Description of Glass	Leachate Analysis[c]
(As-ls) P8-3 10502907	100	0	0	8.2	V-3	Excellent vitreous product	2.0 U (MTCLP); 23 Ca. 23 Si (PCT)
(Soil) P8-4 10502608	100	50	0	5.2	V-1	Vitreous but nonpourable	NA[d]
(Soil) P8-5 10502708	100	50	0	9.8	V-3/V-4	Good vitreous product	1.9 U. 0.1 Cr (MTCLP); 23 Ca. 27 Na. 27 Si (MPCT)
(Soil) P8-6 10503015	100	50	0	11.0	V-3	Good vitreous product	28 Ca. 23 Si. 30 Na (PCT)
(Flyash) P8-7 10502807	100	0	100	8.8	V-3	Good vitreous product	0.14 U (MTCLP); 5 Al. 44 Ca. 14 Si. 4.5 Na (MPCT)
(Flyash) P8-8 10503016	100	0	100	12.0	V-3	Good vitreous product	0.8 U (MTCLP); 6 Al. 13 Ca. 16 Si. 25 Na (MPCT)

[a] Formulations are dry wights given as "part waste"/part soil or flyash"/% Na_2O addition.
[b] Viscosity designations used here are defined in Section A.10 of Appendix B.
[c] Results are given for MTCLP and PCT leach test and are reported in ppm (w/w). Analytes not reported were not dectected.
[d] Not analyzed.

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TABLE C.2-54

VITRIFICATION–PIT–CLEARWELL ADVANCED PHASE FORMULATIONS

Formulation	Normalized Waste	Normalized Soil	Normalized Flyash	Normalized Sodium Oxide
1	100	50	0	16
2	100	0	100	20

TABLE C.2-55

VITRIFICATION–ADVANCED PHASE PIT–CLEARWELL BULKING FACTOR, AVERAGE BULKING FACTOR

Zone	Formulation	Bulking Factor (Percent Volume Increase)	Average Bulking Factor (Percent Volume Increase)
Composite	1	-58	-36
Composite	2	-15	

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TABLE C.2-56

CLEARWELL VITRIFICATION TCLP RADIONUCLIDES DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (pCi/l)	Formula 1 (pCi/l)	Formula 2 (pCi/l)
Cesium-137	NA	ND	ND
Neptunium-237	NA	1.650	0.408
Plutonium-238	NA	0.820	1.356
Plutonium-239/240	NA	ND	ND
Radium-226	NA	ND	0.360
Radium-228	NA	ND	ND
Strontium-90	NA	4.270	ND
Technetium-99	NA	ND	97.080
Thorium-228	NA	1.840	1.788
Thorium-230	NA	3.310	7.644
Thorium-232	NA	0.150	ND
Uranium-234	NA	64.200	4.032
Uranium-235/236	NA	3.190	ND
Uranium-238	NA	163.000	17.160
	Raw Waste Characterization (mg/l)	**Formula 1 (mg/l)**	**Formula 2 (mg/l)**
Thorium (Total)	NA	0.001	ND
Uranium (Total)	NA	0.485	0.052

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from

TABLE C.2-57

CLEARWELL VITRIFICATION TCLP METALS DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)	TC REG LIMITS (mg/l)
Antimony	0.101	ND	ND	
Arsenic	ND	0.007	0.004	5.000
Barium	2.001	1.080	0.136	100.000
Beryllium	ND	ND	ND	
Cadmium	0.010	ND	ND	1.000
Chromium	0.010	2.170	0.103	5.000
Cobalt	0.095	0.019	ND	
Copper	0.822	0.138	0.052	
Cyanide	ND	ND	ND	
Lead	0.123	0.059	0.008	5.000
Manganese	66.986	3.470	0.073	
Mercury	ND	ND	ND	0.200
Molybdenum	0.037	0.092	ND	
Nickel	0.886	0.121	ND	
Selenium	ND	ND	ND	1.000
Silver	0.049	ND	ND	5.000
Thallium	ND	ND	ND	
Vanadium	0.040	0.075	0.013	
Zinc	0.609	0.198	0.020	

TABLE C.2-57
(Continued)

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample. For some vitrification samples, the dilution factor was less than 1. In these cases, a dilution factor of 1 was used.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

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TABLE C.2-58

CLEARWELL - NORMALIZED LEACHATE RATES EXPRESSED AS A PERCENTAGE OF SAVANNAH RIVER HIGH LEVEL WASTE CRITERIA

Formulation	Zone	Al	Mg	Na	Si	U	Li[a]	K	
		Percentages							
1	Composite	1	0.007	3	1	0.05	Not Calc'd	2	Not Calc'd
2	Composite	0.4	0	35	0.4	Not Calc'd	Not Calc'd	1	14

[a] Not Calc'd indicates a normalized leach rate was not calculated because the metal was not found in the glass.

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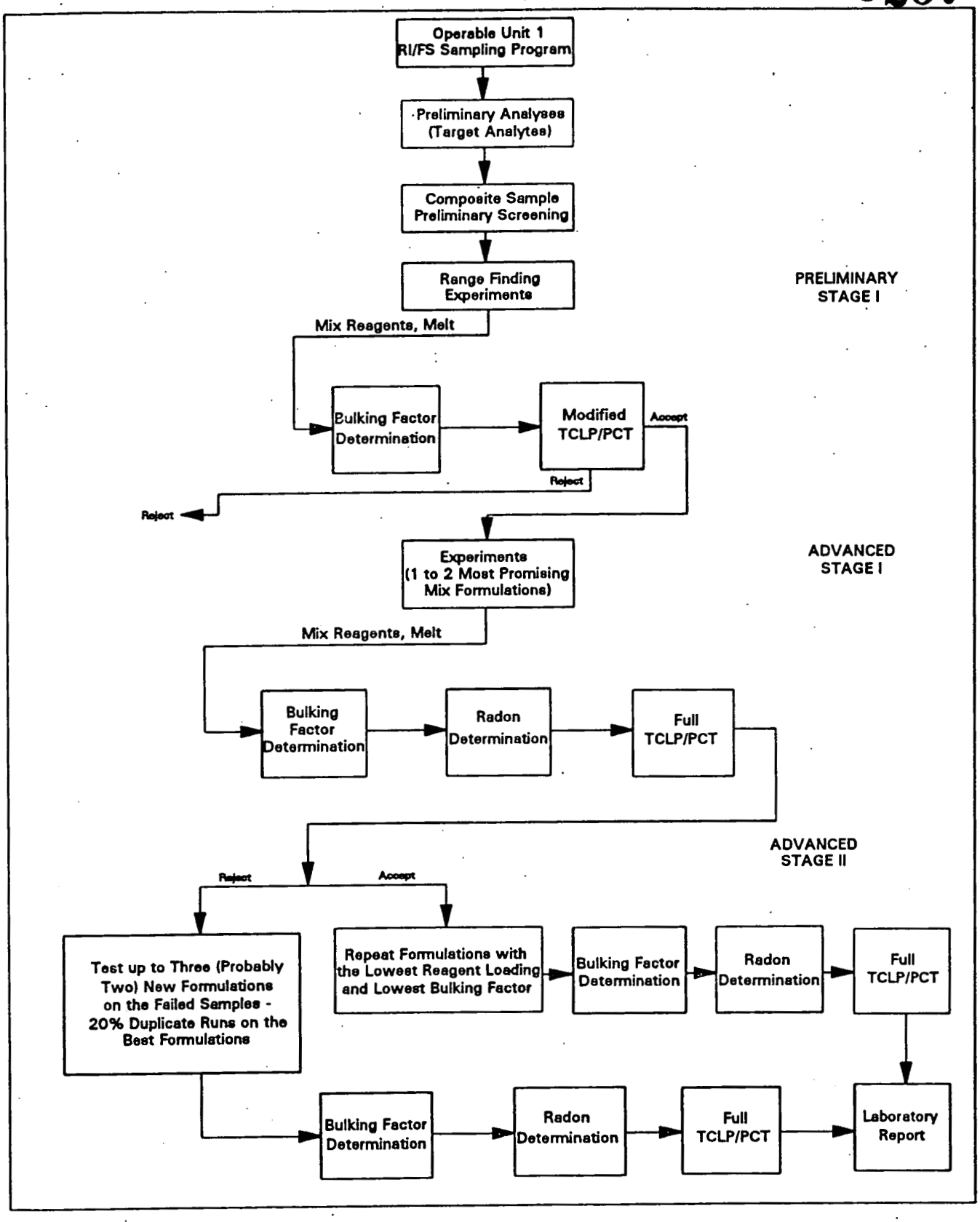

FIGURE C.2-1 VITRIFICATION LABORATORY SCREENING FLOWCHART

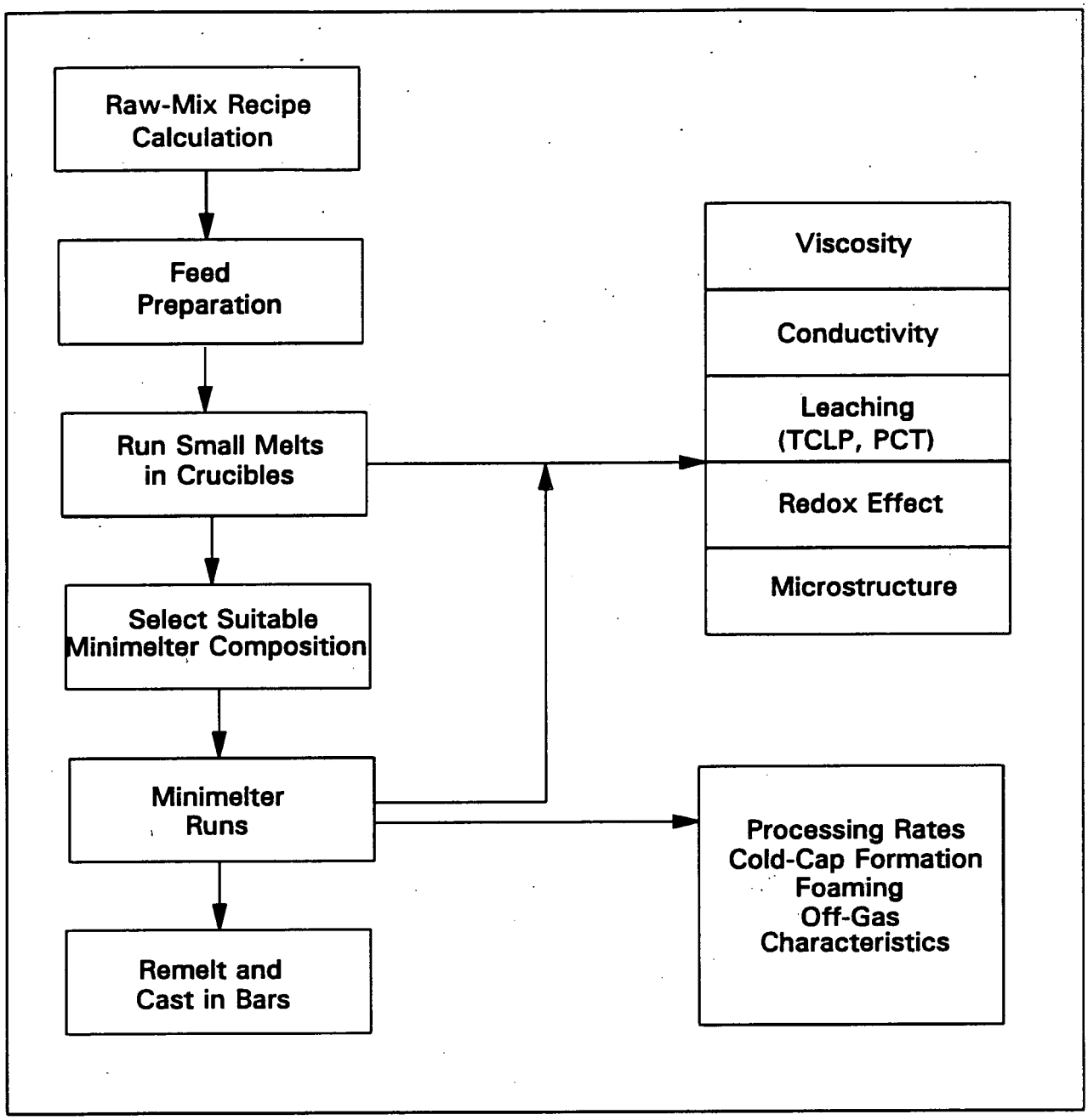

FIGURE C.2-2 FLOW DIAGRAM ILLUSTRATING SEQUENTIAL STEPS FOR GLASS PREPARATION AND CHARACTERIZATION

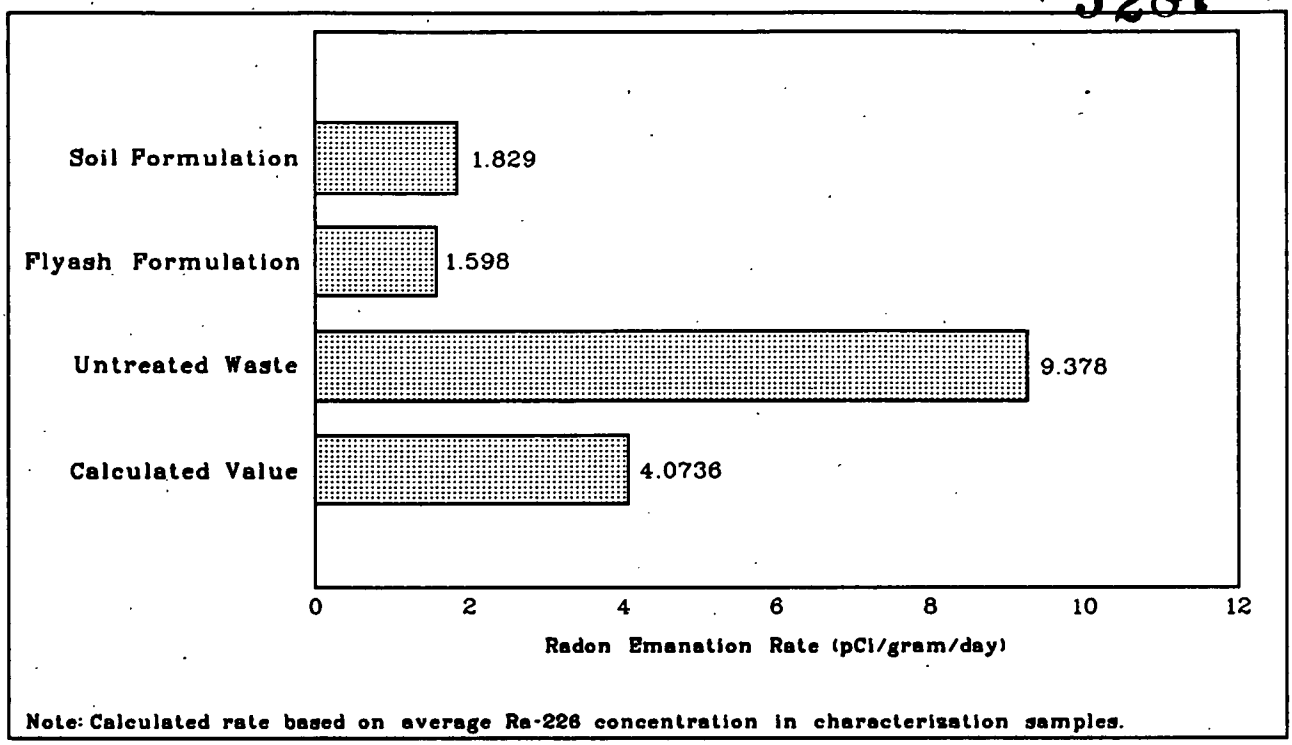

FIGURE C.2-3. WASTE PIT 1 VITRIFICATION: COMPARISON OF DILUTION-ADJUSTED RADON EMANATION RATES

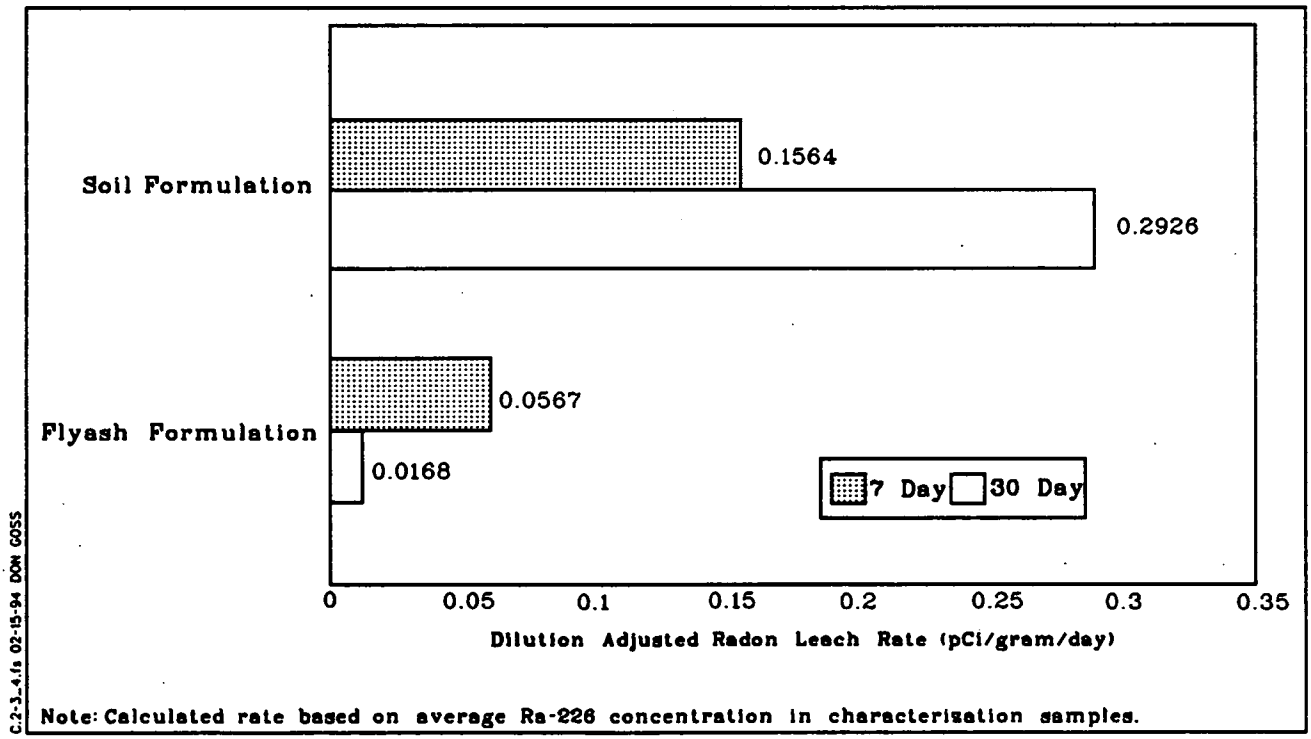

FIGURE C.2-4. WASTE PIT 1 VITRIFICATION: COMPARISON OF DILUTION-ADJUSTED RADON LEACH RATES

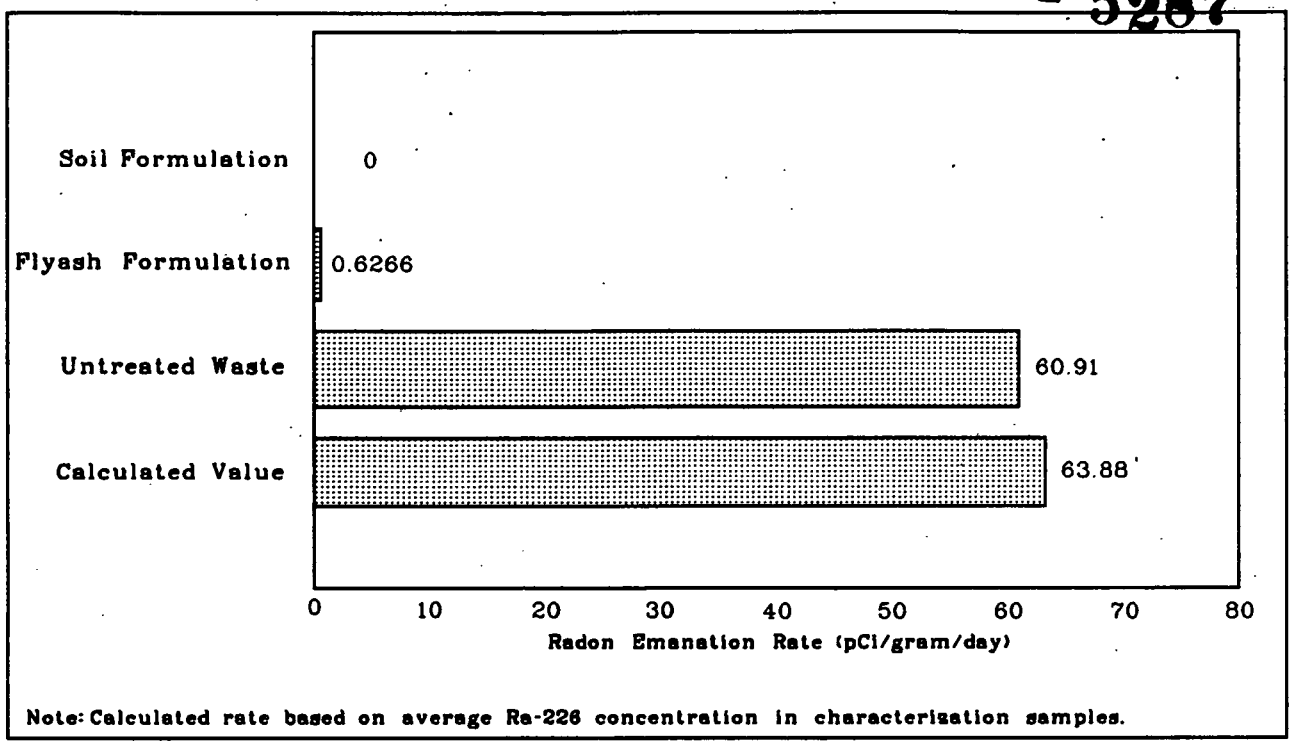

FIGURE C.2-5. WASTE PIT 2 VITRIFICATION: COMPARISON OF DILUTION-ADJUSTED RADON EMANATION RATES

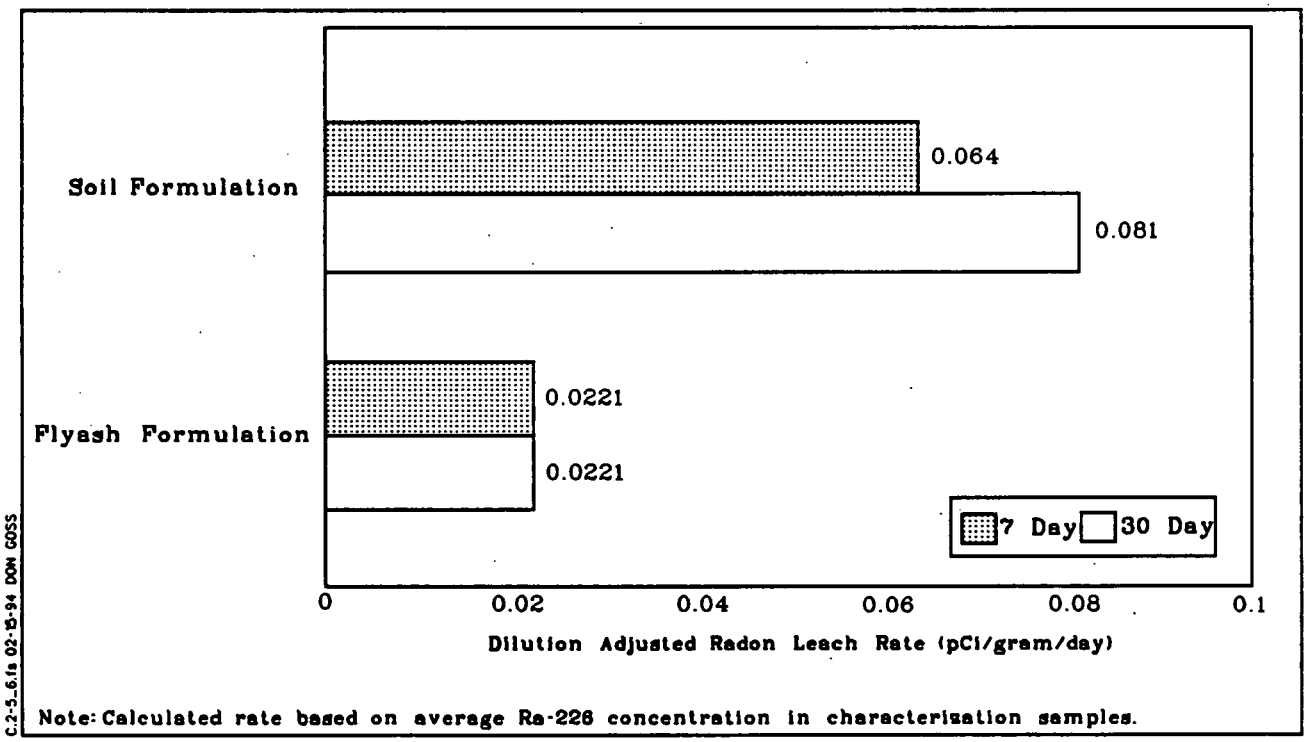

FIGURE C.2-6. WASTE PIT 2 VITRIFICATION: COMPARISON OF DILUTION-ADJUSTED RADON LEACH RATES

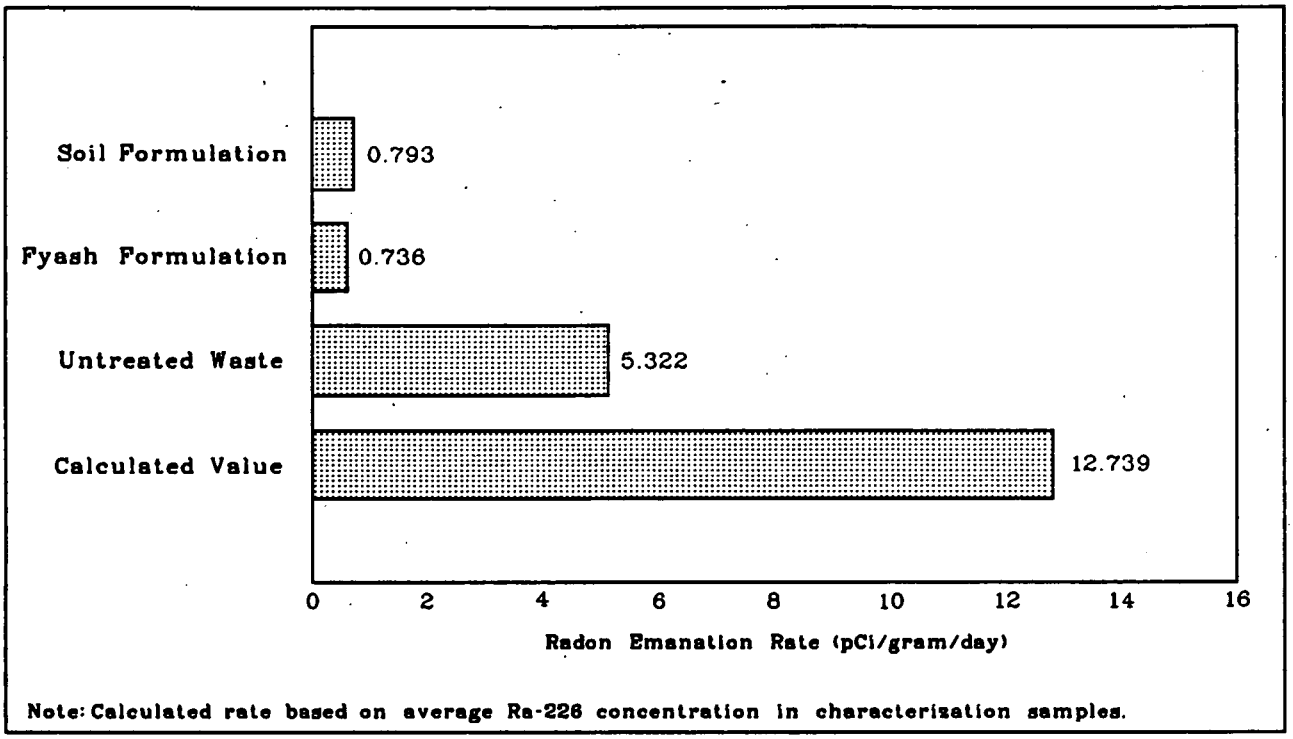

FIGURE C.2-7. WASTE PIT 3 VITRIFICATION: COMPARISON OF DILUTION-ADJUSTED RADON EMANATION RATES

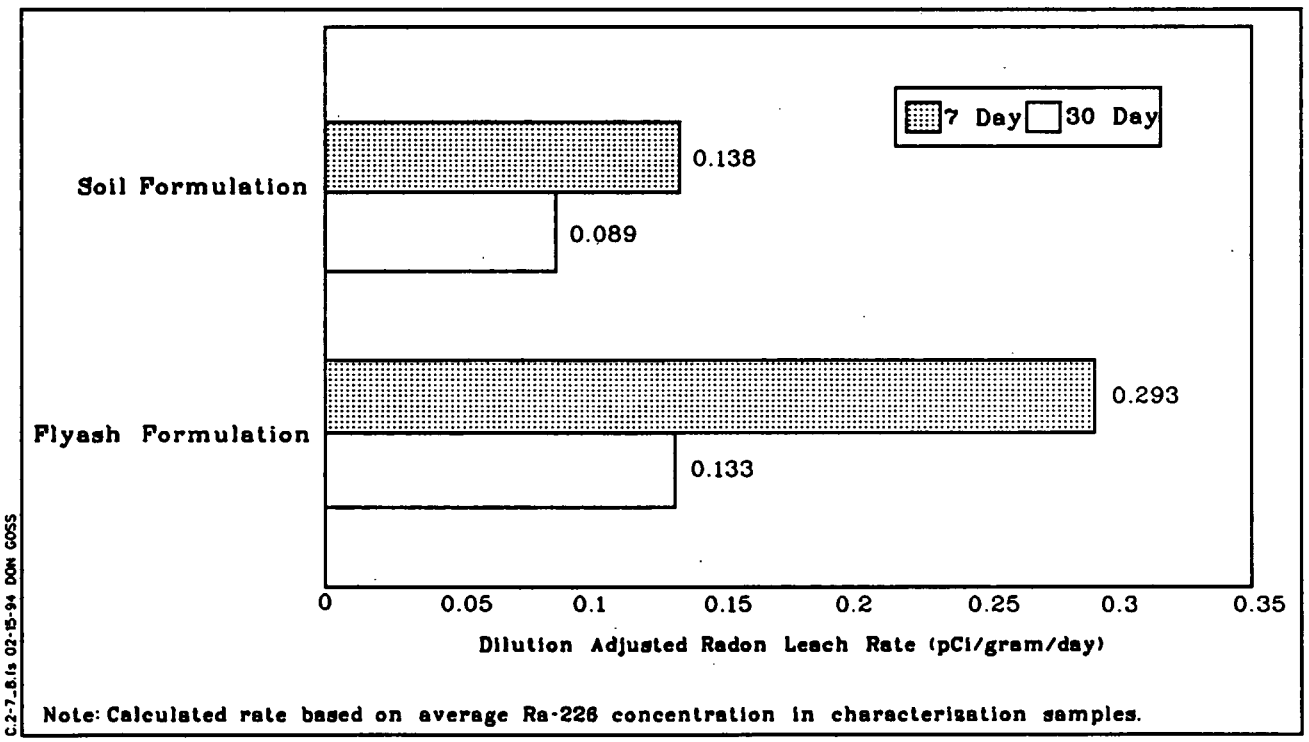

FIGURE C.2-8. WASTE PIT 3 VITRIFICATION: COMPARISON OF DILUTION-ADJUSTED RADON LEACH RATES

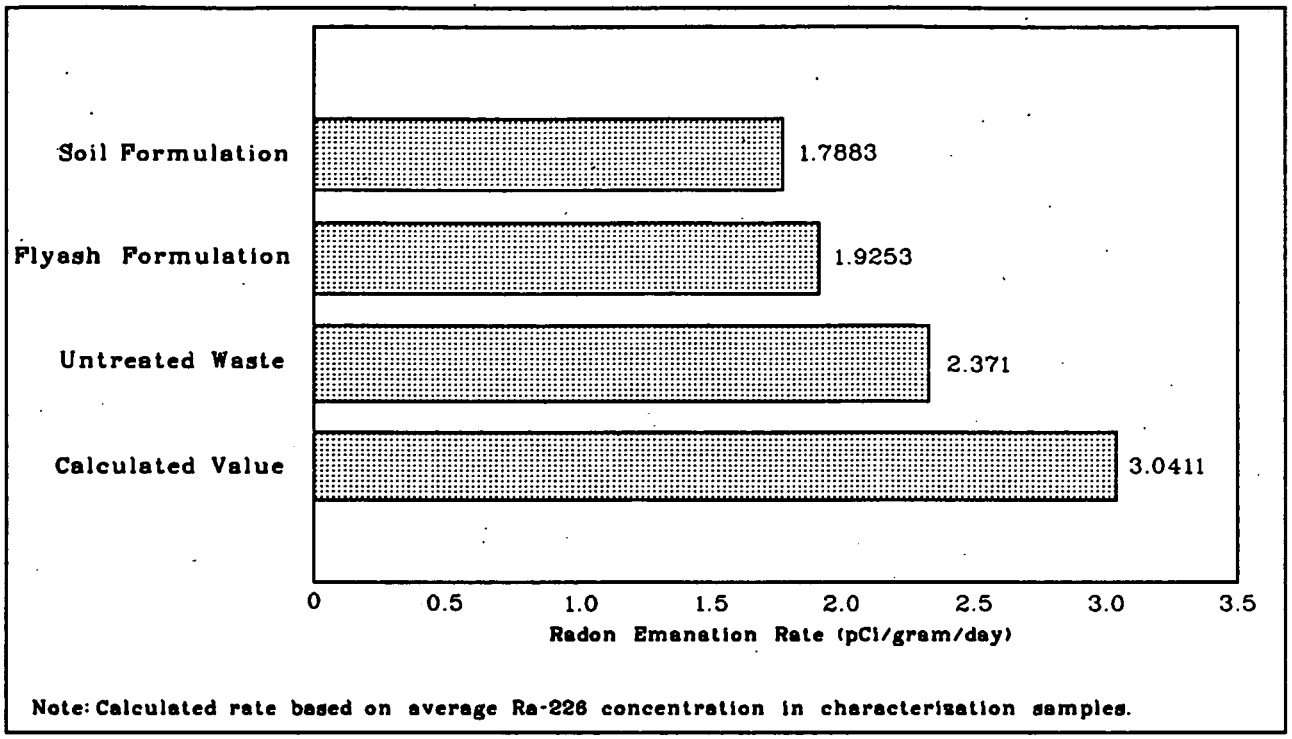

FIGURE C.2-9. WASTE PIT 4 VITRIFICATION: COMPARISON OF DILUTION-ADJUSTED RADON EMANATION RATES

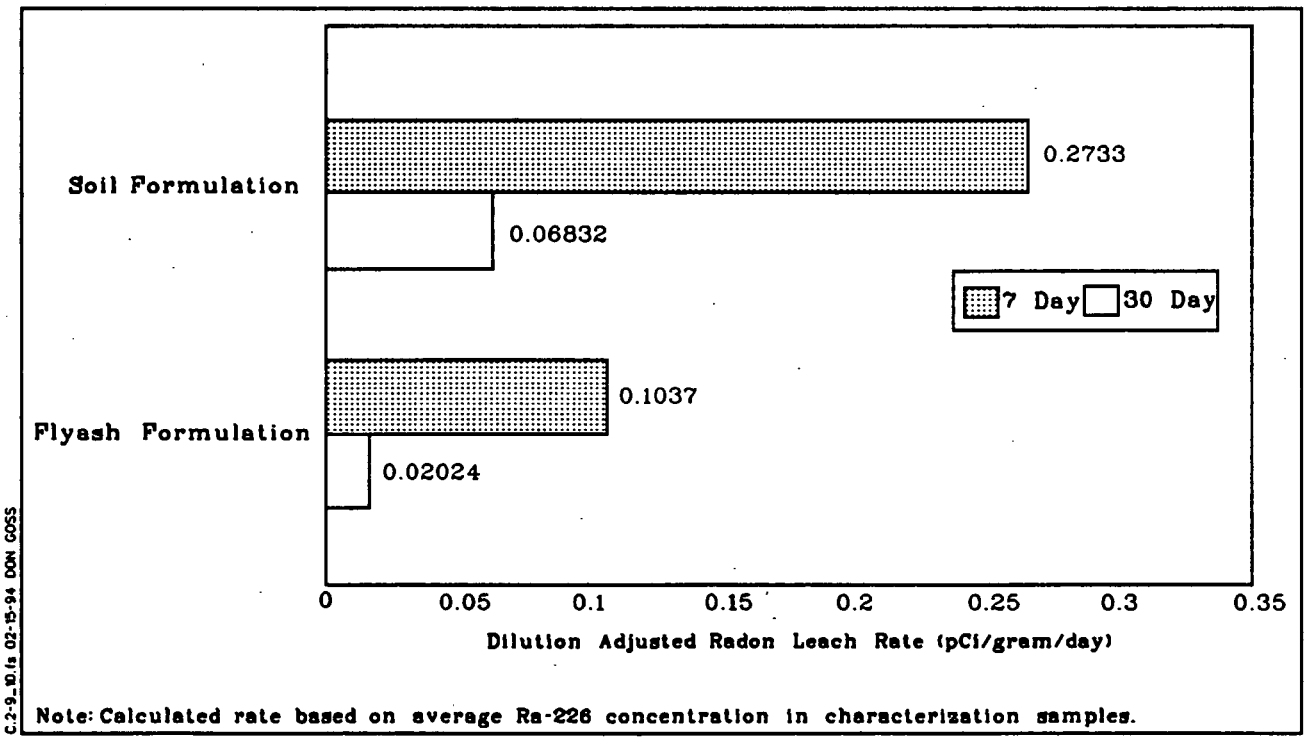

FIGURE C.2-10. WASTE PIT 4 VITRIFICATION: COMPARISON OF DILUTION-ADJUSTED RADON LEACH RATES

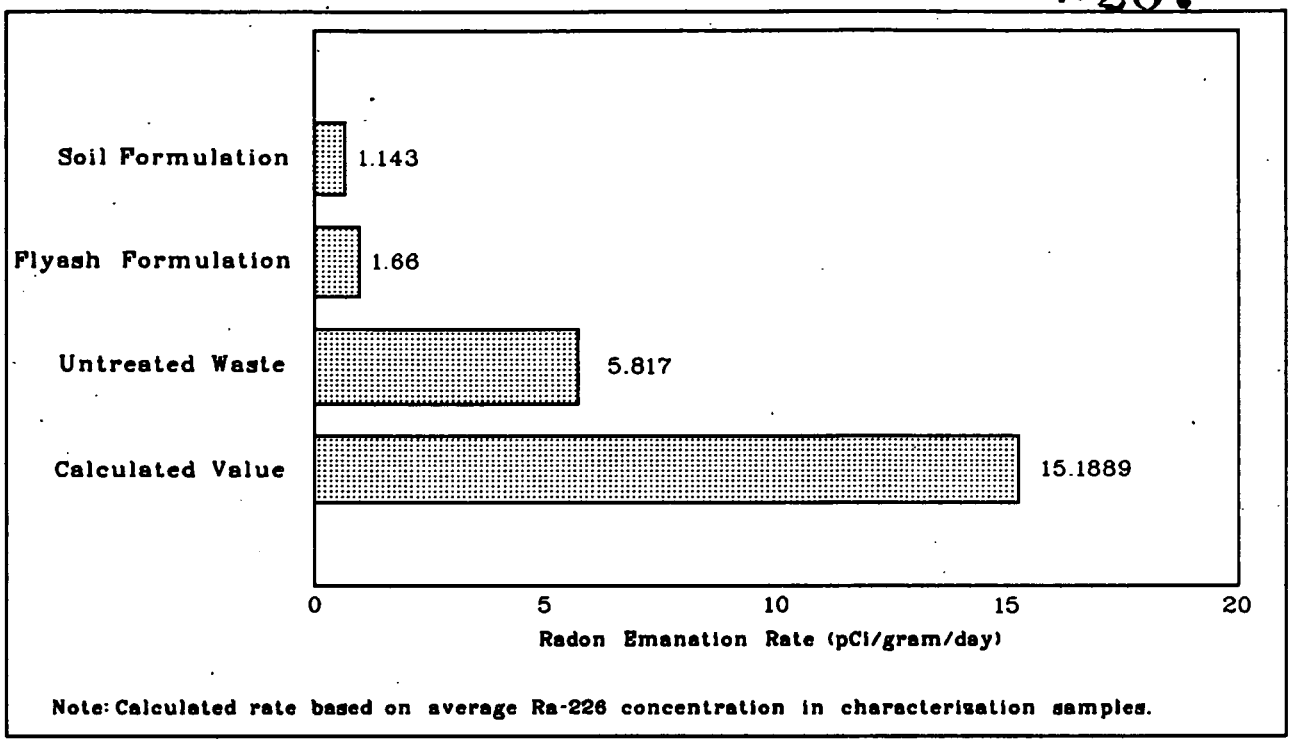

FIGURE C.2-11. WASTE PIT 5 VITRIFICATION: COMPARISON OF DILUTION-ADJUSTED RADON EMANATION RATES

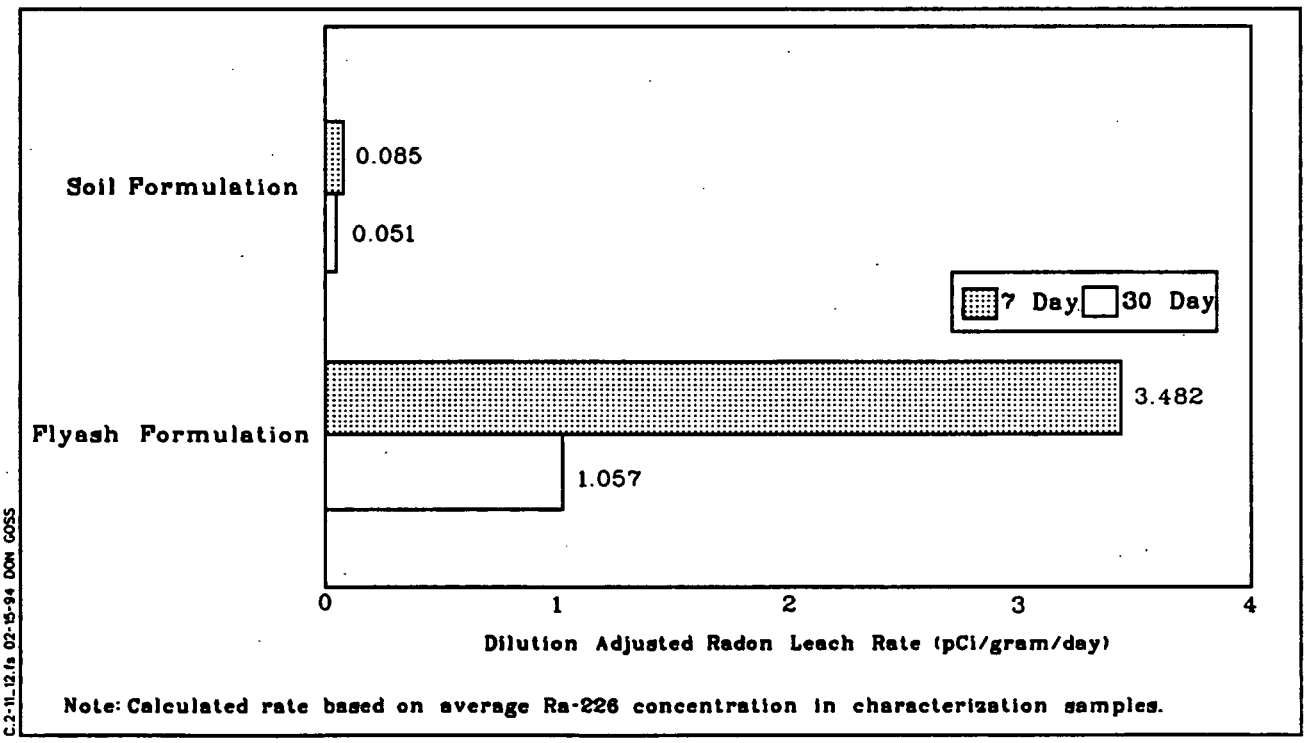

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FIGURE C.2-12. WASTE PIT 5 VITRIFICATION: COMPARISON OF DILUTION-ADJUSTED RADON LEACH RATES

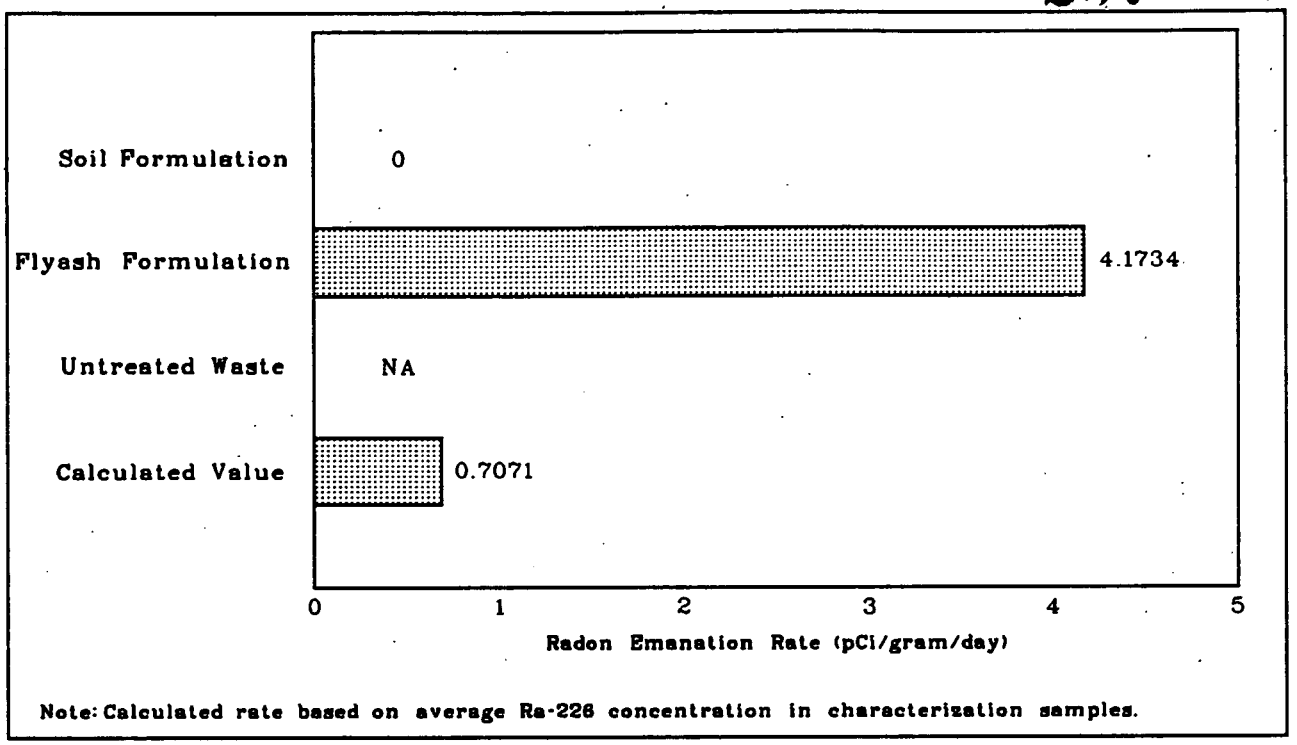

FIGURE C.2-13. WASTE PIT 6 VITRIFICATION: COMPARISON OF DILUTION-ADJUSTED RADON EMANATION RATES

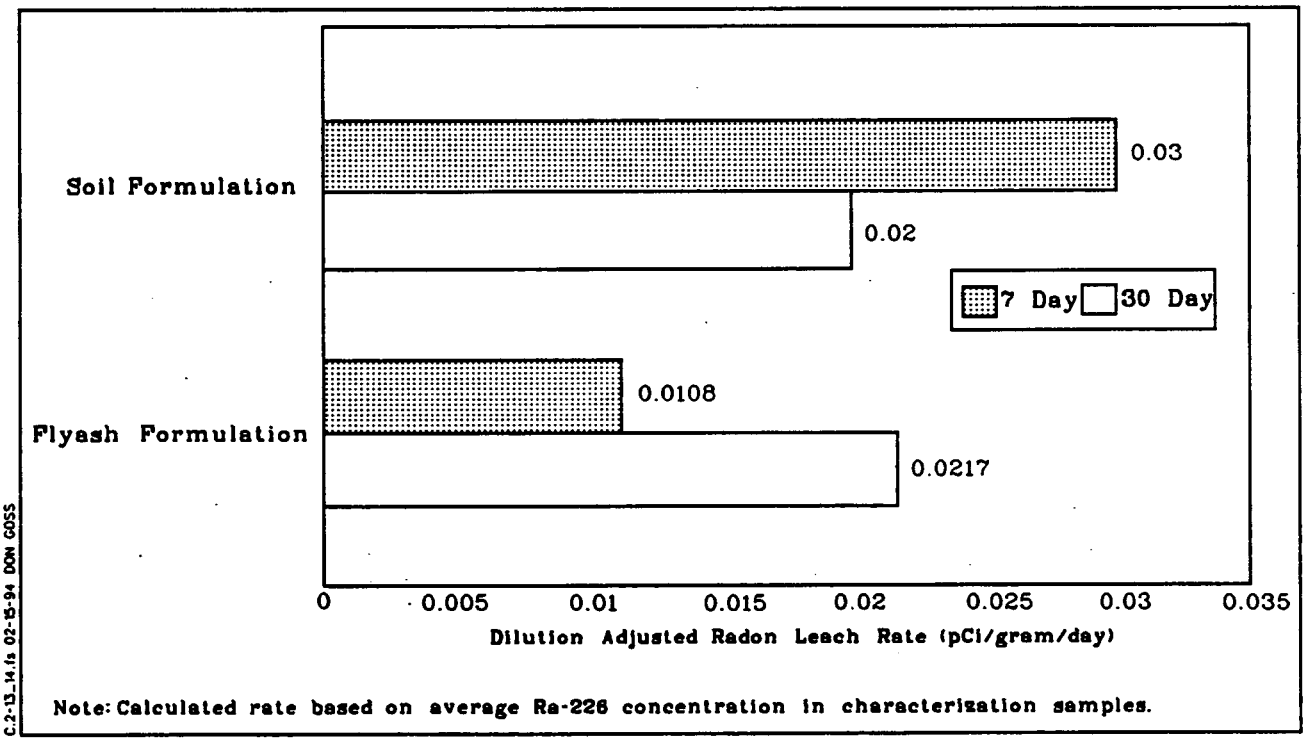

FIGURE C.2-14. WASTE PIT 6 VITRIFICATION: COMPARISON OF DILUTION-ADJUSTED RADON LEACH RATES

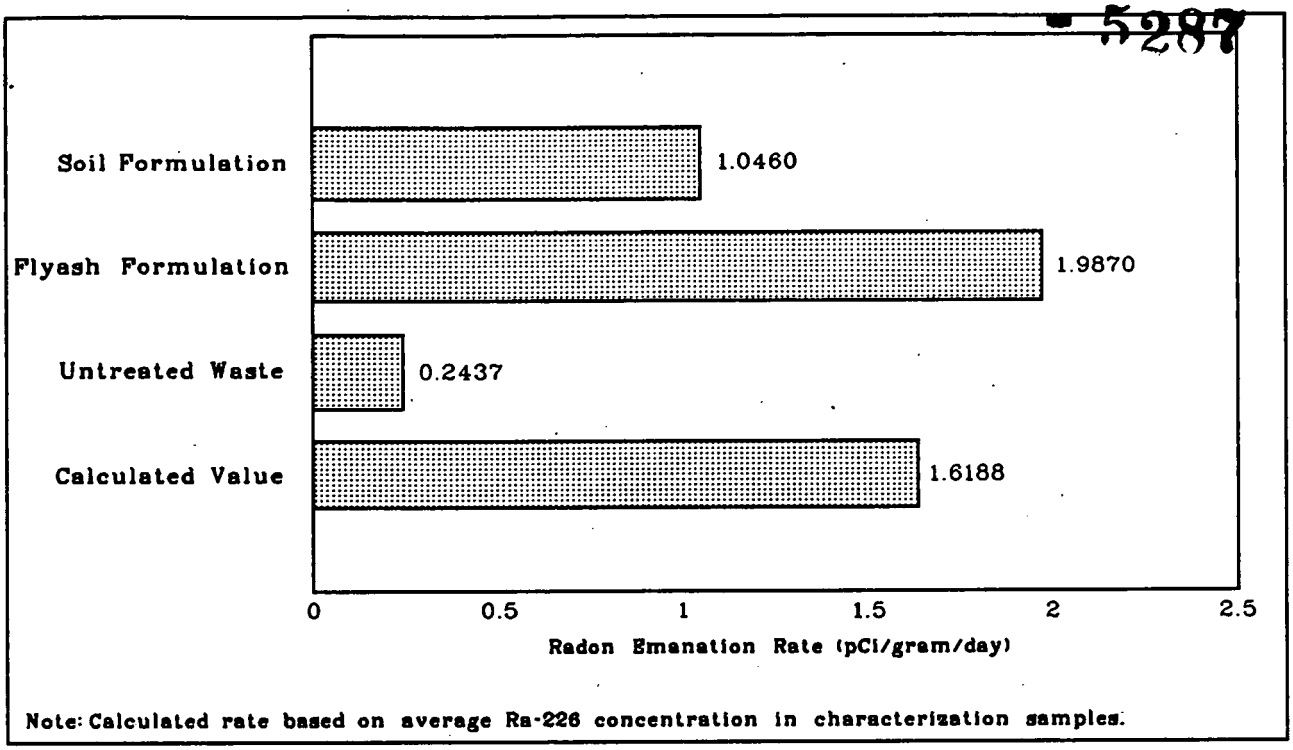

FIGURE C.2-15. BURN PIT VITRIFICATION: COMPARISON OF DILUTION-ADJUSTED RADON EMANATION RATES

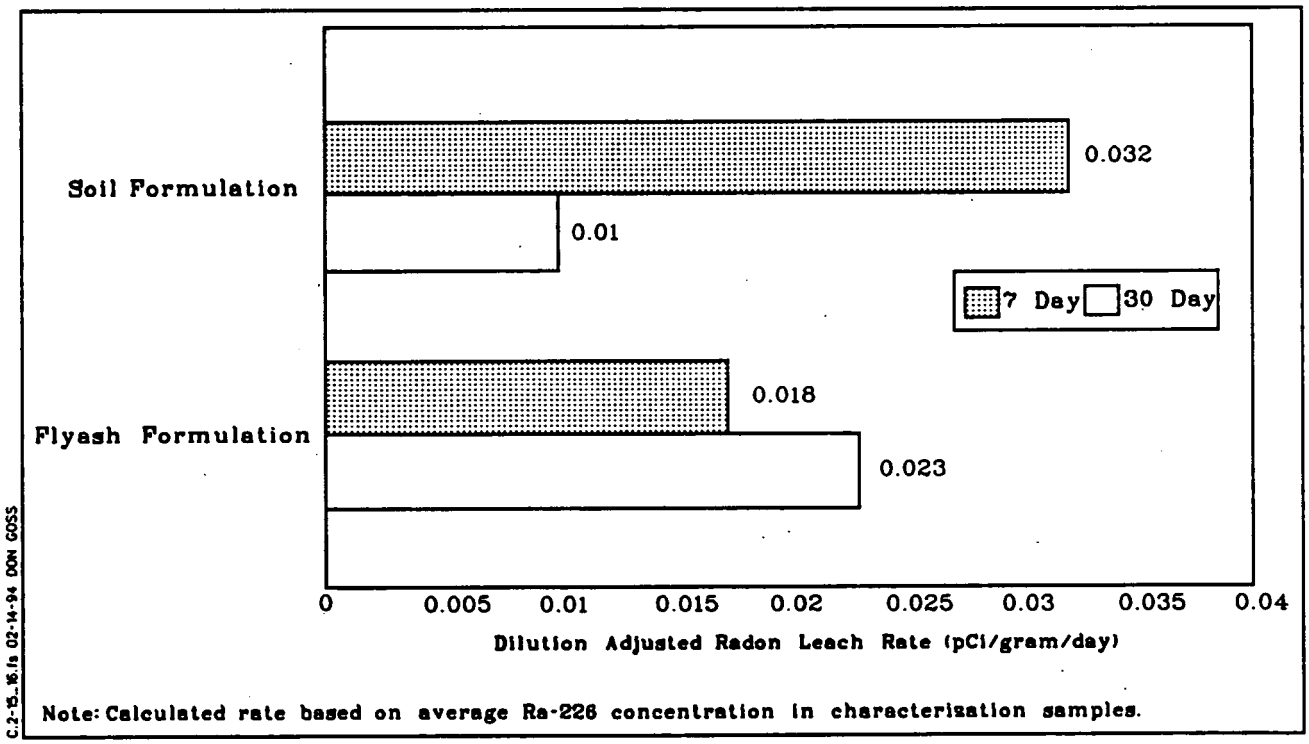

FIGURE C.2-16. BURN PIT VITRIFICATION: COMPARISON OF DILUTION-ADJUSTED RADON LEACH RATES

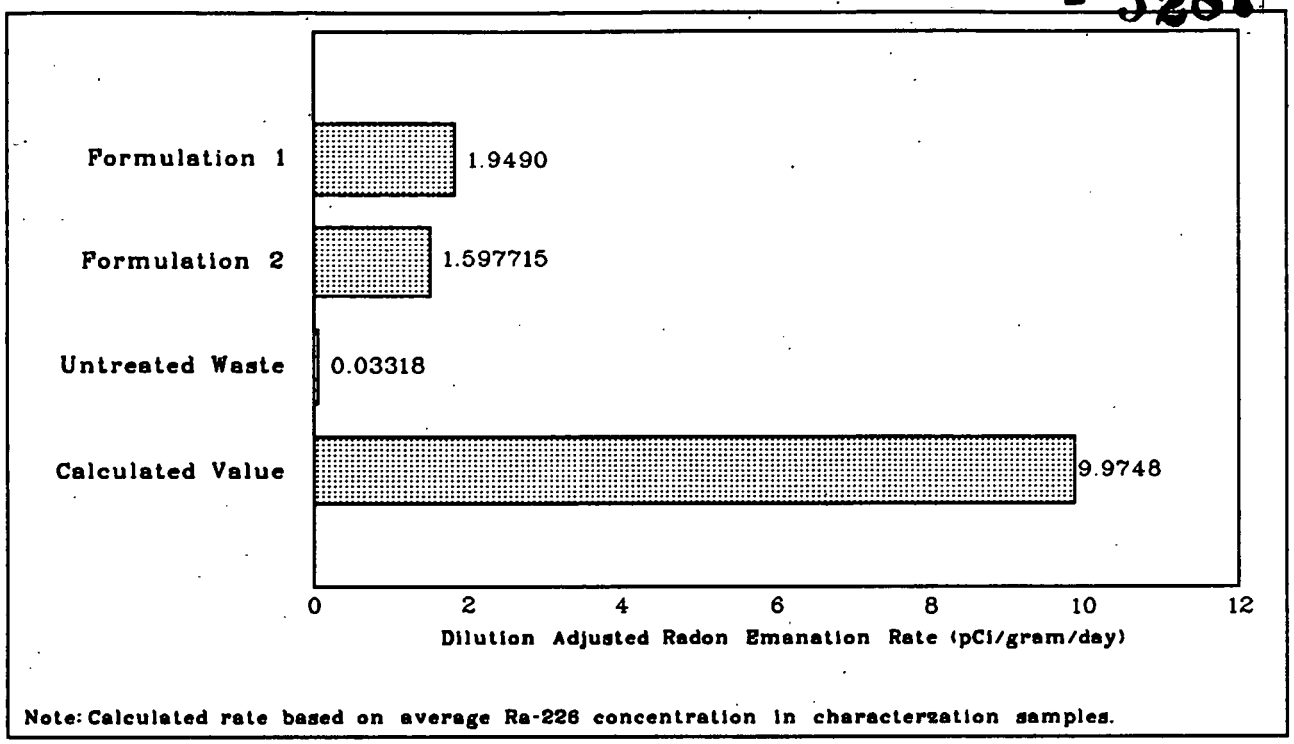

FIGURE C.2-17. CLEARWELL VITRIFICATION: COMPARISON OF DILUTION-ADJUSTED RADON EMANATION RATES

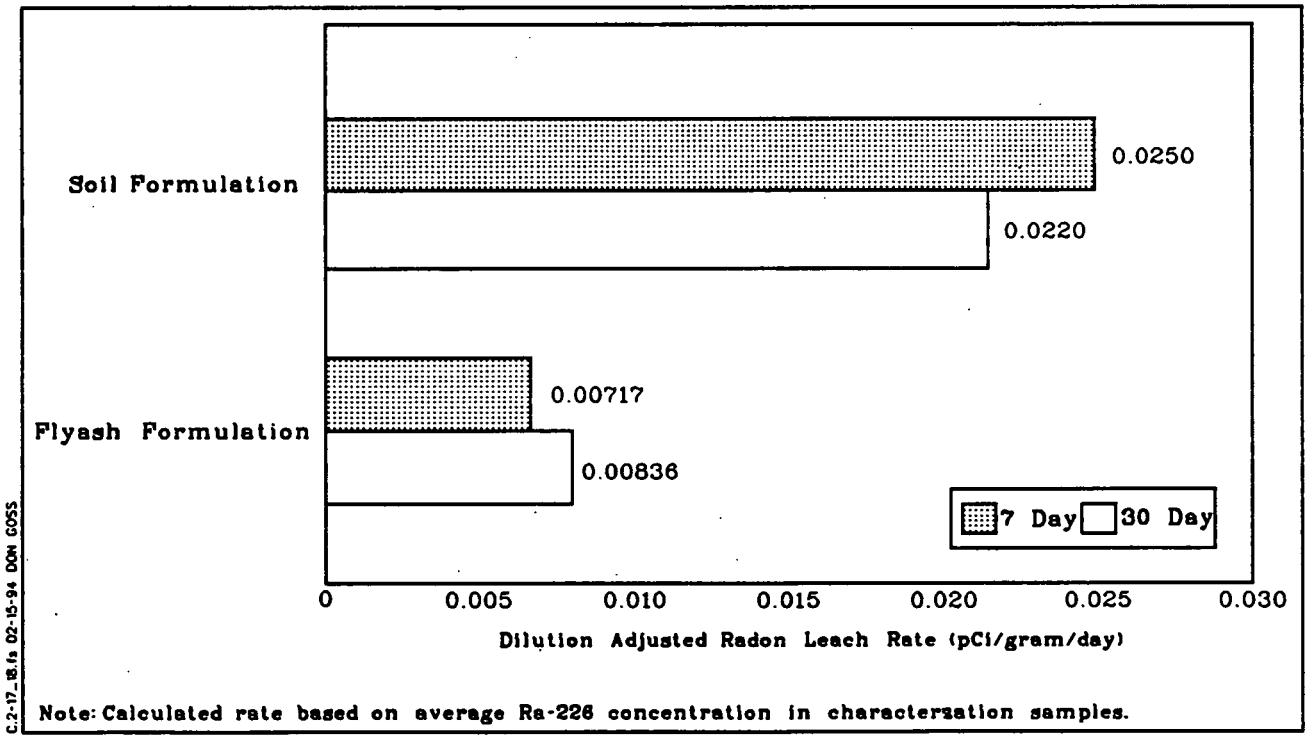

FIGURE C.2-18. CLEARWELL VITRIFICATION: COMPARISON OF DILUTION-ADJUSTED RADON LEACH RATES

APPENDIX C

SECTION 3
CEMENT SOLIDIFICATION/STABILIZATION TREATABILITY STUDY

C.3.0 CEMENT SOLIDIFICATION/STABILIZATION TREATABILITY STUDY

C.3.1 INTRODUCTION

Cement solidification/stabilization treatability studies were carried out in support of the Operable Unit 1 RI/FS process currently underway at the FEMP. All treatability work was performed based on work plans prepared in accordance with the EPA's "Guide for Conducting Treatability Studies Under CERCLA," Interim Final (EPA 1988) and Final (EPA 1992). Additional detail on the studies may be found in the referenced work plans and the "Treatability Study Report for Operable Unit 1," Final (DOE 1993).

C.3.2 TREATABILITY TEST METHODOLOGY

CSS studies were performed in a phased approach under the following work plan:

- CSS Remedy Screening/Remedy Selection Studies; Work Plan - IT 1990, Treatability Study Work Plan for Operable Unit 1

C.3.2.1 CSS Remedy Screening/Remedy Selection Studies

The cement stabilization treatability study consisted of two phases:

- Preliminary Phase - Stages 1 and 2 for Remedy Screening
- Advanced Phase - Stages 1, 2, and Optional for detailed analysis of alternatives and Remedy Selection

An iterative process was used in planning this evaluation, where the results from matrices of experiments were used to determine the course of the next set of experiments. The overall approach is described by Figure C.3-1 and C.3-2. Within each waste area, the effect of stabilization reagents on the unconfined compressive strength, leachability (as defined by the MTCLP results), and general processibility was addressed.

Remedy Screening experiments were statistically designed to yield trends of response variables (e.g., unconfined compressive strength (UCS) values) as a function of the reagent loadings and to determine the envelope of reagents that would meet the performance criteria. The performance criteria for this preliminary phase study were for the 28-day cured treated sample to develop a (UCS) of at least 500

psi and pass the toxicity characteristics (TC) regulatory requirements for metals in the Modified Toxicity Characteristic Leaching Procedure (MTCLP) test. The initial stabilization reagent/wet paste needed a consistency that was readily mixable and which did not exhibit a significant temperature rise. The range of cement and flyash loadings varied from 26 to 68 percent expressed as weight of reagent divided by wet weight (w/w) of waste. The adsorbents (attapulgite and clinoptilolite) and set/strength accelerator (sodium silicate) percentages ranged from 0 to 12 and 0 to 7 (w/w) percent, respectively.

The penetration resistance (PR) of this material was used to monitor the curing and relative set rate. If the treated material did not achieve at least 3.0 tons per square foot (tsf) within a 24-hour cure time, the formulation was considered not easily processible. After curing, samples were analyzed for UCS and MTCLP. Bulk density and BF were determined and indicated the increase or reduction in volume due to the addition of additives.

Several measurements of preliminary stabilization process parameters were obtained. The temperature rise, shear strength, and pH of the stabilization mix were measured as molds were set. A temperature rise of over 5 to 10°C during mixing indicated a reactive system that could potentially cause problems (i.e. flashing of steam and exposure to hot waste) in a larger scale. Excessive shear strength indicated a mixture may be difficult to handle in full scale mixing equipment. The desired consistency of the stabilization reagent/wet paste varies from that of "split pea soup" to "well-cooked oatmeal" (shear strength less than 1 tsf). Initial pH was a parameter monitored to measure the relative alkalinity of the initial mix.

C.3.2.1.1 <u>Preliminary Phase - Stage 1</u>

Ratios of waste to binder were varied to minimize the amounts of binder required to produce an acceptable stabilized waste form. Binding agents considered included portland cement, flyash, and sodium silicate. Clay (attapulgite and clinoptilolite) was added to reduce the leachability of metals in the waste. The most promising formulations from this stage had metal concentrations in the MTCLP near or less than the TCLP standards, a relatively low bulking factor, and UCS values of approximately 500 psi or greater. Composite samples were used in this stage of testing.

The Preliminary Phase - Stage 1 was divided into two sets of experiments: the first involved a statistically designed mixture experiment (Group I experiments), and the second involved five single variable experiments (Groups II through V experiments).

Mathematical models relating results from UCS, MTCLP, and bulking factor to reagent loading were generated from the data gathered during the Group I experiments of the Preliminary Phase. These models aided in the interpretation of data and in the formulation of reagent combinations for the additional testing phase of the screening.

The Group I experiments treated each composite sample with a combination of Portland Type-II cement, PQ Corporation Type N sodium silicate, Type F flyash, clay and zeolite (attapulgite and/or clinoptilolite), and water. The Groups II, III, IV, and V experiments changed a single variable in the reagent mixture. Group II experiments substituted site flyash from the active flyash pile (Operable Unit 2) for commercial Type F flyash. This allowed contaminated material from two operable units to be stabilized in the same treatment system. Group III experiments modified the type and level of adsorbents which may affect the leachability of the heavy metals and radionuclides in the treated waste. In the Group IV experiments, Portland Type I cement was substituted for Type II cement. This was done due to the cost difference between the two types of cement. In Group V experiments, Portland Type II cement with water was the only additive.

For each test run, the waste form temperature rise, bulking factor, shear strength, and general appearance was recorded. The UCS, MTCLP, and bulking factor were measured on day 28. In addition, the general description of the waste before and after reagent addition, percent water in waste, pH of stabilized waste analytical leachate solutions, and whether there was gas evolution during the mixing or curing process were recorded.

C.3.2.1.2 <u>Preliminary Phase - Stage 2</u>

The Preliminary Phase - Stage 2 screening tested additional reagent mixtures if Preliminary Phase - Stage 1 mixtures were unsuccessful, or refined successful formulations. The most promising formulations from this stage had UCS values of 500+ psi, metal concentrations in the MTCLP at or below

the TCLP standards, and a relatively low bulking factor. Blast furnace slag (BFS) was used in Stage II experiments to enhance strength potential, lower permeability, provide silicates for metal retention, increase resistance to sulfate and chlorides, improve workability, and lower the rate of set. The same data were required for these experiments as the Preliminary Phase - Stage 1 experiments.

C.3.2.1.3 Advanced Phase - Stage 1

It was important to test the individual layers of the waste pits because of the heterogeneous nature of the waste pits. The Advanced Phase applied the two most promising mixtures to each of the 15 strata composite samples from Waste Pits 1 through 4 and the Burn Pit, and three composite samples from Waste Pits 5 and 6 and the Clearwell. The most promising formulations were those with a high UCS, low leachability of hazardous and radioactive contaminants, minimum volume increase, and lowest cost of reagents.

Full TCLP, bulking factor, permeability, shear strength, temperature rise, radon emissions, and five-day static leachability tests were run in addition to a UCS test. In addition, the general description of waste before and after reagent addition, percent water in waste, pH of stabilized waste analytical leachate solutions, and indications of gas evolution during mixing or during the curing process were recorded.

C.3.2.1.4 Durability Testing

Successful formulas from the Advanced Phase were analyzed for durability according to the requirements of ASTM D 4842-90, "Standard Test for Determining the Resistance of Solid Wastes to Freezing and Thawing," and ASTM D 4843-88, "Standard Test Method for Wetting and Drying of Solid Waste." Specimens were produced using two different formulations for each of seven different waste pits. Samples from Waste Pit 4 were not tested. A technical determination was made that cement stabilization was not proving to be an effective treatment method for Waste Pit 4 waste due to the high uranium concentration. After each cycle, the weight loss from each specimen was determined. The ASTM procedures for both durability tests specify that when the specimen weight loss exceeds 30 percent, the test is to be terminated.

C.3.3 TEST OBJECTIVES AND DATA REQUIREMENTS

C.3.3.1 Remedy Screening/Remedy Selection Studies

The objectives of the treatability study were to identify formulations which have a UCS of >500 psi, decrease leachability of metals and radionuclides as measured with TCLP and MTCLP near the TCLP standards, and have a relatively low bulking factor. The third criterion was a secondary requirement.

The following test objectives were established:

- To evaluate and determine if a particular reagent mixture produced an acceptable waste form
- To develop a database of stabilization reagents and corresponding hazardous and radioactive materials leachability for stabilized waste forms
- To determine stabilization reagents and relative quantities required to minimize leaching of radionuclides and Hazardous Substance List constituents from the final waste form
- To determine stabilization reagents and relative quantities required to achieve a UCS of approximately 500 psi
- To minimize the final volume of treated waste
- To estimate the volumes of treated waste generated by each process
- To provide leaching characteristics for fate and transport modeling
- To develop preliminary reagent mixtures for future studies
- To develop process parameters for future treatability - shear strength, waste form temperature rise with reagent addition, general description of waste before and after reagent addition, permeability, percent of water in the waste, pH of leachate solutions, and evolution of gas during mixing or during the curing process
- To provide the chemical and radiological data
- To establish proof of process
- To screen a large number of parameters and identify those critical for future bench-scale studies
- To provide data for evaluation of alternatives in the Feasibility Study

C.3.4 DATA ANALYSIS AND INTERPRETATION

This section includes a discussion of the waste stream characteristics for each waste pit and how these characteristics may impact cement solidification/stabilization. Data from the treatability studies are also summarized here.

C.3.4.1 Analysis of Waste Stream Characteristics

The heterogeneity of the waste pits makes the material difficult to characterize adequately and provides a significant challenge in identifying treatment processes which will be effective for all or most of the material types.

A wide variety of chemical constituents within the waste pits may act as set retarders or as set accelerators in a waste and cement mix. The effect of each of these is impossible to predict empirically. The organics present in Waste Pit 2 are in small concentrations, but may impact the setting of Waste Pit 2 formulations. Uranium and thorium metals are readily incorporated into cement mixtures and, except at extremely high concentrations, should not present a significant leaching problem. Technetium-99 (Tc-99) and cesium (Cs) are present in the waste pits and are extremely mobile. Technetium-99 is very water soluble and is difficult to retain in a cement mixture without leaching. Other metals, such as arsenic (As) and mercury (Hg), are also difficult to retain within a cement and waste mixture. Formulations for cement solidification will need to be very robust and capable of handling a potentially wide variation in waste material. Debris also must be removed or size reduced.

C.3.4.2 Analysis of Treatability Study Data

Four response variables - leachability, UCS, permeability, and bulking factor - were the primary criteria for evaluating the various cement solidification mixtures and are presented for each waste pit. These response variables were compared to performance objectives to determine if a particular reagent mixture produced an acceptable waste form.

Reagent loadings are normalized to grams of reagent added to each 100 grams of waste (w/w). The Stage I group numbers are included in the tables.

- Group 1 samples had attapulgite and clinoptilolite at 6 normalized percent.
- Group 2 samples used site flyash instead of commercial flyash.
- Group 3 samples used attapulgite and clinoptilolite loadings at 0 or 12 normalized percent.
- Group 4 samples substituted Portland cement Type 1 Portland cement Type 2.

- Group 5 samples used only Portland cement Type 2 at loadings of 60 and 80 normalized percent.

The UCS values, uranium leachability, and bulking factors were the criteria used for selecting formulations for Remedy Selection. The amount of reagent added to each 100 g of combined wet weight of waste are in grams. Portland cement, blast furnace slag, flyash, and clinoptilolite were added to solidify the waste.

Waste Pits 4, 5 and 6 and the Clearwell had at least 50 percent of the formulations meet or exceed the UCS criteria. Waste Pits 1, 2 and 3 and the Burn Pit had less than 50 percent success rate. Waste Pit 2 and the Burn Pit were significantly more difficult to solidify than the other waste pits.

C.3.4.2.1 Leachability

Data from these analyses are for dilution-adjusted formulation leachate concentrations, leach rates for specific analytes, or leachate concentrations relative to regulatory limits. Leachability can be categorized into five general groups. The first group consisted of the Waste Pit 4 material, which contained lumps of yellow and green uranium salts and had 452 parts per million (ppm) leachable uranium in the MTCLP. The second group contained Waste Pit 6 material, with 18 ppm leachable uranium. The Burn Pit and Clearwell materials made up the third group, with leachable uranium concentrations of 6 and 3 ppm, respectively. The fourth group consisted of Waste Pits 1, 2, and 3, and had leachable uranium concentrations from 0.9 to 1.0 ppm uranium. The final group was Pit 5, with a nondetectable level of uranium in the MTCLP. Uranium leachability was a criterion for the selection of remedy selection formulas.

C.3.4.2.2 MTCLP - RCRA Metals

The concentration of Resource Conservation and Recovery Act (RCRA) metals in the MTCLP tests were all less than one-half the TC regulatory level. Therefore, this was not a selection criteria for Remedy Selection formulas.

C.3.4.2.3 Bulking Factor

Bulking factor is the percent volume increase due to treatment. For all waste pits, the bulking factor was increased by addition of all solid reagents and water. The lowest BFs were measured with the lowest loading of reagents. Typically, flyash, attapulgite, and clinoptilolite additions had a larger effect on the BF than addition of cement or Blast furnace slag. Therefore, to minimize the BF, it is preferable to increase cement loading instead of flyash.

C.3.4.2.4 Permeability Testing

There was no defined goal for permeability in the Work Plan. However, EPA's document, "Handbook for Cement Stabilization/Solidification of Hazardous Waste," states that "permeabilities measured in solidified waste typically range from around 10^{-4} to 10^{-8} cm/s. Such low permeabilities indicate decreased mobility in the treated waste and a slower transfer of contaminants from the solid mass to leaching waters" (EPA 1990b).

C.3.4.2.5 Radon Emissions

All radon results were multiplied by the reagent dilution factor so all results were expressed relative to the amount of pit waste in the stabilized sample. Calculated radon emission rates given for comparison were based on the average radium (Ra)-226 concentration found in characterization samples. Each picoCurie of radium-226 generates radon (Rn)-222 at a rate of 0.1813 picoCuries per day.

C.3.4.3 Waste Pit 1

C.3.4.3.1 Remedy Screening

Data summaries for Remedy Screening are presented in Tables C.3-1 and C.3-2. Results indicate stabilization of the Waste Pit 1 waste can readily achieve the desired UCS and leachability values. All formulations passed the TC regulatory requirements. The wet reagent/waste paste was readily mixable and set to greater than 4.5 tsf within a 24-hour cure time.

Unconfined Compressive Strength (UCS): UCS values ranged from approximately 150 psi to greater than 650 psi. General observation and trends noted for UCS follow:

- With the addition of adsorbents, the UCS generally increases with cement loading and at least 43 percent cement was necessary to meet the UCS requirement.
- Addition of adsorbents lowered the UCS for a given cement loading.
- Addition of BFS increased the UCS and slightly increased the temperature rise of the wet paste for a given cement loading.
- Portland Type 1 and 2 cements had similar results.
- Commercial and site flyash had similar results.
- Sixty and 80 percent cement loadings without addition of adsorbents, blast furnace slag, or flyash were investigated. Sixty percent cement loading without addition of other reagents successfully stabilized the waste.

Bulking Factor: Bulking factors range from approximately 140 to 340 percent.

MTCLP - Radionuclides: Gross alpha and beta were all below detection limits. The uranium concentration was below 1 ppm (w/w) for all treated samples. At pH values above 10.5, all uranium values were below detection limits. The uranium concentration in the MTCLP of similar untreated waste was 27 ppm. Therefore, the treatment appears to significantly reduce the leachability of uranium.

Commercial Type F flyash and site flyash were equally effective at controlling leachability. Site and commercial flyash also had similar effects on UCS results. Thus, site flyash could be considered for stabilizing Waste Pit 1 instead of buying commercial flyash.

Effect of Attapulgite, Clinoptilolite, and Sodium Silicate: Attapulgite and clinoptilolite additions increased the bulking factor, lowered the UCS, and had minimal effect on leachability. The effects of sodium silicate additions were ambiguous. Since the addition of these reagents had minimal positive effects, it is recommended the additives not be used with Waste Pit 1 material.

C.3.4.3.2 Remedy Selection

Formulation numbers 14 (cement, flyash, and blast furnace slag) and 17 (cement and flyash) were carried forward into Remedy Selection. Data summaries are presented in Tables C.3-3 through C.3-6 and Figures C.3-3 and C.3-4.

UCS: UCS values ranged from 1,458 to greater than 3,100 psi.

Bulking Factors: Bulking factors ranged from 152 to 168 percent.

Permeability: Permeabilities were very low, ranging from 2.0×10^{-11} to 3.8×10^{-9} centimeters per second (cm/s). With one exception, Formula 1 had lower permeabilities than Formula 2.

Leachability: Formulas 1 and 2 had similar leaching results for inorganic compounds. The leachability of radionuclides for both Formula 1 and Formula 2 were nearly identical. Uranium-235/236 had an ND for the Formula 2 dilution adjusted concentration. Radium-226, radium-228, strontium-90 and technetium-99 had NDs as dilution adjusted concentrations for both formulations.

Radon Emissions: Formula 1 was more effective in reducing the radon diffusion rate in water. The emanation in air showed Formula 1 to have a lower radon emission rate than Formula 2, although the rate difference did not appear to be significant. The emanation rate for untreated waste was approximately double that of the treated waste. The average radium-226 concentration in the characterization samples was 22.47 picoCuries per gram, with the concentrations ranging from 13.4 to 99.6 picoCuries per gram. The relatively high emanation rates measured, compared to the calculated rate, probably indicate that the radium-226 concentration in the treatability samples is higher than in the characterization samples.

C.3.4.4 Waste Pit 2

C.3.4.4.1 Remedy Screening Tests

Data summaries are presented in Tables C.3-7 and C.3-8. Results indicate stabilization of the Pit 2 waste can achieve the desired UCS and leachability values with at least 50 percent cement added to

the waste. All formulations passed TC regulatory requirements. The wet reagent/waste paste was readily mixable and set to greater than 45 tsf within the 24-hour cure time.

UCS: UCS values ranged from approximately 150 psi to greater than 710 psi. General observations and trends noted for UCS are listed below.

- With the addition of adsorbents, the UCS generally increases with cement loading and at least 50 percent cement was necessary to meet the UCS requirement.
- Addition of adsorbents lowered the UCS for a given cement loading.
- Addition of blast furnace slag increased the UCS and slightly increased the temperature rise of the wet paste for a given cement loading.
- Portland Type 1 and 2 cements had similar results.
- Commercial and site flyash had similar results.
- Without addition of adsorbents, blast furnace slag, or flyash, 80 percent cement loading was required to successfully stabilize the waste.

Bulking Factor(BF): The BFs range from approximately 90 to 250 percent.

MTCLP - Radionuclides: Gross alpha and beta numbers were all below the lower limit of detection. The uranium concentration was below 1.03 ppm (w/w) for all treated samples. Cement loading greater than or equal to 43 percent was necessary to consistently minimize uranium concentrations in the MTCLP. At pH values above 9.7, all uranium values were below detection limits.

Commercial Type F flyash and site flyash were equally effective at controlling leaching. Site and commercial flyash also had similar effects on the UCS. Thus, site flyash could be considered for stabilizing Pit 2 waste instead of buying commercial flyash.

Effect of Attapulgite, Clinoptilolite, and Sodium Silicate: Attapulgite and clinoptilolite additions increased the bulking factor, lowered the UCS, and had a minimal effect on leachability. The effects of sodium silicate additions were ambiguous. Because the addition of these reagents had minimal positive effects, it is recommended these additives not be used for Waste Pit 2.

C.3.4.4.2 Remedy Selection

Data summaries for Remedy Selection are presented in Table C.3-9 through C.3-13 and Figures C.3-5 and C.3-6. Formulation numbers 14 (cement and flyash) and 17 (cement, flyash, and blast furnace slag) were carried forward into Remedy Selection.

UCS: Overall UCSs ranged from >3162 psi for Zone 1, Formula 1, to 554 psi for Zone 2, Formula 2. The average UCS for all the samples was 1,480 psi.

Bulking Factors: Bulking factors were very close, ranging from a high of 131 percent for the Zone 1, Formula 1 sample to a low of 102 percent for the single Zone 3, Formula 2 sample. The average bulking factor was 123 percent.

Permeability: Permeabilities were considered to be low and in the acceptable range of 1.0×10^{-8} to 2.0×10^{-10} cm/s.

Leachability: Both formulas pass TC regulatory criteria. Formula 2 performed slightly better than Formula 1 for inorganic compounds. Radionuclide leachability for Formula 1 was on the average slightly better than Formula 2. There was not much difference for any uranium species and technetium-99. Formula 2 had better leachability for radium-228 and performed better than Formula 1 with respect to thorium-230.

Radon Emissions: Leaching results show little difference in rates between the 7-day and 30-day rates for the same formula. Formula 1 had lower radon leaching rates. For radon emanation, the difference in the radon rates between Formulas 1 and 2 was not significant. Results of treated samples show radon emission rates were reduced to approximately one-third of pretreated values. The average radium-226 concentration in the characterization samples was 352.4 picoCuries per gram.

C.3.4.5 Waste Pit 3

C.3.4.5.1 Remedy Screening Tests

Data summaries for Remedy Screening are presented Tables C.3-14 and C.3-15. Results indicate stabilization of Pit 3 waste can achieve the desired UCS and leachability values. All formulations passed TC regulatory requirements. The wet reagent/waste paste was readily mixable and set to greater than 4.5 tsf within the 24-hour cure time. Generally, the samples which set quickly had poor UCS values.

UCS: UCS values ranged from approximately 190 psi to greater than 650 psi, with an average of approximately 455 psi. General observations and trends noted for UCS follow:

- With the addition of adsorbents, the UCS generally increases with cement loading and at least 43 percent cement was necessary to meet the UCS requirement.
- Addition of adsorbents lowered the UCS for a given cement loading.
- The UCS for samples substituting Blast furnace slag for flyash was similar to that of the cement/flyash formulation.
- Waste treated with Portland Type 1 cement had larger UCS values than samples treated with Portland Type 2 cement.
- Commercial and site flyash had similar results.
- Sixty and 80 percent cement loadings without addition of adsorbents, Blast furnace slag, or flyash were investigated. Sixty percent cement loading without addition of other reagents successfully stabilized the waste.

Bulking Factor: The bulking factors range from approximately 60 to 220 percent. The average BF was about 113 percent.

MTCLP - Radionuclides: All except one of the gross alpha and beta values were at the lower limit of detection. The one gross beta value had a low value at 9 dpm of 4 cc of MTCLP extract. Uranium concentrations were below 1.0 ppm (w/w) for all treated samples. Of the 9 samples out of 24 having uranium concentrations above the detection limit, the average uranium value was 0.63 ppm. Cement loadings greater than or equal to 43 percent were necessary to consistently minimize the uranium concentration in the MTCLP. The concentration of uranium in the MTCLP decreased as the cement and/or flyash loadings were increased.

The uranium concentration in the MTCLP of the sample of untreated waste was 0.3 ppm. The cement-based stabilization treatment would appear to reduce the leachability of uranium. At pH values above 10.1, all uranium values were below detection limits except for one sample at 11.7 pH with 0.018 ppm uranium in it.

Commercial Type F flyash and site flyash were equally effective at controlling leachability. Site and commercial flyash also had similar effects on the UCS results. Thus, site flyash could be considered for stabilizing the waste in Waste Pit 3 instead of buying commercial flyash.

Effect of Attapulgite, Clinoptilolite, and Sodium Silicate: The addition of attapulgite and clinoptilolite increased the BF and lowered the UCS. In experiments with 12 normalized percent attapulgite or clinoptilolite, concentrations of uranium in the MTCLP extractants were decreased. The addition of sodium silicate may increase the UCS values. The effect is greater at lower cement loadings.

C.3.4.5.2 Remedy Selection Tests

The cement/flyash formulation chosen for the Advanced Phase was not listed in Tables C.3-14 and C.3-15. Several of the 43 percent cement/43 percent flyash formulations from the preliminary phase had MTCLP uranium concentration above the detection level. Therefore, cement and flyash loadings were increased from 43 percent of each reagent to 51 and 31 percent, respectively. In addition, 4 percent clinoptilolite was added because clinoptilolite additions lowered the MTCLP uranium concentration. The blast furnace slag formula number 15 was selected from formulas presented in Table C.2-14. Data summaries for Remedy Selection are presented in Tables C.3-16 through C.3-19, and Figures C.3-7 and C.3-8.

UCS: UCSs were very high, exceeding the goal of >500 psi. The highest (3,156 psi) was developed for the Zone 1, Formulas 1 and 2 samples, while the lowest (1,520 psi) was found in the Zone 3, Formula 1, sample. The average UCS was 2,393 psi.

Bulking Factors: Bulking factors were considered low, with the highest +97 percent for the Zone 3, Formula 1 sample, and the lowest was 81 percent found in the Zone 2, Formula 1 sample. The average bulking factor was 87 percent.

Permeability: Permeabilities were very low, with the highest for the Zone 2, Formula 2 sample (1.0 x 10^{-7} cm/s) and the lowest for the Zone 1, Formula 2 sample (5.1 x 10^{-9} cm/s).

Leachability: Both formulations pass TC regulatory criteria. Formula 1 performed slightly better than Formula 2 for metals. Formula 1 had better results for radium-226, and thorium-230. Formula 2 shows better results for radium-228, thorium-228, and uranium-238.

Radon Emissions: Formulation 1 was more effective in reducing the radon emanation rate in water. The raw waste emanation rate was much lower than the calculated rate. This effect might be explained by the wet nature of the untreated sample. Water will absorb some radon, and will also lower the rate of diffusion from the material. The calculated radon emission rate used for comparison was based on the average radium-226 concentration found in characterization samples. The average concentration of radium-226 in the characterization samples was 70.3 pCi/g.

C.3.4.6 Waste Pit 4

C.3.4.6.1 Remedy Screening Tests

Data summaries are presented in Tables C.3-20 and C.3-21. Results indicate solidification of the Waste Pit 4 waste can readily achieve the desired UCS. High loadings of cement are necessary to control the uranium leachability. All formulations passed TC regulatory requirements. The wet reagent/waste paste was readily mixable and set to greater than 3.0 tsf within a 24-hour cure time.

UCS: UCS values ranged from approximately 120 psi to greater than 600 psi. General observations and trends noted for UCS follow:

- With the addition of adsorbents and flyash, the UCS generally increased with cement loading and at least 38 to 45 percent cement was necessary to meet the UCS requirement.
- Addition of adsorbents lowered the UCS for a given cement loading.

- Blast furnace slag additions had similar UCS results to cement and flyash additions.
- No obvious trend was observed when comparing the UCS results for samples made with Portland Type 1 and 2 cements.
- Commercial and site flyash had similar results.
- Sixty 60 and 80 percent cement loadings without addition of adsorbents, blast furnace slag, or flyash were investigated. Sixty percent cement loading without addition of other reagents successfully solidified the waste.
- Additions of sodium silicate may have a negative impact on the UCS.

Bulking Factor: The bulking factors range from approximately 90 to 300 percent.

MTCLP - Radionuclides: It was determined that the uranium concentration in Waste Pit 4 was greater than 15 percent (w/w). This high concentration of uranium corresponds to the higher concentration of uranium seen in the MTCLP. The MTCLP uranium concentration from the untreated material was 948 ppm (w/w). In addition, the Pit 4 waste had relatively hard green or yellow chunks in it. These chunks had more radiological activity than the bulk of the waste. It is believed these chunks contained high concentrations of uranium. These chunks were not evenly dispersed throughout the waste, nor were they always completely dispersed or dissolved during the stabilization process. Since the waste stream was heterogenous in reference to uranium concentration, the variability of the MTCLP uranium concentration was not surprising.

Gross alpha and beta numbers ranged from lower limits of detection to more than 1,000 dpm/4 cc (alpha) and 133 dpm/4 cc (beta). The uranium concentration ranged from 0.13 ppm (w/w) to greater than 400 ppm with the average concentration being approximately 104 ppm. The addition of adsorbents had no obvious trend on uranium leachability. The addition of blast furnace slag did not improve the uranium leachability. The addition of flyash at low cement loadings may increase the uranium leachability. There is a trend of decreasing uranium leachability with increasing cement loading.

The uranium concentration in the MTCLP of the untreated waste was 948 ppm. The cement-based stabilization treatment reduced the leachability of uranium to below 0.13 ppm when only 60 and 80

percent cement was used (Formula numbers 19 and 23). Therefore, the treatment can reduce the concentration of leachable uranium removed from the waste. At pH values above 10.2, all uranium values were below 0.2 ppm.

Effect of Attapulgite, Clinoptilolite, and Sodium Silicate: Additions of attapulgite and clinoptilolite increased the bulking factor, lowered the UCS, and had minimal effect on leachability. The effects of sodium silicate additions were ambiguous. Since the addition of these reagents had minimal positive effects, it is recommended these additives not be used with Waste Pit 4 material at the 6 percent loadings for the adsorbents, or at any loading for the sodium silicate.

C.3.4.6.2 Remedy Selection Tests

Formula numbers 17 (cement, flyash, and clinoptilolite) and a modification of number 23 (cement and clinoptilolite) were carried forward into Remedy Selection. These formulations had the lowest uranium concentrations in the MTCLPs. Data summaries for Remedy Selection are presented in Tables C.3-22 through C.3-25, and Figures C.3-9 and C.3-10.

UCS: UCSs were considered high with the highest given by the Zone 3, Formula 2 sample (>3157 psi), and the lowest was found in the Zone 2, Formula 2 sample. The average UCS was 2,005 psi, well above the >500 psi goal.

Bulking Factors: Bulking factors were higher than the other waste pits, with the highest shown by the Zone 1, Formula 1 sample and the lowest from the Zone 2 and 3, Formula 2 sample. The average bulking factor was 136 percent.

Permeability: Permeabilities were very low, with the highest result coming from Zone 1, Formula 2 (1.0×10^{-7} cm/s) and the lowest from Zone 3, Formula 2 (2.3×10^{-9} cm/s).

Leachability: Both formulations pass TC regulatory criteria. The leachability of Formula 1 and 2 were nearly identical. The leachability of radionuclides for Formula 2, on the average, was better than for Formula 1.

Radon Emissions: Formula 2 appeared to be slightly more effective in reducing the rate at which radon diffuses from the treatability samples into water. The emanation in air also showed Formula 2 to have a lower radon emission rate than Formula 2. The emanation rate for untreated waste was approximately double that of the treated waste. The average radium-226 concentration in the characterization samples was 16.8 picoCuries per gram.

C.3.4.7 Waste Pit 5

C.3.4.7.1 Remedy Screening

Data summaries are presented in Tables C.3-26 and C.3-27. Results indicate solidification of the Pit 5 waste can readily be achieved. Only one formulation lowered the gross alpha, beta, and uranium levels to nondetectable levels. All formulations passed TC regulatory requirements. The wet reagent/wet paste was readily mixable and set to greater than 4.5 tsf within a 24-hour cure time. Generally, at cement loadings below 43 percent, the samples set more slowly.

UCS: UCS values ranged from approximately 65 psi to greater than 650 psi. General observations and trends noted for UCS follow:

- With the addition of adsorbents, the UCS generally increases with cement loading and at least 43 to 45 percent cement was necessary to meet the UCS requirement.
- Untreated Waste Pit 5 material had a high moisture content (84 percent). The percent water in the cured treated samples was higher than most of the other Operable Unit 1 treated material. The Waste Pit 5 moisture content of the treated material normally ranged from upper 30 to 40 percent, with a few above 50 percent. At a percent moisture in the cured material above approximately 42 percent, the UCS decreased rapidly. Most of these latter samples used formulations with less than 43 percent cement in them.
- Addition of adsorbents increased the UCS for given cement loadings. The increase in UCS was likely the result of attapulgite and clinoptilolite adsorbing excess water from the waste. At the lower free water concentration in the wet reagent/waste paste, the water to cement ratio would be closer to the optimum ratio. The effect of adsorbent addition was greatest with the lower cement loadings.
- Addition of blast furnace slag increased the UCS.
- Portland Type 1 and 2 cements had similar results.
- Formulations using commercial flyash had higher UCS values than those with site flyash.

- Sixty 60 and 80 percent cement loadings without addition of adsorbents, blast furnace slag, or flyash were investigated. Sixty percent cement loading without addition of other reagents successfully solidified the waste. The cement only formulations did not control the release of gross alpha and beta components in the MTCLP of treated material.

Bulking Factor: The bulking factors range from approximately 25 to 100 percent.

MTCLP - Radionuclides: Gross alpha and beta values ranged from lower limits of detection to approximately 50 and 60 dpm/4 cc, respectively. The uranium concentration was below detection limit except for one sample at 0.17 ppm uranium. The addition of 60 and 80 percent cement without other additives did not significantly reduce gross alpha and beta values in the MTCLP. Addition of adsorbents at 6 percent each of attapulgite and clinoptilolite reduced gross alpha and beta values in the extract. Analysis of the data shows high flyash loading lowers the gross alpha and beta values.

The one blast furnace slag formulation investigated, Formula 14, had a lower limit of detection for leachable gross alpha, beta, and uranium. This was the only formulation that had no positive hits for all three analytes.

Commercial Type F flyash and site flyash were equally effective at controlling the leachability of the treated waste.

Effect of Attapulgite, Clinoptilolite, and Sodium Silicate: The addition of attapulgite and clinoptilolite increased the BF, increased the UCS, and decreased the leachability of gross alpha and beta in the MTCLP. The effects of sodium silicate additions were ambiguous.

C.3.4.7.2 Remedy Selection Tests

Formulation numbers 14 (cement, flyash, and blast furnace slag) and augmented formulation number 14 (cement, flyash, and additional blast furnace slag) were carried forward into Remedy Selection. Data summaries for Remedy Selection are presented in Tables C.3-28 through C.3-31, and Figures

C.3-11 and C.3-12. No zone samples were tested. Only a composite was tested with duplicate Formulas 1 and 2.

UCS: UCSs were much higher than 500 psi. The largest UCS value was 2257 psi for the Formula 2 samples, with a low of 1294 psi for one Formula 1 sample.

Bulking Factors: BFs were considered good, with the highest result found in the Formula 2 sample (49 percent) and the lowest results in two Formula 1 samples (37 psi). The average BF was 41 psi.

Permeability: Permeabilities were also low, with the highest value in the two Formula 1 samples (7.2 x 10^{-8} cm/s), and the low in the Formula 2 sample (3.2 x 10^{-8} cm/s).

Leachability: Both formulas pass TC regulatory criteria. The leachability of the two formulas was almost identical. However, a comparison of the dilution adjusted results for Formulas 1 and 2 shows that for most of the radionuclides, Formula 2 performed better than Formula 1. Thorium-232, thorium-total, uranium-235/236, uranium-238, and uranium-total for Formula 1 had dilution adjusted concentrations reported, while Formula 2 had NDs. Formula 2 also had lower concentrations for neptunium-237, plutonium-238, radium-226, radium-228, strontium-90, thorium-228, thorium-230 and uranium-234. Formula 1 had lower concentrations for plutonium-239/240 and technetium-99, although the difference (199 versus 206) is not significant.

Radon Emissions: The radon emanation rate from the raw waste may be lower than the rates from the treated waste because the Waste Pit 5 waste was extremely wet and soupy. Radon will not diffuse through water as readily as it will through a porous or semiporous substrate. The average radium-226 concentration in the characterization samples was 83.8 picoCuries per gram.

C.3.4.8 Waste Pit 6

C.3.4.8.1 Remedy Screening Tests

Data summaries for Remedy Screening are presented in Tables C.3-32 and C.3-33. Results indicate that stabilization of the Waste Pit 6 materials can readily achieve the desired UCS and leachability

values. All formulations passed TC regulatory requirements. The wet reagent/waste paste was readily mixable and set to greater than 4.5 tsf within the 24-hour cure time. The shear strength of the wet reagent/waste paste was slightly higher for Pit 5 than for the other waste pits.

UCS: The UCS values ranged from approximately 240 psi to greater than 700 psi. General observations and trends noted for UCS follow:

- Almost all formulations achieved a UCS value greater than 500 psi. Only at the lowest cement loadings did the UCS not exceed 500 psi.
- Untreated Waste Pit 6 material had a high moisture content (63 percent). The percent water in the cured treated samples ranged from approximately 25 to 38 percent. Addition of adsorbents increased the UCS for a given cement loading. The increase in UCS was likely the result of attapulgite and clinoptilolite adsorbing excess water from the waste. At the lower free water concentration in the wet reagent/waste paste, the water-to-cement ratio would be closer to the optimum ratio. The effect of adsorbent addition was greatest with the lower cement loadings.
- Portland Type 1 and 2 cements had similar results.
- Commercial and site flyash had similar results.
- Sixty and 80 percent cement loadings without addition of adsorbents, blast furnace slag, or flyash were investigated. Sixty percent cement loading without addition of other reagents successfully stabilized the waste.

Bulking Factor: The bulking factors range from approximately 25 to 120 percent.

MTCLP - Radionuclides: Gross alpha and beta numbers are all below the limit of detection except for one sample using formula number 12. The uranium concentration was the below detection limit, except for two samples. Uranium concentrations were 0.17 and 17.7 ppm for formulation numbers 5 and 12.

At pH values above 10.5, all uranium values were below detection limits. The uranium concentration in the MTCLP of the untreated waste was 263 ppm. Therefore, the treatment significantly reduced the leachability of uranium.

Commercial Type F flyash and site flyash were equally effective at controlling the leachability of the treated waste. Site and commercial flyash also had similar effect on the UCS results. Thus, site flyash could be considered for stabilizing the waste in Waste Pit 6 instead of using commercial flyash.

Effect of Attapulgite, Clinoptilolite, and Sodium Silicate: The addition of attapulgite and clinoptilolite increased the BF, increased the UCS, and had minimal effect on leachability. The effects of sodium silicate additions were ambiguous.

C.3.4.8.2 Remedy Selection Tests

Formula number 13 (cement, flyash) was carried forward into Remedy Selection. A cement/flyash/blast furnace slag formulation not previously tested with Pit 6 material was also selected. This formulation had proven to be successful in other Operable Unit 1 pit material. Data summaries for Remedy Selection are presented in Tables C.3-34 through C.3-37, and Figures C.3-13 and C.3-14. No zone samples were tested for Pit 6. Duplicate composite samples were tested with Formulation 2 and a single sample by Formulation 1.

UCS: UCSs for the samples were considered acceptable, with the highest given by a sample tested with Formula 1 (>3142 psi). Lower results were given by the two Formula 2 samples, with the lowest having a UCS of 697 psi. The average UCS was 1,662 psi.

Bulking Factors: BFs were low, with all samples having a bulking factor of approximately 40 percent.

Permeability: Permeabilities were also low, with the highest result given by the Formula 1 sample (6.5×10^{-9} cm/s) and the lowest by one of the Formula 2 samples (1.1×10^{-9} cm/s).

Leachability: Both formulations pass TC regulatory criteria. The leachability of the two formulations was almost identical. A comparison of the dilution adjusted results shows Formula 1 seems to give the better overall results. Formula 1 had NDs for plutonium-239/240 and technetium-99 while Formula 2 had dilution adjusted concentrations reported. Formula 2 had a relatively high technetium-

99 dilution adjusted concentration of 65 picoCuries per liter. Formula 1 also had lower values for thorium-228, thorium-230, uranium-238, and uranium-Total. Formula 2 had better results than Formula 1 for plutonium-238, strontium-90, and uranium-234 (NDs for Formula 2). Formula 2 also had slightly lower dilution adjusted concentration of neptunium-237.

Radon Emissions: Results show very low or undetectable radon emission rates. The average radium-226 concentration in the characterization samples was 3.9 picoCuries per gram. An emanation rate from the untreated waste was not reported because the test was not performed.

C.3.4.9 Burn Pit

C.3.4.9.1 Remedy Screening Tests

Data summaries for Remedy Screening are presented in Tables C.3-38 and C.3-39. Results indicate stabilization of the Burn Pit waste could be achieved. All formulations passed TC regulatory requirements. The wet reagent/waste paste was readily mixable and set to greater than 4.5 tsf within a 24-hour cure time.

UCS: UCS values ranged from approximately 55 psi to greater than 700 psi. None of the original 20 formulations from Stage 1 met the UCS criteria. This includes the 80 percent cement loading formulation and the 68/68 percent cement/flyash loading formulation. In Stage II, multiple formulations with blast furnace slag, calcium hydroxide, or ferrous chloride supplementation were tested. In addition, since 6 to 12 percent adsorbent loading appears to lower the UCS, a test with reduced levels of clinoptilolite was performed.

General observations and trends noted for UCS follow:

- With the addition of adsorbents, the UCS generally increases with cement loading and 80 to 90 percent cement loading was necessary to meet the UCS criteria. When both attapulgite and clinoptilolite are at 6 percent loading, no formulation met the UCS criteria. The highest cement and flyash loadings investigated with adsorbents added was 68 percent cement and flyash.
- Addition of adsorbents lowered the UCS for a given cement loading.

- Blast furnace slag additions increased the UCS. All Blast furnace slag formulations had UCS values greater than 500 psi.
- The UCS value was higher with Type 1 Portland cement than with Type 2 Portland cement.
- Commercial and site flyash had similar results.
- Sixty, 80, 100, and 150 percent cement loadings without addition of adsorbents, blast furnace slag, or flyash were investigated. One hundred percent cement loading without addition of other reagents successfully stabilized the waste.
- Addition of 1 percent calcium hydroxide to 80 percent cement improved the UCS of the treated sample.

Bulking Factor: The bulking factors range from approximately 80 to 265 percent.

MTCLP - Radionuclides: Gross alpha and beta values ranged from lower limits of detection to approximately 47 and 21 dpm/4 cc. Uranium concentrations varied between below the detection limit to 6 ppm. Cement loadings greater than approximately 50 percent and flyash loadings greater than zero percent loadings lower the gross alpha and beta and uranium values to their minimum values.

The addition of Blast furnace slag and the addition of clinoptilolite at 4 percent loading reduced radionuclide leachability.

At pH values above 10.5, all uranium values were below detection limits. The uranium concentration in the MTCLP of the untreated waste was 19 ppm. Therefore, the treatment significantly reduced the leachability of uranium.

Commercial Type F flyash and site flyash were equally effective at controlling leachability. Site and commercial flyash also had similar effect on the UCS results. Thus, site flyash could be considered for stabilizing the waste in Burn Pit instead of using commercial flyash.

Effect of Attapulgite, Clinoptilolite, and Sodium Silicate: The addition of attapulgite and clinoptilolite increased the BF, lowered the UCS, and had minimal effects on leachability. The effects of sodium silicate additions were ambiguous.

C.3.4.9.2 Remedy Selection Tests

Formulas 14 (cement, flyash, and blast furnace slag) and 18 (cement, flyash, and clinoptilolite) were carried forward into Remedy Selection. Data summaries for Remedy Selection are presented in Tables C.3-40 through C.3-43, and Figures C.3-15 and C.3-16.

UCS: UCSs were lower than for most of the other waste pits. The highest value was exhibited by the sample of Zone 1, Formula 1, which was 1,828 psi. The lowest was given by the Zone 2, Formula 2 sample, which was 522 psi. The average UCS was 1,080 psi.

Bulking Factors: Bulking factors were considered high, with the highest given by the Zone 1, Formula 1 sample (148 percent), and the lowest given by the Zone 3, Formula 2 sample (123 percent). The average bulking factor was 132 percent.

Permeability: All permeabilities were at least 3.0×10^{-7} cm/s.

Leachability: Both formulations pass TC regulatory criteria. The leachability of the two formulations was almost identical.

Radon Emissions: Radon emission rates from the treated waste are in the same range as the untreated waste in air, and significantly lower than calculated rates. For radon emanation rates at the levels reported, the differences detected by the instrument for the emanation in air cannot be considered significant because changing background levels could account for the difference. The average concentration of radium-226 in the characterization samples was 8.9 picoCuries per gram.

C.3.4.10 Clearwell

C.3.4.10.1 Remedy Screening Tests

Data summaries for Remedy Screening are presented in Tables C.3-44 and C.3-45. Results indicate stabilization of Clearwell wastes can achieve the desired UCS and leachability values. All formulations passed TC regulatory requirements. The wet reagent/waste paste was readily mixable and set to greater than 4.5 tsf within a 24-hour cure time.

UCS: UCS values ranged from approximately 40 psi to greater than 700 psi. General observations and trends noted for UCS follow:

- With the addition of adsorbents, cement, and flyash, the UCS generally increases with cement loading and at least 70 percent cement is needed to meet UCS requirements. It is important to note that these samples have adsorbents in them which lower the UCS, especially at the lower cement loading. When adsorbents are not added to the sample (see formula numbers 5 versus 6), the UCS is significantly higher.
- Addition of adsorbents lowered the UCS for a given cement loading.
- Addition of Blast furnace slag increased the UCS.
- Portland Type 1 and 2 cements had similar results.
- Samples with site flyash had larger UCS values than samples with commercial flyash.
- Sixty and 80 percent cement loadings without addition of adsorbents, blast furnace slag, or flyash were investigated. Sixty percent cement loadings without addition of other reagents successfully stabilized the waste.

Bulking Factor: The bulking factors range from approximately 35 to 230 percent.

MTCLP - Radionuclides: Gross alpha and beta values range between lower limits of detection to 23 and 18.5 dpm/4 cc, respectively. Most values are below detection limits. Uranium concentration varies from below detection limits and approximately 3 ppm. Cement loadings greater than approximately 50 percent are required to lower gross beta and uranium values to their minimum values when adsorbents are added to the stabilization formulation.

At pH values above 10.5, all uranium values were below the detection limit. The pH of the MTCLP extract is unusually low for the cement loadings used in these experiments. It is presumed this is due to an unidentified material in the waste which slowly neutralized part of the alkalinity of the added Portland cement.

The uranium concentration in the MTCLP of the untreated waste was 4.9 ppm. Therefore, the treatment reduced the leachability of uranium.

Commercial Type F flyash and site flyash were equally effective at controlling the leachability of the treated waste. Site and commercial flyash also had similar effect on the UCS results. Thus, site flyash could be considered for stabilizing the waste in the Clearwell instead of buying commercial flyash.

Effect of Attapulgite, Clinoptilolite, and Sodium Silicate: Attapulgite and clinoptilolite additions increased the BF, lowered the UCS, and had minimal effect on leachability. Additions of sodium silicate increased the UCS.

C.3.4.10.2 Remedy Selection Tests

Formulas 1 (cement and blast furnace slag) and 4 (cement only) were selected for Remedy Selection. Data summaries for Remedy Selection are presented in Tables C.3-46 through C.3-49, and Figures C.3-17 and C.3-18. No zone samples were tested for the Clearwell.

UCS: UCS values were the lowest of the eight waste streams. The lowest UCS value was below the goal of 500 psi. This came from a composite sample stabilized using Formula 2 (451 psi). The sample with the highest value was stabilized using Formula 1 (1250 psi). The average UCS was 696 psi.

Bulking Factors: Bulking factors were generally very close, with a high of 49 percent and a low of 44 percent. The average was 47 percent.

Permeability: Permeabilities were considered adequate, with the lowest given by the sample stabilized with Formula 1 (8.9×10^{-8} cm/s) and the highest given by the Formula 2 sample (1.6×10^{-7} cm/s).

Leachability: Both formulations pass TC regulatory criteria. Dilution adjusted results indicate Formula 1 seems to give better overall results. The dilution adjusted concentrations for every radionuclide were lower for Formula 1, with the exception of radium-226, which was slightly lower for Formula 2.

Radon Emissions: Both formulations had roughly the same effectiveness in reducing radon emissions. The relatively low emanation rates from the untreated waste were probably due to the wet, clay-like nature of the waste tested. Such material would be expected to have extremely low porosity, reducing the ability of radon to diffuse through it. The average radium-226 concentration in the characterization samples was 55 picoCuries per gram.

C.3.4.11 Durability Testing of Cement Stabilized Samples

Wet/Dry and Freeze/Thaw tests were performed on two formulations for each waste pit with the exception of Waste Pit 4. Data summaries are presented in Table C.3-50. Both ASTM D4842 and D4843 specify that the tests be terminated if the cumulative mass loss of any of the three specimens exceeds 30 percent (failure). However, no criteria currently exist to certify the stabilized waste sample has passed these durability tests. The U.S. EPA does propose that weight loss in excess of 15 percent is unacceptable. It should be emphasized that significant cracking can be present in a specimen that has exhibited only nominal weight loss during durability testing. Considerable value should be given to the visual information recorded for each specimen.

None of the mix designs failed the wet/dry tests. However, the mix design containing blast furnace slag for Pit 6, 6-BFS, failed the freeze/thaw test (even the average of the weight loss for the three specimens slightly exceeded 30 percent). While the average of the weight loss for the Pit 3 mix design containing blast furnace slag, 3-BFS, did not exceed 30 percent for the freeze/thaw test, a single specimen lost over 44 percent weight. Thus, mix design 3-BFS also failed the freeze/thaw tests.

The large average weight loss during the freeze/thaw testing for the mix design for Pit 5 that does not contain blast furnace slag, 5-FA, resulted from a unique occurrence. During transfer from a beaker, specimen number 2009 unexpectedly cracked completely through the cross-section with no other signs of significant deterioration. The other two specimens from the same mix had minimal deterioration throughout the testing cycles. Therefore, the large average weight loss for this mix design is not representative of its durability.

Freeze/thaw tests typically, but not always, had a more detrimental effect than wet/dry tests on the mix designs. Generally, mix formulas without blast furnace slag performed significantly better than mix designs containing blast furnace slag, especially for the freeze/thaw tests.

C.3.4.12 Comparison to Test Objectives

Results from Remedy Screening Stage 1 indicate solidification of Waste Pits 4, 5 and 6 and the Clearwell readily achieved the desired UCS. Waste Pits 1, 2, and 3 required higher loadings of reagents to solidify the waste because <50 percent of the formulas achieved 500 psi UCS. Waste Pit 2 and the Burn Pit required re-formulation in Stage 2 because <20 percent of the initial 20 formulations in Stage 1 achieved the 500 psi UCS. Uranium was more leachable in Waste Pits 4 and 5 than all other waste pits. The MTCLP leachate for all formulations of all waste pit materials passed TC regulatory requirements.

In Stage 2, results indicated solidification of all waste pits can readily achieve the 500 psi UCS. All waste pits, except Pit 6, had BFS in the Stage 2 formulas. In all cases, Blast furnace slag improved UCS. The most promising formulas derived from the Remedy Screening (Stage 2) testing program were used in the Remedy Selection phase of the program. These formulas had a UCS >500 psi, met TC regulatory limits, had relatively low uranium, gross alpha, and beta values in the MTCLP extraction fluid, and had a relatively low bulking factor.

The overall objectives of the treatability study were met. All cement stabilized waste forms in the Advanced Phase passed TCLP and attained an UCS of >500 psi. Sufficient information on permeability and durability was generated to assess cement stabilization as a treatment technology.

C.3.5 RECOMMENDATIONS AND CONCLUSIONS

The potential robustness of a process is perhaps the most important consideration for evaluation of CSS because the waste pits are extremely heterogenic. Since full characterization prior to excavation is not possible, the treatment process chosen must be robust to handle the wide variety of materials to be processed.

The conclusions reached regarding cement solidification as a treatment alternative for the waste pit material are as follows:

1) Cement solidification was effective in controlling leachability. All formulations pass TC regulatory criteria in the TCLP leachate.

2) Except for Waste Pit 4 (which has a large quantity of uranium in the raw waste), the leachability of uranium was effectively controlled in the stabilization process.

3) Formulations developed would appear to be capable of scale-up without significant problems. No significant increase in temperatures were observed during mixing and no observable gases were detected during mixing.

4) Typically formulas with >43 percent Portland cement Type II were effective in meeting UCS requirements of 500 psi set for an on-property retrievable waste form and controlling the leaching of uranium and gross alpha and beta.

5) The typical bulking factor for the cement stabilization was relatively high. The increase in volume may significantly impact the cost of disposal both on or off-site.

6) Waste Pit 4 showed significant uranium in the TCLP leachate. Due to the high uranium content in the Waste Pit 4 samples, Waste Pit 4 may require pretreatment or treatment with an alternative technology.

7) No significant problems were encountered with "setting" of the waste mixtures in Waste Pits 1, 3, 4, 5 and 6, and the Clearwell. The Burn Pit would not set with the addition of cement but did set with the addition of blast furnace slag. Waste Pit 2 also experienced problems with setting in the preliminary stage, most probably due to the presence of organics in the waste.

8) Permeabilities of all of the solidified samples were low.

9) Solidified samples passed the criteria set for durability testing (wet/dry and freeze/thaw). The addition of blast furnace slag to the solidification mixtures had a detrimental effect on their durability.

Sufficient data exists at this stage of the RI/FS process to evaluate cement stabilization as a treatment option. Cement stabilization is a widely utilized technology for treatment of predominately inorganic wastes. Cement stabilization has often been used for stabilization of low level radioactive wastes and is in common use today. Cost and implementability data are available from the literature.

If cement stabilization is selected as a treatment option for any of the waste pit material, additional testing would be required to refine formulations and develop operational data for remedial design.

The waste in the waste pits is extremely heterogeneous and contains many elements which are considered "set retarders" and "set accelerators." The impact on each individual batch of waste may be difficult to predict. If the cement mixture were to be placed in monoliths or in lifts in a disposal cell, the impact of a removing and reworking a failed batch would be significant in terms of cost and time. Additional testing in the laboratory would be required to develop more refined formulations to carry forward this option. An alternate treatment method may be required for material in Waste Pit 4 if blending of the waste could not be performed to reduce the uranium concentration on a batch basis.

Because of the extreme heterogeneity of the waste pits, pretreatment alternatives to reduce the possibility of spikes or pockets of high concentrations of contaminants should be investigated. These may include blending and/or drying of the waste prior to solidification.

Cement stabilization is relatively inexpensive based on the cost of equipment and reagents; however, careful formulation and stringent quality control is required for a successful process. The extreme heterogeneity of the waste pit material may make both successful formulation and quality control extremely difficult.

The creation of a low strength cement material was also considered but no testing was performed. The low strength, possibly soil-like material would require considerably less quantities of cement and would lower the volume increase. Also by creating a soil-like material the problems associated with gel and set of the cement would be eliminated. The higher pH of the mixture would likely be effective in reducing the leach potential of the metals and uranium. The effect of the heterogeneity of the waste would be somewhat mitigated, but spikes could still easily occur which could affect product performance.

TABLE C.3-1

FORMULATIONS[a] WITH UCS AND BULKING FACTOR RESULTS

WASTE PIT 1 - REMEDY SCREENING (PRELIMINARY PHASE) - CEMENT STABILIZATION

Formulation Number	Waste	Type II Portland Cement	Type F Flyash	Sodium Silicate	Attapulgite	Clinoptilolite	Water	Blast Furnace Slag	Group[b]	Stage[b]	UCS (psi)	Bulking Factor
1	100	26	26	0	6	6	50	0	1	1	164	180
2	100	27	20	7	6	6	50	0	1	1	223	191
3	100	29	29	0	0	0	34	0	3	1	547	137
4	100	33	54	7	6	6	65	0	1	1	205	275
5	100	33	54	0	6	6	58	0	1	1	309	245
6	100	43	43	4	12	0	68	0	3	1	304	272
7	100	43	43	4	0	12	68	0	3	1	334	255
8	100	43	43	4	6	6	64	0	4	1	396	252
9	100	43	43	0	6	6	63	0	4	1	485	244
10	100	43	43	4	6	6	55	0	1	1	395	238
11	100	43	43[c]	4	6	6	54	0	2	1	425	246
12	100	43	42[c]	0	6	6	54	0	2	1	386	226
13	100	43	43	0	0	0	50	0	4	1	580	196
14	100	50	15	0	0	0	47	25	_	2	580	195
15	100	50	40	0	0	0	52	0	_	2	509	217
16	100	51	31	0	6	6	53	0	1	1	520	220
17	100	51	31	0	0	0	44	0	_	2	580	185
18	100	54	33	8	6	6	66	0	1	1	580	266
19	100	60	0	0	0	0	37	0	5	1	580	140

TABLE C.3-1
(Continued)

WASTE PIT 1 - REMEDY SCREENING (PRELIMINARY PHASE) - CEMENT STABILIZATION

Formulation Number	Waste	Type II Portland Cement	Type F Flyash	Sodium Silicate	Attapulgite	Clinoptilolite	Water	Blast Furnace Slag	Group[b]	Stage[b]	UCS (psi)	Bulking Factor
20	100	60	60	0	6	6	70	0	1	1	580	300
21	100	64	64	0	0	0	65	0	3	1	580	264
22	100	69	68	7	6	6	76	0	1	1	580	337
23	100	80	0	0	0	0	47	0	5	1	580	168

[a]Reagent loadings in grams per 100 grams of wet weight of waste
[b]As listed in the Operable Unit 1 Treatability Study Work Plan
[c]Site flyash used

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TABLE C.3-2

FORMULATIONS[a] WITH ANALYTICAL RESULTS[b]

WASTE PIT 1 - REMEDY SCREENING (PRELIMINARY PHASE) CEMENT STABILIZATION

Formulation Number	Gross Alpha[c] (dpm/4cc)	Gross Beta[c] (dpm/4cc)	Uranium by IC[d] (ppm)	pH of MTCLP Extraction Fluid (std. units)
1	LLD	LLD	ND	9.5
2	LLD	LLD	0.21	9.1
3	LLD	LLD	ND	9.7
4	LLD	LLD	ND	11.4
5	LLD	LLD	ND	9.2
6	LLD	LLD	ND	10.3
7	LLD	LLD	ND	9.8
8	LLD	LLD	0.9761	5.7
9	LLD	LLD	ND	9.5
10	LLD	LLD	ND	9.6
11	LLD	LLD	ND	11.4
12	LLD	LLD	ND	11.7
13	LLD	LLD	ND	11.1
14	LLD	LLD	ND	10.12
15	LLD	LLD	ND	11.07
16	LLD	LLD	ND	9.7
17	LLD	LLD	ND	11.42
18	LLD	LLD	ND	10.5
19	LLD	LLD	ND	11.9
20	LLD	LLD	ND	10.2
21	LLD	LLD	ND	11.5
22	LLD	LLD	0.0265	10.2
23	LLD	LLD	ND	12.1

[a] Reagent loading per 100 grams of wet weight of waste
[b] Only metals that have results above detection limits are shown.
[c] LLD - Under the lower limit detection level
[d] ND - Not detected

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TABLE C.3-3

CEMENT STABILIZATION
ADVANCED PHASE FORMULATIONS
WASTE PIT 1[a]

Formulation	Normalized Waste	Normalized Cement	Normalized Flyash	Normalized Blast Furnace Slag	Normalized Clinoptilolite	Normalized Water (Range)
1	100	50	15	25	0	30-43
2	100	51	31	0	0	29-40

[a] All quantities are normalized to express quantities of reagents in grams used per 100 grams of waste. Waste was not dried before mixing.

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TABLE C.3-4

CEMENT STABILIZATION
ADVANCED PHASE
RESULTS OF UCS, BULKING FACTOR, AVERAGE BULKING FACTOR, AND PERMEABILITY - WASTE PIT 1

Zone	Formulation	UCS (psi)	Bulking Factor (Percent Volume Increase)	Average Bulking Factor (Percent Volume Increase)	Permeability (cm/s)
1	1	>3107	168	159	2.0×10^{-11}
1	1	>3150	168		
2	1	>3154	158		$<4.0 \times 10^{-11}$
2	1	3151	159		
2	1	>3133	164		$<6.2 \times 10^{-11}$
2	1	>3141	162		
3	1	>3167	158		1.0×10^{-9}
3	1	>3173	159		
1	2	1458	164		3.8×10^{-9}
1	2	1599	158		
2	2	2203	153		1.2×10^{-9}
2	2	2604	154		
3	2	3131	155		8.8×10^{-10}
3	2	2756	152		

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TABLE C.3-5

WASTE PIT 1 SOLIDIFICATION TCLP RADIONUCLIDES DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (pCi/l)	Formula 1 (pCi/l)	Formula 2 (pCi/l)
Cesium-137	ND	ND	ND
Radium-226	83.500	ND	ND
Radium-228	27.300	ND	ND
Strontium-90	7.290	ND	ND
Technetium-99	35.350	ND	ND
Thorium-228	ND	ND	ND
Thorium-230	ND	ND	ND
Thorium-232	ND	ND	ND
Uranium-234	3990.000	11.230	14.030
Uranium-235/236	247.000	24.440	ND
Uranium-238	4910.000	32.660	8.810
	Raw Waste Characterization (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)
Thorium (Total)	ND	ND	ND
Uranium (Total)	7.380	0.110	0.030

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

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TABLE C.3-6

WASTE PIT 1 SOLIDIFICATION TCLP METALS DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)	TC REG LIMITS (mg/l)
Antimony	0.055	ND	ND	
Arsenic	0.003	ND	ND	5.000
Barium	1.562	3.309	3.803	100.000
Beryllium	0.007	ND	ND	
Boron	ND	0.670	0.397	
Cadmium	0.008	ND	ND	1.000
Chromium	0.100	ND	0.164	5.000
Cobalt	0.022	ND	ND	
Copper	0.048	ND	0.022	
Cyanide	ND	ND	ND	
Lead	0.005	ND	ND	5.000
Manganese	0.213	ND	ND	
Mercury	ND	ND	ND	0.200
Molybdenum	0.027	ND	ND	
Nickel	0.121	ND	ND	
Selenium	0.002	ND	ND	1.000
Silver	0.080	ND	ND	5.000
Thallium	ND	ND	0.042	
Vanadium	0.048	ND	ND	
Zinc	0.086	0.103	0.096	

TABLE C.3-6
(Continued)

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

TABLE C.3-7

FORMULATIONS[a] WITH UCS AND BULKING FACTOR RESULTS

WASTE PIT 2 - REMEDY SCREENING (PRELIMINARY PHASE) - CEMENT STABILIZATION

Formulation Number	Waste	Type II Portland Cement	Type F Flyash	Sodium Silicate	Attapulgite	Clinoptilolite	Water	Blast Furnace Slag	Group[b]	Stage[b]	UCS (psi)	Bulking Factor
1	100	26	26	0	6	6	40	0	1	1	148	118
2	100	26	26	0	0	0	31	0	3	1	175	91
3	100	28	20	7	6	6	44	0	1	1	151	129
4	100	31	31	0	6	7	53	0	1	1	106	163
5	100	33	54	7	6	6	53	0	1	1	209	176
6	100	42	42	4	12	0	58	0	3	1	291	180
7	100	43	43	0	6	6	62	0	4	1	134	176
8	100	43	43[c]	4	6	6	53	0	2	1	210	179
9	100	43	43	4	0	12	52	0	3	1	399	166
10	100	44	43	0	0	0	49	0	4	1	210	147
11	100	44	43	5	7	6	55	0	1	1	218	173
12	100	44	43	5	6	6	60	0	4	1	246	183
13	100	44	43[c]	0	6	6	53	0	2	1	315	173
14	100	51	31	0	0	0	45	0	_	2	586	138
15	100	51	32	0	6	6	53	0	1	1	312	160
16	100	53	0	0	0	0	53	53	_	2	710	167
17	100	53	15	0	0	0	44	25	_	2	710	143
18	100	53	53	0	0	0	53	0	_	2	600	171

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WASTE PIT 2 - REMEDY SCREENING (PRELIMINARY PHASE) - CEMENT STABILIZATION

Formulation Number	Waste	Type II Portland Cement	Type F Flyash	Sodium Silicate	Attapulgite	Clinoptilolite	Water	Blast Furnace Slag	Group[b]	Stage[b]	UCS (psi)	Bulking Factor
19	100	54	33	7	6	6	56	0	1	1	516	177
20	100	60	0	0	0	0	31	0	5	1	251	96
21	100	64	64	0	6	6	77	0	1	1	308	234
22	100	65	64	0	0	0	58	0	3	1	574	197
23	100	68	68	7	6	6	80	0	1	1	476	255
24	100	80	0	0	0	0	47	0	5	1	710	124

[a] Reagent loadings in grams per 100 grams of wet weight of waste
[b] As listed in the Operable Unit 1 Treatability Study Work Plan
[c] Site flyash used

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TABLE C.3-8

FORMULATIONS[a] WITH ANALYTICAL RESULTS[b]

WASTE PIT 2 - REMEDY SCREENING (PRELIMINARY PHASE) CEMENT STABILIZATION

Formulation Number	Gross Alpha[c] (dpm/4cc)	Gross Beta[c] (dpm/4cc)	Uranium by IC[d] (ppm)	pH of MTCLP Extraction (std. units)
1	LLD	LLD	0.3903	8.45
2	LLD	LLD	0.133	9.05
3	LLD	LLD	0.3505	8.15
4	LLD	LLD	0.3256	8.55
5	LLD	LLD	0.8803	7.65
6	LLD	LLD	ND	9.7
7	LLD	LLD	0.7016	7.45
8	LLD	LLD	ND	10.35
9	LLD	LLD	ND	9.75
10	LLD	LLD	1.0247	7.75
11	LLD	LLD	ND	9.95
12	LLD	LLD	ND	9.75
13	LLD	LLD	ND	10.35
14	LLD	LLD	ND	11.5
15	LLD	LLD	ND	11.35
16	LLD	LLD	ND	11.58
17	LLD	LLD	ND	11.57
18	LLD	LLD	ND	11.22
19	LLD	LLD	ND	10.82
20	LLD	LLD	0.0124	11.45
21	LLD	LLD	ND	11.25
22	LLD	LLD	0.0126	11.5
23	LLD	LLD	ND	10.85
24	LLD	LLD	ND	11.75

[a] Reagent loading per 100 grams of wet weight of waste
[b] Only metals that have results above detection limits are shown.
[c] ND - Not detected (detection limit ranged from 0.005 to 0.1 ppm [w/w]).
[d] LLD - Under the lower limit detection level which ranged from 5 to 25 dpm/4cc.

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TABLE C.3-9

CEMENT STABILIZATION
ADVANCED PHASE FORMULATIONS
WASTE PIT 2

Formulation	Normalized Waste	Normalized Cement	Normalized Flyash	Normalized Blast Furnace Slag	Normalized Clinoptilolite	Normalized Water (Range)
1	100	53	15	25	0	24-42
2	100	51	31	0	0	15-41

NOTE: All quantities are normalized to express quantities of reagents in grams used per 100 grams of waste. Waste was not dried before mixing.

TABLE C.3-10

CEMENT STABILIZATION
ADVANCED PHASE
RESULTS OF UCS, BULKING FACTOR, AVERAGE BULKING FACTOR, AND PERMEABILITY - WASTE PIT 2

Zone	Formulation	UCS (psi)	Bulking Factor (Percent Volume Increase)	Average Bulking Factor (Percent Volume Increase)	Permeability (cm/s)
1	1	>3149	131	123	5.2×10^{-8}
1	1	>3162	131		
2	1	1443	127		1.0×10^{-8}
2	1	1233	126		
1	2	1582	126		2.0×10^{-10}
1	2	835	125		
2	2	599	118		1.2×10^{-8}
2	2	554	119		
3	2	762	102		--

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TABLE C.3-11

WASTE PIT 2 SOLIDIFICATION TCLP RADIONUCLIDES DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (pCi/l)	Formula 1 (pCi/l)	Formula 2 (pCi/l)
Cesium-137	ND	ND	ND
Plutonium-238	ND	1.290	0.669
Plutonium-239/240	ND	ND	0.424
Radium-226	13.180	726.000	1517.000
Radium-228	3.510	ND	335.000
Ruthenium-106	ND	ND	ND
Strontium-90	ND	5.100	23.700
Technetium-99	67.600	ND	ND
Thorium-228	1.690	8.600	11.400
Thorium-230	1.780	2.770	1.570
Thorium-232	ND	ND	ND
Uranium-234	61.710	1.030	1.530
Uranium-235/236	13.500	ND	ND
Uranium-238	112.170	1.600	2.440
	Raw Waste Characterization (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)
Thorium (Total)	0.010	ND	ND
Uranium (Total)	0.050	0.005	0.007

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

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TABLE C.3-12

WASTE PIT 2 SOLIDIFICATION TCLP METALS DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)	TC REG LIMITS (mg/l)
Antimony	0.156	ND	ND	
Arsenic	0.600	0.007	0.007	5.000
Barium	0.048	1.851	2.738	100.000
Beryllium	0.004	ND	ND	
Boron	0.569	0.357	0.277	
Cadmium	0.028	ND	ND	1.000
Chromium	0.077	0.400	0.281	5.000
Cobalt	1.913	ND	ND	
Copper	0.244	0.038	0.059	
Cyanide	ND	0.014	ND	
Lead	0.006	ND	ND	5.000
Manganese	5.215	ND	ND	
Mercury	ND	ND	ND	0.200
Molybdenum	0.235	0.402	0.451	
Nickel	2.181	ND	ND	
Selenium	0.025	0.012	0.007	1.000
Silicon	29.650	12.784	8.976	
Silver	0.052	ND	ND	5.000
Thallium	0.008	ND	ND	
Vanadium	0.429	ND	ND	
Zinc	0.134	ND	ND	

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples, but are not identical.

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TABLE C.3-13

WASTE PIT 2 SOLIDIFICATION TCLP
ORGANICS DILUTION ADJUSTED CONCENTRATION

	Raw Waste Characterization[b] (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)	TC REG LIMITS (mg/l)
2-Methylnaphthalene		0.016	0.011	
4.4-DDT	ND	ND	ND	
4-Nitroaniline	ND	ND	ND	
4-Nitrophenol	ND	ND	ND	
Acenaphthene	0.055	0.064	0.021	
Acenaphthyine	ND	ND	ND	
Anthracene	0.012	0.026	0.025	
Aroclor-1248	ND	ND	ND	
Aroclor-1254	ND	ND	ND	
Benzene	ND	ND	ND	0.500
Benzo(a)anthracene	ND	ND	ND	
Benzo(a)pyrene	ND	ND	ND	
Benzo(b)fluoranthene	ND	ND	ND	
Benzo(g.h.i.)perylene	ND	ND	ND	
Benzo(k)fluoranthene	ND	ND	ND	
Chrysene	ND	ND	ND	
Dibenzo(a.h.)anthracene	ND	ND	ND	
Dibenzofuran	0.030	ND	ND	
Fluoranthene	0.011	0.042	0.034	
Fluorene	0.038	ND	ND	
Indeno(1.2.3-cd)prene	ND	ND	ND	
Naphthalene	0.130	0.059	0.038	
Phenanthrene	0.084	0.209	0.134	
Pyrene	0.007	0.031	0.020	
Tetrachloroethene	ND	ND	ND	0.700
Tributyl phosphate		0.300		0.036
Vinyl chloride	ND	ND	ND	0.200

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TABLE C.3-13
(Continued)

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

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TABLE C.3-14

FORMULATIONS[a] WITH UCS AND BULKING FACTOR RESULTS

WASTE PIT 3 - REMEDY SCREENING (PRELIMINARY PHASE) - CEMENT STABILIZATION

Formulation Number	Waste	Type II Portland Cement	Type F Flyash	Sodium Silicate	Attapulgite	Clinoptilolite	Water	Blast Furnace Slag	Group[b]	Stage[b]	UCS (psi)	Bulking Factor
1	100	26	26	0	6	6	27	0	1	1	293	87
2	100	26	26	0	0	0	19	0	3	1	375	64
3	100	27	20	7	6	6	33	0	1	1	311	100
4	100	31	51	0	6	6	47	0	1	1	255	132
5	100	33	54	7	6	6	49	0	1	1	190	152
6	100	43	43	4	12	0	53	0	3	1	262	152
7	100	43	43	0	6	6	43	0	4	1	277	131
8	100	43	43	4	0	12	40	0	3	1	383	129
9	100	43	43	0	0	0	27	0	4	1	396	108
10	100	43	43	4	6	6	40	0	1	1	422	131
11	100	43	43[c]	4	6	6	34	0	2	1	593	128
12	100	43	43[c]	0	6	6	24	0	2	1	616	107
13	100	43	43	4	6	6	47	0	4	1	638	134
14	100	51	0	0	0	4	29	31	_	2	650	98
15	100	51	15	0	0	0	32	25	_	2	650	101
16	100	51	31	0	6	6	47	0	1	1	566	128
17	100	51	31	0	0	0	25	0	_	2	650	95
18	100	54	33	7	6	6	47	0	1	1	370	144
19	100	60	0	0	0	0	20	0	5	1	650	65
20	100	64	64	0	6	6	67	0	1	1	340	190

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TABLE C.3-14
(Continued)

WASTE PIT 3 - REMEDY SCREENING (PRELIMINARY PHASE) - CEMENT STABILIZATION												
Formulation Number	Waste	Type II Portland Cement	Type F Flyash	Sodium Silicate	Attapulgite	Clinoptilolite	Water	Blast Furnace Slag	Group[b]	Stage[b]	UCS (psi)	Bulking Factor
21	100	64	64	0	0	0	43	0	3	1	650	148
22	100	68	68	7	6	6	75	0	1	1	650	217
23	100	81	0	0	0	0	28	0	5	1	372	89

[a] Reagent loadings in grams per 100 grams of wet weight of waste
[b] As listed in the Operable Unit 1 Treatability Study Work Plan
[c] Site flyash used

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TABLE C.3-15

FORMULATIONS[a] WITH ANALYTICAL RESULTS[b]

PIT 3 - REMEDY SCREENING (PRELIMINARY PHASE) CEMENT STABILIZATION

Formulation Number	Gross Alpha[c] (dpm/4cc)	Gross Beta[c] (dpm/4cc)	Uranium by IC[d] (ppm)	pH of MTCLP Extraction Fluid (std. units)
1	LLD	LLD	0.2723	8.35
2	LLD	9.3	0.9434	8.05
3	LLD	LLD	0.1709	8.1
4	LLD	LLD	ND	9.15
5	LLD	LLD	ND	8.4
6	LLD	LLD	0.2206	8.6
7	LLD	LLD	ND	10.15
8	LLD	LLD	0.3152	8.9
9	LLD	LLD	ND	10.65
10	LLD	LLD	0.0221	10.05
11	LLD	LLD	ND	10.85
12	LLD	LLD	ND	11
13	LLD	LLD	0.0189	9.15
14	LLD	LLD	ND	10.61
15	LLD	LLD	ND	11.79
16	LLD	LLD	ND	11.2
17	LLD	LLD	ND	11.31
18	LLD	LLD	ND	11.05
19	LLD	LLD	0.0177	11.7
20	LLD	LLD	ND	11.1
21	LLD	LLD	0.5971	9.2
22	LLD	LLD	ND	11.15
23	LLD	LLD	ND	11.8

[a] Reagent loading per 100 grams of wet weight of waste
[b] Only metals that have results above detection limits are shown.
[c] LLD - Under the lower limit detection level
[d] ND - Not detected

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TABLE C.3-16

CEMENT STABILIZATION
ADVANCED PHASE FORMULATIONS
WASTE PIT 3

Formulation	Normalized Waste	Normalized Cement	Normalized Flyash	Normalized Blast Furnace Slag	Normalized Clinoptilolite	Normalized Water (Range)
1	100	51	15	25	0	22-32
2	100	51	31	0	4	18-32

NOTE: All quantities are normalized to express quantities of reagents in grams used per 100 grams of waste. Waste was not dried before mixing.

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TABLE C.3-17

CEMENT STABILIZATION
ADVANCED PHASE
RESULTS OF UCS, BULKING FACTOR, AVERAGE BULKING FACTOR, AND PERMEABILITY - WASTE PIT 3

Zone	Formulation	UCS (psi)	Bulking Factor (Percent Volume Increase)	Average Bulking Factor (Percent Volume Increase)	Permeability (cm/s)
1	1	>3148	90	87	2.1×10^{-9}
1	1	>3156	89		
2	1	>3156	81		4.7×10^{-9}
2	1	1642	81		
2	1	2289	84		3.3×10^{-9}
2	1	3138	86		
3	1	1520	91		5.1×10^{-9}
3	1	1591	97		
1	2	2878	89		1.0×10^{-7}
1	2	2868	88		
1	2	2166	87		3.0×10^{-9}
1	2	2848	88		
2	2	1590	88		2.1×10^{-7}
2	2	1821	88		
3	2	2240	86		1.4×10^{-9}
3	2	2243	86		

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TABLE C.3-18

WASTE PIT 3 SOLIDIFICATION TCLP
RADIONUCLIDES DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (pCi/l)	Formula 1 (pCi/l)	Formula 2 (pCi/l)
Neptunium-237	ND	0.036	0.490
Plutonium-238	ND	0.290	0.360
Plutonium-239/240	ND	0.270	0.520
Radium-226	9.620	70.560	587.520
Radium-228	13.030	49.950	ND
Strontium-90	ND	2.880	ND
Technetium-99	867.000	20.140	24.620
Thorium-228	6.440	4.380	2.990
Thorium-230	1.070	0.600	1.850
Thorium-232	ND	0.090	ND
Uranium-234	74.900	0.690	1.430
Uranium-235/236	7.240	ND	ND
Uranium-238	181.250	ND	1.170
	Raw Waste Characterization (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)
Thorium (Total)	ND	ND	ND
Uranium (Total)	0.390	ND	0.002

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

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TABLE C.3-19

WASTE PIT 3 SOLIDIFICATION TCLP METALS DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b](mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)	TC REG LIMITS (mg/l)
Aluminum	3.432	3.084	0.788	
Antimony	0.184	ND	ND	
Arsenic	0.298	0.011	0.024	5.000
Barium	0.312	2.800	2.011	100.000
Beryllium	0.007	ND	0.004	
Boron	0.998	0.381	0.588	
Cadmium	0.054	ND	ND	1.000
Chromium	0.124	ND	0.095	5.000
Cobalt	0.120	ND	ND	
Copper	0.475	0.036	0.054	
Cyanide	ND	ND	ND	
Lead	0.007	0.025	0.009	5.000
Manganese	49.812	ND	ND	
Mercury	0.001	ND	ND	0.200
Molybdenum	0.370	0.952	2.382	
Nickel	0.709	ND	ND	
Selenium	0.218	0.013	0.006	1.000
Silver	0.092	ND	ND	5.000
Thallium	0.013	0.004	ND	
Vanadium	0.729	0.060	0.495	
Zinc	0.397	0.074	ND	

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

TABLE C.3-20

FORMULATIONS[a] WITH UCS AND BULKING FACTOR RESULTS

WASTE PIT 4 - REMEDY SCREENING (PRELIMINARY PHASE) - CEMENT STABILIZATION

Formulation Number	Waste	Type II Portland Cement	Type F Flyash	Sodium Silicate	Attapulgite	Clinoptilolite	Water	Blast Furnace Slag	Group[b]	Stage[b]	UCS (psi)	Bulking Factor
1	100	26	26	0	6	6	54	0	1	1	179	156
2	100	26	26	0	0	0	32	0	3	1	540	92
3	100	27	20	7	6	6	55	0	1	1	273	162
4	100	31	51	0	6	6	77	0	1	1	118	221
5	100	33	54	7	6	6	75	0	1	1	201	231
6	100	43	43	4	12	0	71	0	3	1	317	217
7	100	43	43	0	6	6	40	0	4	1	376	165
8	100	43	43[c]	4	6	6	53	0	2	1	413	198
9	100	43	43	4	6	6	67	0	1	1	463	213
10	100	43	43	4	0	12	63	0	3	1	593	199
11	100	43	43	0	0	0	40	0	4	1	600	141
12	100	43	43	4	6	6	61	0	4	1	600	199
13	100	43	43[c]	0	6	6	53	0	2	1	600	192
14	100	51	15	0	0	0	48	25	-	2	600	156
15	100	51	31	0	6	6	57	0	1	1	474	177
16	100	51	31	0	0	0	39	0	-	2	600	139
17	100	51	31	0	0	4	47	0	-	2	600	154
18	100	54	33	7	6	6	67	0	1	1	557	212
19	100	60	0	0	0	0	33	0	5	1	600	93
20	100	64	64	0	6	6	80	0	1	1	524	265
21	100	64	64	0	0	0	60	0	3	1	600	217

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TABLE C.3-20
(Continued)

WASTE PIT 4 - REMEDY SCREENING (PRELIMINARY PHASE) - CEMENT STABILIZATION

Formulation Number	Waste	Type II Portland Cement	Type F Flyash	Sodium Silicate	Attapulgite	Clinoptilolite	Water	Blast Furnace Slag	Group[b]	Stage[b]	UCS (psi)	Bulking Factor
22	100	68	68	7	6	6	93	0	1	1	459	303
23	100	80	0	0	0	0	35	0	5	1	600	113

[a] Reagent loadings in grams per 100 grams of wet weight of waste
[b] As listed in the Operable Unit 1 Treatability Study Work Plan
[c] Site flyash used

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TABLE C.3-21

FORMULATIONS[a] WITH ANALYTICAL RESULTS[b]

WASTE PIT 4 - REMEDY SCREENING (PRELIMINARY PHASE) CEMENT STABILIZATION

Formulation Number	Gross Alpha[c] (dpm/4cc)	Gross Beta[c] (dpm/4cc)	Uranium by IC (ppm)	pH of MTCLP Extraction Fluid (std. units)
1	1278.7	128	407.1	7
2	431	133	175.5	7.2
3	1003.4	88.3	452.1	7
4	424.5	114	223.6	6.45
5	331.2	91.5	162.1	6.25
6	96.8	21.5	24.83	8.05
7	LLD	9.9	7.255	9.75
8	297.5	18.2	118.3	7
9	516.8	42.2	5.4108	7
10	127.9	43.9	63.64	8.05
11	LLD	LLD	0.0469	10.35
12	208.3	52.6	50	7.35
13	705.1	57.9	243.8	7
14	265.5	83.1	181.93	7.39
15	LLD	LLD	7.222	9.6
16	280.6	64.1	83.29	7.55
17	LLD	LLD	0.2	10.21
18	LLD	LLD	0.2829	9.25
19	LLD	LLD	0.0532	11.5
20	77.1	27	39.43	9.05
21	117	84.4	94.32	7.75
22	120.8	20.4	44.3	9
23	LLD	LLD	0.1281	11.75

[a] Reagent loading per 100 grams of wet weight of waste
[b] Only metals that have results above detection limits are shown.
[c] LLD - Under the lower limit detection level

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TABLE C.3-22

CEMENT STABILIZATION
ADVANCED PHASE FORMULATIONS
WASTE PIT 4

Formulation	Normalized Waste	Normalized Cement	Normalized Flyash	Normalized Blast Furnace Slag	Normalized Clinoptilolite	Normalized Water (Range)
1	100	51	31	0	4	34-59
2	100	80	0	0	6	33-61

NOTE: All quantities are normalized to express quantities of reagents in grams used per 100 grams of waste. Waste was not dried before mixing.

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TABLE C.3-23

CEMENT STABILIZATION
ADVANCED PHASE
RESULTS OF UCS, BULKING FACTOR, AVERAGE BULKING FACTOR, AND PERMEABILITY
WASTE PIT 4

Zone	Formulation	UCS (psi)	Bulking Factor (Percent Volume Increase)	Average Bulking Factor (Percent Volume Increase)	Permeability (cm/s)
1	1	1862	173	136	1.5×10^{-8}
1	1	1981	170		
2	1	1289	132		2.3×10^{-8}
2	1	1626	130		
3	1	1470	129		5.6×10^{-9}
3	1	2171	126		
1	2	2608	168		1.0×10^{-7}
1	2	1812	169		
2	2	1957	120		2.8×10^{-9}
2	2	>3131	118		
2	2	1026	119		4.2×10^{-9}
2	2	832	118		
3	2	>3157	118		2.3×10^{-9}
3	2	>3149	118		

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TABLE C.3-24

WASTE PIT 4 SOLIDIFICATION TCLP RADIONUCLIDES DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (pCi/l)	Formula 1 (pCi/l)	Formula 2 (pCi/l)
Neptunium-237	3.630	0.910	0.320
Plutonium-238	ND	0.220	0.310
Plutonium-239/240	ND	ND	0.150
Radium-226	48.960	34.050	ND
Radium-228	76.900	37.480	ND
Strontium-90	19.680	2.200	ND
Technetium-99	95.910	23.350	21.370
Thorium-228	ND	5.210	6.020
Thorium-230	ND	1.690	2.380
Thorium-232	ND	ND	ND
Uranium-234	8518.000	3.430	12.070
Uranium-235/236	1891.500	ND	1.390
Uranium-238	67550.000	6.620	79.360
	Raw Waste Characterization (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)
Thorium (Total)	ND	ND	ND

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

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TABLE C:3-25

WASTE PIT 4 SOLIDIFICATION TCLP
METALS DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)	TC REG LIMITS (mg/l)
Antimony	0.400	ND	ND	
Arsenic	ND	ND	ND	5.000
Barium	3.744	3.092	6.165	100.000
Beryllium	0.047	ND	ND	
Boron	0.401	0.586	0.241	
Cadmium	0.046	ND	ND	1.000
Chromium	1.276	0.047	0.027	5.000
Cobalt	0.193	ND	ND	
Copper	0.439	0.033	0.025	
Cyanide	ND	ND	ND	
Lead	0.007	ND	ND	5.000
Manganese	28.344	ND	ND	
Mercury	ND	ND	ND	0.200
Molybdenum	0.111	ND	ND	
Nickel	0.365	ND	ND	
Selenium	ND	ND	ND	1.000
Silicon	11.457	11.885	3.075	
Silver	0.706	ND	ND	5.000
Thallium	ND	ND	ND	
Vanadium	0.508	ND	ND	
Zinc	0.484	ND	0.074	

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

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TABLE C.3-26

FORMULATIONS[a] WITH UCS AND BULKING FACTOR RESULTS

WASTE PIT 5 - REMEDY SCREENING (PRELIMINARY PHASE) - CEMENT STABILIZATION

Formulation Number	Waste	Type II Portland Cement	Flyash	Sodium Silicate	Attapulgite	Clinoptilolite	Water	Blast Furnace Slag	Group[b]	Stage[b]	UCS (psi)	Bulking Factor
1	100	26	26	0	0	0	0	0	3	1	66	27
2	100	26	26	0	6	6	3	0	1	1	267	36
3	100	27	20	7	6	6	0	0	1	1	329	34
4	100	31	51	0	6	6	10	0	1	1	455	60
5	100	33	54	7	6	6	13	0	1	1	393	73
6	100	43	43[c]	4	6	6	0	0	2	1	412	59
7	100	43	43[c]	0	6	6	0	0	2	1	422	55
8	100	43	43	0	0	0	0	0	4	1	541	42
9	100	43	43	4	12	0	4	0	3	1	591	61
10	100	43	43	4	6	6	5	0	1	1	603	56
11	100	43	43	4	6	6	6	0	4	1	650	58
12	100	43	43	0	6	6	4	0	4	1	650	54
13	100	43	43	4	0	12	0	0	3	1	650	54
14	100	51	15	0	0	0	0	25	-	2	650	40
15	100	51	31	0	0	4	0	0	-	2	374	44
16	100	51	31	0	6	6	10	0	1	1	650	56
17	100	54	33	7	6	6	15	0	1	1	531	70
18	100	60	0	0	0	0	0	0	5	1	408	27
19	100	64	64	0	6	6	12	0	1	1	650	81
20	100	64	64	0	0	0	0	0	3	1	650	65
21	100	65	31	0	0	4	0	0	-	2	522	47
22	100	68	68	7	6	6	12	0	1	1	650	100
23	100	80	0	0	0	0	0	0	5	1	650	32

[a] Reagent loadings in grams per 100 grams of wet weight of waste
[b] As listed in the Operable Unit 1 Treatability Study Work Plan
[c] Site flyash used

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TABLE C.3-27

FORMULATIONS[a] WITH ANALYTICAL RESULTS[b]

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PIT 5 - REMEDY SCREENING (PRELIMINARY PHASE)
CEMENT STABILIZATION

Formulation Number	Gross Alpha[c] (dpm/4cc)	Gross Beta[c] (dpm/4cc)	Uranium by IC[d] (ppm)	pH of MTCLP Extraction Fluid (std. units)
1	18.6	61.6	ND	11.24
2	LLD	28.7	ND	11.14
3	LLD	30	ND	10.75
4	LLD	35.3	ND	10.2
5	LLD	29.4	ND	9.99
6	18.4	33.9	ND	11.68
7	19.3	27.7	ND	11.85
8	28.1	0.4	ND	11.42
9	25.9	45.6	ND	11.2
10	33.7	33.2	ND	11.74
11	LLD	30	ND	9.27
12	35.5	47.2	ND	9.87
13	LLD	40.8	ND	11.1
14	LLD	LLD	ND	11.72
15	25.5	28.1	0.17	12.34
16	LLD	30.4	ND	12.29
17	LLD	22.3	ND	12.21
18	40.9	53	ND	12.34
19	LLD	18.4	ND	11.96
20	18.7	37.9	ND	11.93
21	19.4	20.4	ND	12.43
22	LLD	16	ND	11.97
23	47.8	58.6	ND	12.39

[a] Reagent loading per 100 grams of wet weight of waste
[b] Only metals that have results above detection limits are shown.
[c] LLD - Under the lower limit detection level
[d] ND - Not detected

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TABLE C.3-28

CEMENT STABILIZATION
ADVANCED PHASE FORMULATIONS
WASTE PIT 5

Formulation	Normalized Waste	Normalized Cement	Normalized Flyash	Normalized Blast Furnace Slag	Normalized Clinoptilolite	Normalized Water (Range)
1	100	51	15	25	0	0
2	100	51	30	25	0	0-4

NOTE: All quantities are normalized to express quantities of reagents in grams used per 100 grams of waste. Waste was not dried before mixing.

TABLE C.3-29

CEMENT STABILIZATION
ADVANCED PHASE
RESULTS OF UCS, BULKING FACTOR, AVERAGE BULKING FACTOR, AND PERMEABILITY
WASTE PIT 5

Zone	Formulation	UCS (psi)	Bulking Factor (Percent Volume Increase)	Average Bulking Factor (Percent Volume Increase)	Permeability (cm/s)
Composite	1	1535 1870	37 37	41	7.2×10^{-8}
Composite	1	1991 1294	38 37		7.2×10^{-8}
Composite	2	2257 2067	49 48		3.2×10^{-8}

TABLE C.3-30

WASTE PIT 5 SOLIDIFICATION TCLP RADIONUCLIDES DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (pCi/l)	Formula 1 (pCi/l)	Formula 2 (pCi/l)
Cesium-137	NA	103.000	ND
Neptunium-237	NA	0.535	0.420
Plutonium-238	NA	0.573	0.420
Plutonium-239/240	NA	0.172	0.252
Radium-226	NA	352.000	273.000
Radium-228	NA	68.000	38.900
Ruthenium-106	NA	ND	ND
Strontium-90	NA	79.000	65.300
Technetium-99	NA	199.000	206.000
Thorium-228	NA	5.120	3.300
Thorium-230	NA	204.000	0.483
Thorium-232	NA	2.580	ND
Uranium-234	NA	9.900	0.441
Uranium-235/236	NA	0.401	ND
Uranium-238	NA	3.930	ND
	Raw Waste Characterization (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)
Thorium (Total)	NA	0.023	ND
Uranium (Total)	NA	0.012	ND

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

TABLE C.3-31

WASTE PIT 5 SOLIDIFICATION TCLP
METALS DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)	TC REG LIMITS (mg/l)
Antimony	0.082	ND	ND	
Arsenic	0.027	ND	ND	5.000
Barium	3.904	14.745	8.736	100.000
Beryllium	0.006	ND	ND	
Cadmium	0.003	ND	ND	1.000
Chromium	0.014	ND	ND	5.000
Cobalt	0.032	ND	ND	
Copper	1.916	ND	ND	
Cyanide	ND	ND	ND	
Lead	0.035	ND	ND	5.000
Manganese	2.307	ND	ND	
Mercury	0.002	ND	ND	0.200
Molybdenum	0.190	0.810	1.117	
Nickel	0.296	ND	ND	
Selenium	ND	ND	ND	1.000
Silver	0.099	ND	ND	5.000
Thallium	0.223	0.015	0.015	
Vanadium	0.815	ND	ND	
Zinc	0.326	0.094	0.160	

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

TABLE C.3-32

FORMULATIONS[a] WITH UCS AND BULKING FACTOR RESULTS

WASTE PIT 6 - REMEDY SCREENING (PRELIMINARY PHASE) - CEMENT STABILIZATION

Forumlation Number	Waste	Type II Portland Cement	Flyash	Sodium Silicate	Attapulgite	Clinoptilolite	Water	Group[b]	Stage[b]	UCS (psi)	Bulking Factor
1	100	26	26	0	0	0	0	3	1	240	24
2	100	26	26	0	6	6	0	1	1	467	31
3	100	27	20	7	6	6	3	1	1	397	36
4	100	31	51	0	6	6	8	1	1	700	58
5	100	33	54	7	6	6	12	1	1	700	74
6	100	43	43	4	12	0	17	3	1	473	76
7	100	43	43[c]	0	6	6	3	2	1	607	59
8	100	43	43	4	6	6	3	1	1	700	58
9	100	43	43[c]	4	6	6	3	2	1	700	63
10	100	43	43	4	0	12	3	3	1	700	62
11	100	43	43	4	6	6	4	4	1	700	61
12	100	43	43	0	6	6	2	4	1	700	49
13	100	43	43	0	0	0	0	4	1	700	42
14	100	51	31	0	6	6	9	1	1	700	53
15	100	54	33	7	6	6	15	1	1	700	70
16	100	60	0	0	0	0	0	5	1	700	23
17	100	64	64	0	6	6	19	1	1	700	94
18	100	64	64	0	0	0	6	3	1	700	80
19	100	68	68	7	6	6	25	1	1	385	116
20	100	80	0	0	0	0	0	5	1	700	30

[a] Reagent loadings in grams per 100 grams of wet weight of waste
[b] As listed in the Operable Unit 1 Treatability Study Work Plan
[c] Site flyash used

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TABLE C.3-33

FORMULATIONS[a] WITH ANALYTICAL RESULTS[a]

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PIT 6 - REMEDY SCREENING (PRELIMINARY PHASE) CEMENT STABILIZATION

Formulation Number	Gross Alpha[c] (dpm/4cc)	Gross Beta[c] (dpm/4cc)	Uranium by IC[d] (ppm)	pH MTCLP Extraction Fluid (std. units)
1	LLD	LLD	ND	11.16
2	LLD	LLD	ND	10.46
3	LLD	LLD	ND	9.71
4	LLD	LLD	ND	10.94
5	LLD	LLD	0.1679	9.63
6	LLD	LLD	ND	11.54
7	LLD	LLD	ND	11.79
8	LLD	LLD	ND	11.5
9	LLD	LLD	ND	11.75
10	LLD	LLD	ND	10.5
11	LLD	LLD	ND	11.21
12	32.6	LLD	17.7111	6.25
13	LLD	LLD	ND	11.48
14	LLD	LLD	ND	12.12
15	LLD	LLD	ND	11.77
16	LLD	LLD	ND	12.57
17	LLD	LLD	ND	11.92
18	LLD	LLD	ND	12.2
19	7.8	LLD	ND	11.23
20	LLD	LLD	ND	12.74

[a] Reagent loading per 100 grams of wet weight of waste
[b] Only metals that have results above detection limits are shown.
[c] LLD - Under the lower limit detection level
[d] ND - Not detected

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TABLE C.3-34

CEMENT STABILIZATION
ADVANCED PHASE FORMULATIONS
WASTE PIT 6

Formulation	Normalized Waste	Normalized Cement	Normalized Flyash	Normalized Blast Furnace Slag	Normalized Clinoptilolite	Normalized Water (Range)
1	100	53	15	25	0	4
2	100	43	43	0	0	2

NOTE: All quantities are normalized to express quantities of reagents in grams used per 100 grams of waste. Waste was not dried before mixing.

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TABLE C.3-35

CEMENT STABILIZATION
ADVANCED PHASE
RESULTS OF UCS, BULKING FACTOR, AVERAGE BULKING FACTOR, AND PERMEABILITY
WASTE PIT 6

Zone	Formulation	UCS (psi)	Bulking Factor (Percent Volume Increase)	Average Bulking Factor (Percent Volume Increase)	Permeability (cm/s)
Composite	1	>3139	41	41	6.5×10^{-9}
		>3142	41		
Composite	2	697	41		1.1×10^{-9}
		936	41		
Composite	2	1032	40		4.1×10^{-9}
		1028	39		

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TABLE C.3-36

WASTE PIT 6 SOLIDIFICATION TCLP RADIONUCLIDES DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[6]+ (pCi/l)	Formula 1 (pCi/l)	Formula 2 (pCi/l)
Cesium-137	NA	ND	ND
Neptunium-237	NA	0.670	0.649
Plutonium-238	NA	0.197	ND
Plutonium-239/240	NA	ND	0.254
Radium-226	NA	ND	ND
Radium-228	NA	ND	ND
Strontium-90	NA	11.879	ND
Technetium-99	NA	ND	65.330
Thorium-228	NA	2.049	2.538
Thorium-230	NA	1.497	2.726
Thorium-232	NA	ND	ND
Uranium-234	NA	1.281	ND
Uranium-235/236	NA	ND	ND
Uranium-238	NA	3.211	7.652
	Raw Waste Characterization (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)
Thorium (Total)	NA	ND	ND
Uranium (Total)	NA	0.010	0.023

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

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TABLE C.3-37

WASTE PIT 6 SOLIDIFICATION TCLP METALS DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)	TC REG LIMITS (mg/l)
Antimony	ND	ND	ND	
Arsenic	0.550	ND	ND	5.000
Barium	1.731	1.324	1.058	100.000
Beryllium	0.009	ND	ND	
Cadmium		ND	ND	1.000
Chromium	ND	ND	0.028	5.000
Cobalt	ND	ND	ND	
Copper	ND	0.024	0.036	
Cyanide	ND	ND	ND	
Lead	0.596	ND	ND	5.000
Manganese	1.255	ND	ND	
Mercury	ND	ND	ND	0.200
Molybdenum	ND	ND	0.098	
Nickel	0.095	ND	ND	
Selenium	ND	ND	ND	1.000
Silver	0.047	ND	ND	5.000
Thallium	0.660	ND	ND	
Vanadium	ND	ND	ND	
Zinc	1.551	ND	ND	

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

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TABLE C.3-38

FORMULATIONS[a] WITH UCS AND BULKING FACTOR RESULTS

BURN PIT - REMEDY SCREENING (PRELIMINARY PHASE) - CEMENT STABILIZATION

Formulation Number	Waste	Type II Portland Cement	Type F Flyash	Sodium Silicate	Attapulgite	Clinoptilolite	Water	Blast Furnace Slag	Calcium Hydroxide	Group[b]	Stage[b]	UCS (psi)	Bulking Factor
1	100	20	27	7	6	6	53	0	0	1	1	110	126
2	100	26	26	0	6	6	50	0	0	1	1	56	118
3	100	26	26	0	0	0	33	0	0	3	1	268	79
4	100	31	51	0	6	6	61	0	0	1	1	255	161
5	100	33	54	7	6	6	83	0	0	1	1	55	208
6	100	43	43	4	6	6	72	0	0	4	1	165	186
7	100	43	43[c]	0	6	6	57	0	0	2	1	187	161
8	100	43	43	4	0	12	67	0	0	3	1	207	173
9	100	43	43	4	12	0	79	0	0	3	1	209	189
10	100	43	43	4	6	0	59	0	0	1	1	241	165
11	100	43	43[c]	4	6	6	60	0	0	2	1	274	172
12	100	43	43	0	6	6	67	0	0	4	1	277	165
13	100	43	43	0	0	0	53	0	0	4	1	337	139
14	100	51	15	0	0	0	55	31	0	_	2	700	132
15	100	51	31	0	6	6	60	0	0	1	1	329	155
16	100	51	31	0	0	0	53	15	0	_	2	700	139
17	100	54	33	7	6	6	67	0	0	1	1	289	181
18	100	54	33	0	0	4	54	0	0	_	2	700	129
19	100	60	0	0	0	0	38	0	0	5	1	393	86
20	100	64	50	0	0	0	79	50	0	_	2	700	222

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TABLE C.3-38
(Continued)

BURN PIT - REMEDY SCREENING (PRELIMINARY PHASE) - CEMENT STABILIZATION

Formulation Number	Waste	Type II Portland Cement	Type F Flyash	Sodium Silicate	Attapulgite	Clinoptilolite	Water	Blast Furnace Slag	Calcium Hydroxide	Group[b]	Stage[b]	UCS (psi)	Bulking Factor
21	100	64	64	0	6	6	80	0	0	1	1	374	222
22	100	64	64	0	0	0	65	0	0	3	1	441	183
23	100	68	68	7	6	6	93	0	0	1	1	315	253
24	100	72	44	0	0	0	70	21	0	_	2	700	192
25	100	73	21	0	0	0	70	44	0	_	2	700	181
26	100	75	50	0	0	6	66	0	0	_	2	700	182
27	100	80	0	0	0	0	43	0	0	5	1	313	107
28	100	80	0	0	0	0	55	0	1	_	2	700	118
29	100	80	80	0	0	0	79	0	0	_	2	700	217
30	100	100	0	0	0	0	52	0	0	_	2	700	127
31	100	100	0	0	0	0	49	0	0	_	2	700	120
32	100	100	100	0	0	0	90	0	0	_	2	700	266
33	100	120	0	0	0	0	60	0	1	_	2	700	152
34	100	150	0	0	0	0	68	0	0	_	2	700	176
35	100	150	0	0	0	0	66	0	0	_	2	700	174

[a] Reagent loadings in grams per 100 grams of wet weight of waste
[b] As listed in the Operable Unit 1 Treatability Study Work Plan
[c] Site flyash used

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TABLE C.3-39

FORMULATIONS[a] WITH ANALYTICAL RESULTS[b]

BURN PIT - REMEDY SCREENING (PRELIMINARY PHASE)
CEMENT STABILIZATION

Formulation Number	Gross Alpha[c] (dpm/4cc)	Gross Beta[c] (dpm/4cc)	Uranium by IC[d] (ppm)	pH of MTCLP Extraction Fluid (std. units)
1	46.7	21.1	5.9965	7
2	LLD	LLD	1.049	8.5
3	41	LLD	4.6705	7.09
4	LLD	LLD	3.9751	7.5
5	28	11.5	3.8658	7.5
6	LLD	LLD	0.1015	8.5
7	LLD	LLD	0.5132	10.01
8	25	LLD	3.9338	7.19
9	34.9	LLD	4.1633	6.91
10	48	13.3	5.005	7
11	LLD	LLD	1.5787	7.41
12	LLD	10.2	2.4832	7.5
13	LLD	LLD	1.1178	8.5
14	LLD	LLD	ND	11.4
15	LLD	LLD	0.1803	10.5
16	LLD	LLD	ND	10.21
17	LLD	LLD	ND	10
18	LLD	LLD	ND	10.21
19	35.1	10.8	0.2291	10.5
20	LLD	LLD	ND	9.96
21	LLD	LLD	0.1704	10.26
22	LLD	LLD	2.4937	8.23
23	LLD	0.6	ND	9.58
24	LLD	LLD	ND	11.25
25	LLD	LLD	ND	11.12
26	LLD	LLD	ND	11.49
27	23.2	11.8	ND	10.5
28	LLD	LLD	ND	11.95
29	LLD	LLD	ND	10.1

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TABLE C.3-39
(Continued)

BURN PIT - REMEDY SCREENING (PRELIMINARY PHASE)
CEMENT STABILIZATION

Formulation Number	Gross Alpha[c] (dpm/4cc)	Gross Beta[c] (dpm/4cc)	Uranium by IC[d] (ppm)	pH of MTCLP Extraction Fluid (std. units)
30	LLD	LLD	ND	12
31	LLD	LLD	ND	11.88
32	LLD	LLD	ND	11.08
33	LLD	LLD	ND	12.02
34	LLD	LLD	0.05	11.91
35	LLD	LLD	ND	11.98

[a] Reagent loading per 100 grams of wet weight of waste
[b] Only metals that have results above detection limits are shown
[c] LLD - Under the lower limit detection level
[d] ND - Not detected

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TABLE C.3-40

CEMENT STABILIZATION
ADVANCED PHASE FORMULATIONS
BURN PIT

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Formulation	Normalized Waste	Normalized Cement	Normalized Flyash	Normalized Blast Furnace Slag	Normalized Clinoptilolite	Normalized Water (Range)
1	100	51	15	31	0	44-69
2	100	54	33	0	4-6	42-63

NOTE: All quantities are normalized to express quantities of reagents in grams used per 100 grams of waste. Waste was not dried before mixing.

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TABLE C.3-41

CEMENT STABILIZATION
ADVANCED PHASE
RESULTS OF UCS, BULKING FACTOR, AVERAGE BULKING FACTOR, AND PERMEABILITY
BURN PIT

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Zone	Formulation	UCS (psi)	Bulking Factor (Percent Volume Increase)	Average Bulking Factor (Percent Volume Increase)	Permeability (cm/s)
1	1	1828	148	132	5.3×10^{-9}
2	1	770	126		5.0×10^{-7}
3	1	1656	135		8.1×10^{-9}
1	2	530	138		1.2×10^{-8}
2	2	522	124		3.0×10^{-7}
3	2	1171	123		7.3×10^{-8}

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TABLE C.3-42
BURN PIT SOLIDIFICATION TCLP
RADIONUCLIDES DILUTION ADJUSTED CONCENTRATION

	Raw Waste Characterization (pCi/l)	Formula 1 (pCi/l)	Formula 2 (pCi/l)
Neptunium-237	ND	0.904	0.507
Plutonium-238	ND	0.293	0.333
Plutonium-239/240	ND	0.426	0.320
Radium-226	23.600	46.079	44.050
Radium-228	4.500	17.051	16.450
Strontium-90	ND	ND	ND
Technetium-99	25.000	79.800	ND
Thorium-228	2.010	1.498	2.190
Thorium-230	2.160	1.117	0.614
Thorium-232	ND	ND	ND
Uranium-234	10200.000	1.104	2.610
Uranium-235/236	643.000	ND	ND
Uranium-238	11000.000	1.020	2.140
	Raw Waste Characterization (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)
Thorium (Total)	ND	0.001	ND
Uranium (Total)	23.920	0.003	0.008

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

TABLE C.3-43

BURN PIT SOLIDIFICATION TCLP METALS DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)	TC REG LIMITS (mg/l)
Antimony	0.095	ND	ND	
Arsenic	0.078	ND	ND	5.000
Barium	1.395	3.130	3.660	100.000
Beryllium	0.005	ND	ND	
Cadmium	0.017	ND	ND	1.000
Chromium	0.176	0.069	0.054	5.000
Cobalt	0.050	ND	ND	
Copper	0.053	0.059	0.054	
Cyanide	ND	ND	ND	
Lead	0.065	0.013	0.031	5.000
Manganese	3.820	ND	ND	
Mercury	ND	ND	ND	0.200
Molybdenum	0.025	0.067	ND	
Nickel	0.081	ND	ND	
Selenium	0.190	0.005	ND	1.000
Silicon	4.760	5.300	4.370	
Silver	0.121	ND	ND	5.000
Thallium	ND	ND	ND	
Vanadium	0.070	ND	ND	
Zinc	0.513	0.081	0.198	

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

TABLE C.3-44

FORMULATIONS[a] WITH UCS AND BULKING FACTOR RESULTS

CLEARWELL - REMEDY SCREENING (PRELIMINARY PHASE) - CEMENT STABILIZATION

Formulation Number	Waste	Type II Portland Cement	Flyash	Sodium Silicate	Attapulgite	Clinoptilolite	Water	Blast Furnace Slag	Group[b]	Stage[b]	UCS (psi)	Bulking Factor
1	100	15	0	0	0	0	11	15	_	2	700	45
2	100	15	15	0	0	0	11	0	_	2	268	44
3	100	26	0	0	0	0	11	26	_	2	41	58
4	100	26	0	0	0	0	9	0	_	2	623	35
5	100	26	26	0	6	6	40	0	1	1	338	113
6	100	26	26	0	0	0	24	0	3	1	511	79
7	100	27	20	7	6	6	40	0	1	1	227	123
8	100	31	51	0	6	6	49	0	1	1	554	151
9	100	33	54	7	6	6	50	0	1	1	549	170
10	100	43	43	4	6	6	0	0	4	1	342	114
11	100	43	43	4	6	6	50	0	1	1	426	156
12	100	43	43	4	0	12	53	0	3	1	491	167
13	100	43	43[c]	0	6	6	47	0	2	1	515	160
14	100	43	43	4	12	0	58	0	3	1	534	177
15	100	43	43	0	6	6	50	0	4	1	601	158
16	100	43	43	0	0	0	31	0	4	1	700	116
17	100	43	43[c]	4	6	6	48	0	2	1	700	166
18	100	51	31	0	6	6	47	0	1	1	700	146
19	100	54	33	7	6	6	45	0	1	1	499	160

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TABLE C.3-44

(Continued)

CLEARWELL - REMEDY SCREENING (PRELIMINARY PHASE) - CEMENT STABILIZATION												
Formulation Number	Waste	Type II Portland Cement	Flyash	Sodium Silicate	Attapulgite	Clinoptilolite	Water	Blast Furnace Slag	Group[b]	Stage[b]	UCS (psi)	Bulking Factor
20	100	60	0	0	0	0	23	0	5	1	700	77
21	100	64	64	0	6	6	61	0	1	1	665	207
22	100	64	64	0	0	0	48	0	3	1	700	180
23	100	68	68	7	6	6	67	0	1	1	627	230
24	100	80	0	0	0	0	31	0	5	1	700	100

[a] Reagent loadings in grams per 100 grams of wet weight of waste
[b] As listed in the Operable Unit 1 Treatability Study Work Plan
[c] Site flyash used

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TABLE C.3-45

FORMULATIONS[a] WITH ANALYTICAL RESULTS[b]

CLEARWELL - REMEDY SCREENING (PRELIMINARY PHASE) CEMENT STABILIZATION

Formulation Number	Gross Alpha [c] (dpm/4cc)	Gross Beta [c] (dpm/4cc)	Uranium by IC [d] (ppm)	pH of MTCLP Extraction Fluid (std. units)
1	LLD	LLD	2.46	7.42
2	22.7	18.4	4.72	7.34
3	LLD	9.8	5.46	7.47
4	LLD	16.8	ND	9
5	LLD	11.2	3.0543	7.67
6	LLD	18.1	ND	10.62
7	LLD	LLD	2.8642	7.83
8	LLD	LLD	1.0186	8.24
9	LLD	LLD	2.5685	7.76
10	LLD	LLD	2.5986	7.7
11	LLD	LLD	2.6424	7.63
12	LLD	LLD	3.0242	7.65
13	LLD	LLD	ND	10.22
14	LLD	11.2	0.7884	8.64
15	LLD	LLD	2.039	7.87
16	17.5	LLD	2.271	8
17	LLD	LLD	ND	8.88
18	LLD	10.6	ND	11.18
19	LLD	LLD	0.9521	9.05
20	LLD	LLD	ND	12.07
21	LLD	LLD	ND	11.17
22	LLD	LLD	ND	10.7
23	LLD	LLD	0.3223	9.22
24	LLD	LLD	ND	12.05

[a] Reagent loading per 100 grams of wet weight of waste
[b] Only metals that have results above detection limits are shown.
[c] LLD - Under the lower limit detection level
[d] ND - Not detected

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TABLE C.3-46

CEMENT STABILIZATION
ADVANCED PHASE FORMULATIONS
CLEARWELL

Formulation	Normalized Waste	Normalized Cement	Normalized Flyash	Noramalized Blast Furnace Slag	Normalized Clinoptilolite	Normalized Water (Range)
1	100	15	0	15	0	20
2	100	26	0	0	0	20-22

NOTE: All quantities are normalized to express quantities of reagents in grams used per 100 grams of waste. Waste was not dried before mixing.

TABLE C.3-47

CEMENT STABILIZATION
ADVANCED PHASE
RESULTS OF UCS, BULKING FACTOR, AVERAGE BULKING FACTOR, AND PERMEABILITY CLEARWELL

Zone	Formulation	UCS (psi)	Bulking Factor (Percent Volume Increase)	Average Bulking Factor (Percent Volume Increase)	Permeability (cm/s)
Composite	1	824 1250	48 48	47	8.9×10^{-8}
Composite	2	593 525	44 45		1.6×10^{-7}
Composite	2	451 536	49 48		1.5×10^{-7}

TABLE C.3-48

CLEARWELL SOLIDIFICATION TCLP RADIONUCLIDES DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (pCi/l)	Formula 1 (pCi/l)	Formula 2 (pCi/l)
Cesium-137	NA	ND	ND
Neptunium-237	NA	0.120	0.592
Plutonium-238	NA	ND	0.548
Plutonium-239/240	NA	ND	ND
Radium-226	NA	21.600	19.011
Radium-228	NA	18.300	19.802
Strontium-90	NA	12.300	15.281
Technetium-99	NA	114.300	333.740
Thorium-228	NA	2.025	2.923
Thorium-230	NA	0.615	2.760
Thorium-232	NA	ND	0.414
Uranium-234	NA	0.225	0.370
Uranium-235/236	NA	ND	0.148
Uranium-238	NA	0.345	0.703
	Raw Waste Characterization (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)
Thorium (Total)	NA	ND	0.004
Uranium (Total)	NA	0.002	0.001

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample. For some vitrification samples, the dilution factor was less than 1. In these cases, a dilution factor of 1 was used.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

TABLE C.3-49

CLEARWELL SOLIDIFICATION TCLP METALS DILUTION ADJUSTED CONCENTRATION[a]

	Raw Waste Characterization[b] (mg/l)	Formula 1 (mg/l)	Formula 2 (mg/l)	TC REG LIMITS (mg/l)
Antimony	0.101	ND	ND	
Arsenic	ND	ND	ND	5.000
Barium	2.001	2.640	4.360	100.000
Beryllium	ND	ND	ND	
Cadmium	0.010	ND	ND	1.000
Chromium	0.010	ND	0.020	5.000
Cobalt	0.100	ND	ND	
Copper	0.822	0.687	0.570	
Cyanide	ND	ND	ND	
Lead	0.123	ND	0.010	5.000
Manganese	66.9900	ND	ND	
Mercury	ND	ND	ND	0.200
Molybdenum	0.037	0.273	0.160	
Nickel	0.886	0.081	0.110	
Selenium	ND	0.005	ND	1.000
Silver	0.049	ND	ND	5.000
Thallium	ND	ND	ND	
Vanadium	0.040	0.024	ND	
Zinc	0.609	0.039	0.070	

[a] Dilution Adjusted Concentration - The results for treatability samples were multiplied by a dilution factor, defined as the weight of a treated sample divided by the weight of the raw waste that went into the treated sample.

[b] TCLP results on similar raw waste samples provided for relative comparison purposes only. Results are from samples taken from the same borehole and same zone as treatability samples but are not identical.

Table C.3-50
Summary of CRUDD Results

Pit	Mix	Total Weight Loss in %		Final Visual Observations	
		Wet/Dry	Freeze/Thaw		
1	1-BFS	0.02%	0.00%	Pinhole cracking and crazing	Pinhole cracking and slight cracking
	1-FA	-0.06%	0.04%	Pinhole cracking and slight crazing	Pinhole cracking and slight crazing
2	2-BFS	0.04%	0.07%	Surface cracking and 20 air voids	Slight cracking and 30 air voids
	2-FA	0.07%	0.22%	Pinhole cracking, slight crazing and slight cracking	Pinhole cracks, crazing and about 30 air voids
3	3-BFS	0.09%	24.24%	Crazing, pinhole cracking, and slight cracking	1407: hunks fell off, other ready to do same
	3-FA	-0.13%	0.24%	Crazing, pinhole cracking, and slight cracking	Pinhole cracking and slight crazing
5	5-BFS	1.05%	0.22%	Pinhole cracking and slight crazing	Pinhole cracking 1" crack near end on one and slight crazing
	5-FA	0.38%	15.73%	Pinhole cracking, crazing on ends and about 15 air voids	Pinhole cracking and slight crazing, except 2009 split in half
6	6-BFS	0.04%	30.27%	Pinhole cracking and crazing	Specimens practically disintegrated
	6-FA	-0.08%	0.27%	Pinhole cracking, crazing and surface cracking	Pinhole cracking, few air voids and surface flaking
Clearwell	CW-1	-0.44%	4.50%	3-3/8" cracks, pinhole cracks and few air voids	Pinhole cracking, 3-1/4" cracks, slight cracking and obvious surface flaking
	CW-BFS	0.01%	-0.08%	Pinhole cracks, few air voids and 3-1/4" cracks	Pinhole cracking, 2-1/4" cracks, slight cracking and surface flaking
Burn Pit	BP-BFS	0.01%	-0.01%	Pinhole cracking and surface cracking	Pinhole cracking and cracking
	BP-FA	0.01%	-0.04%	Pinhole cracking, few air voids and slight crazing	Pinhole cracking, 1/4" crack, few air voids and slight crazing
3 (dup.)	3-BFS	-0.04%	0.04%	Crazing and pinhole cracking	Few air voids and slight cracking
6 (dup.)	6-BFS	0.07%	1.39%	Crazing and pinhole cracking	Pinhole cracking and cracking

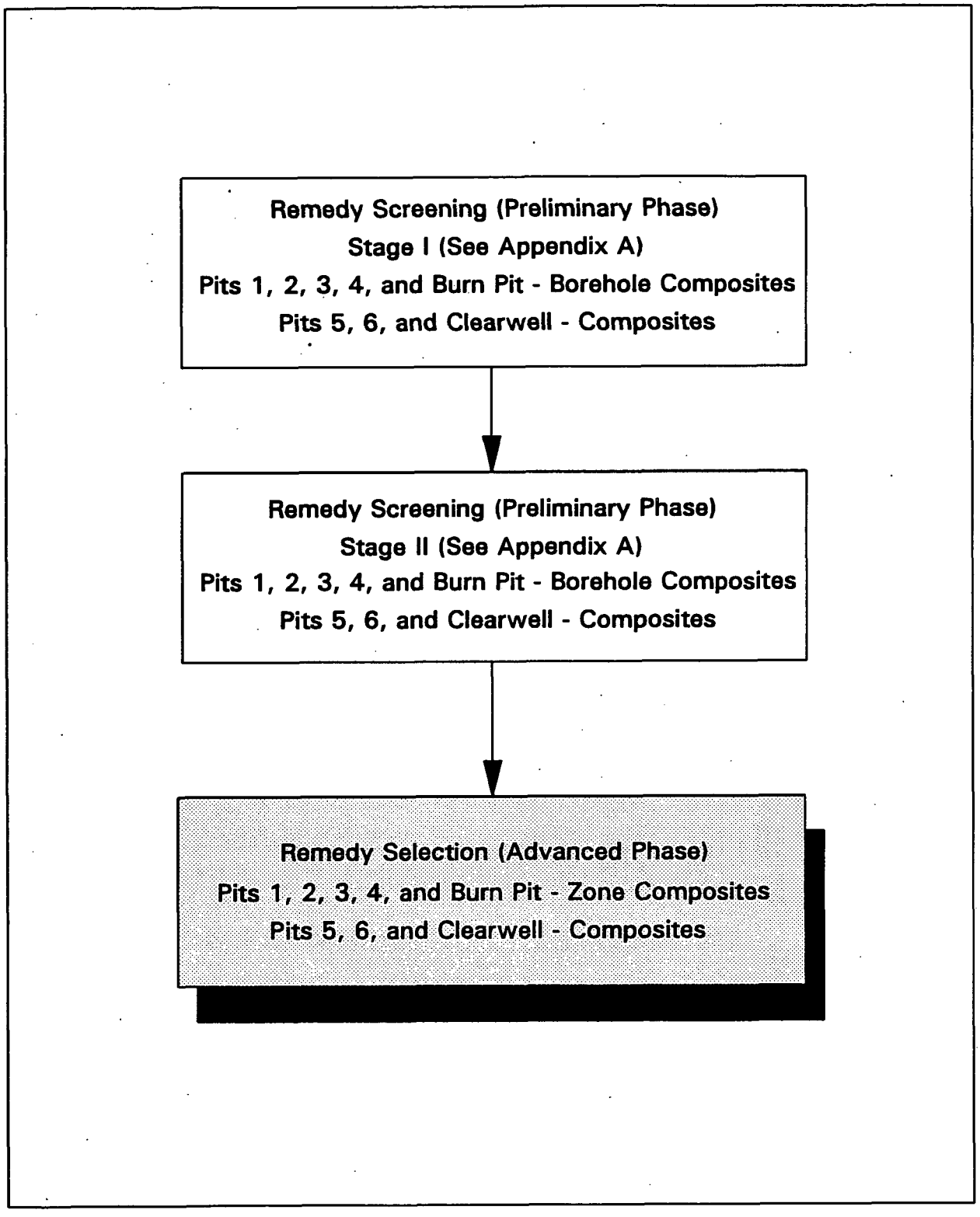

FIGURE C.3-1 STABILIZATION OF UNTREATED MATERIAL

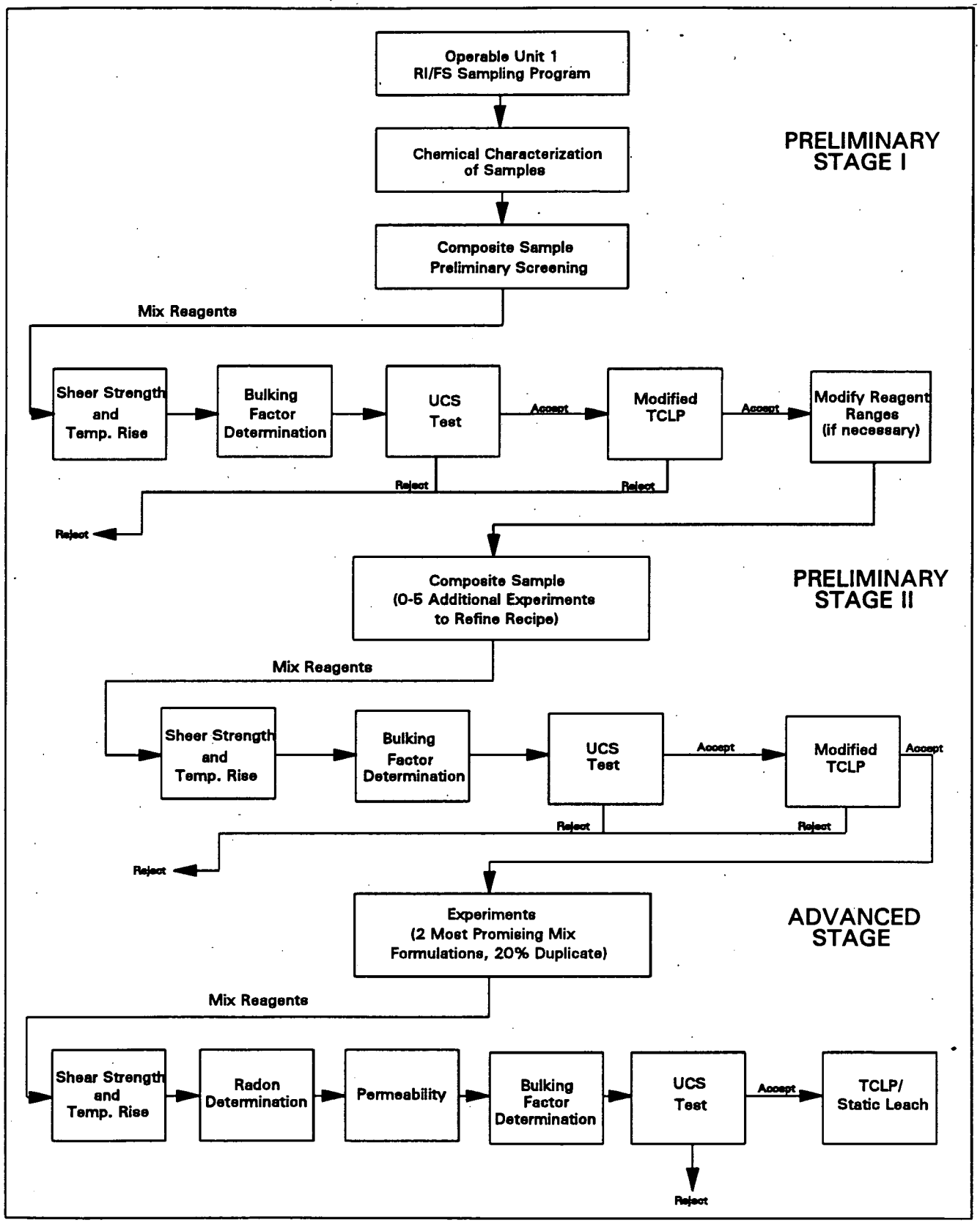

FIGURE C.3-2 CEMENT STABILIZATION LABORATORY SCREENING FLOWCHART

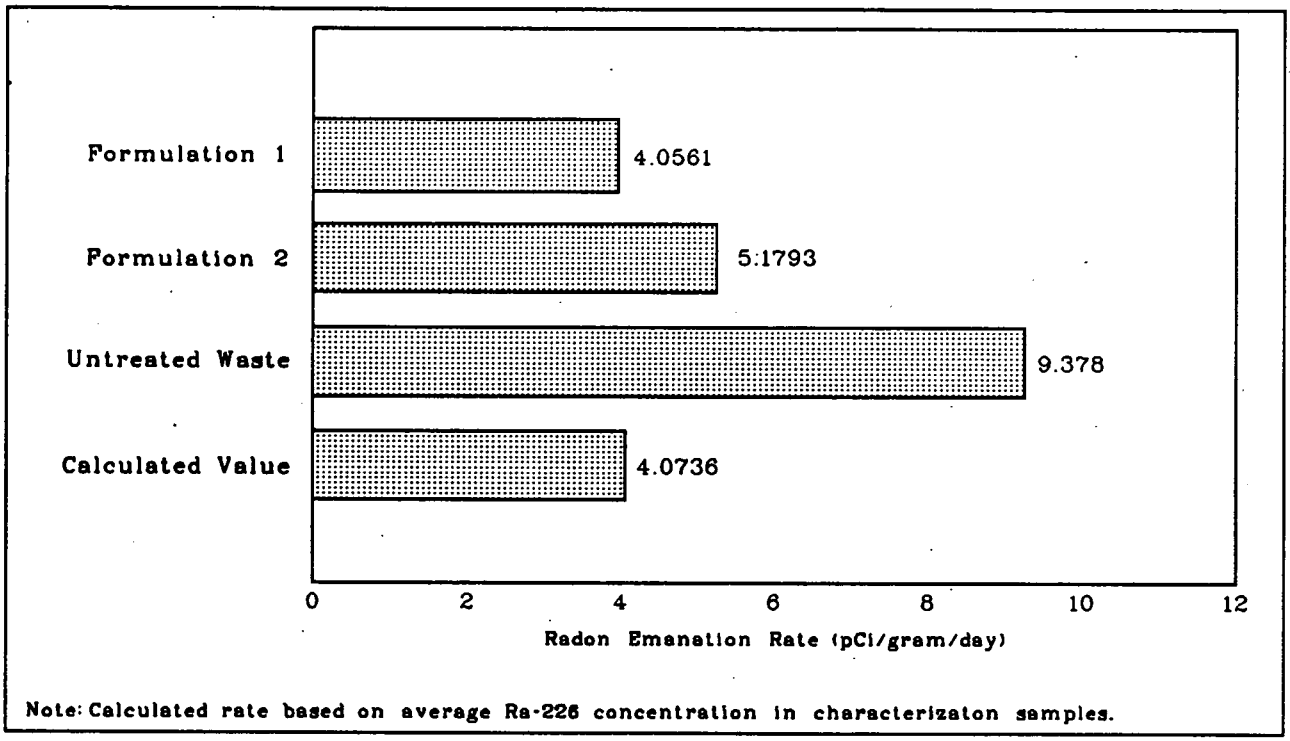

FIGURE C.3-3. WASTE PIT 1 STABILIZATION: COMPARISON OF DILUTION-ADJUSTED RADON EMANATION RATES

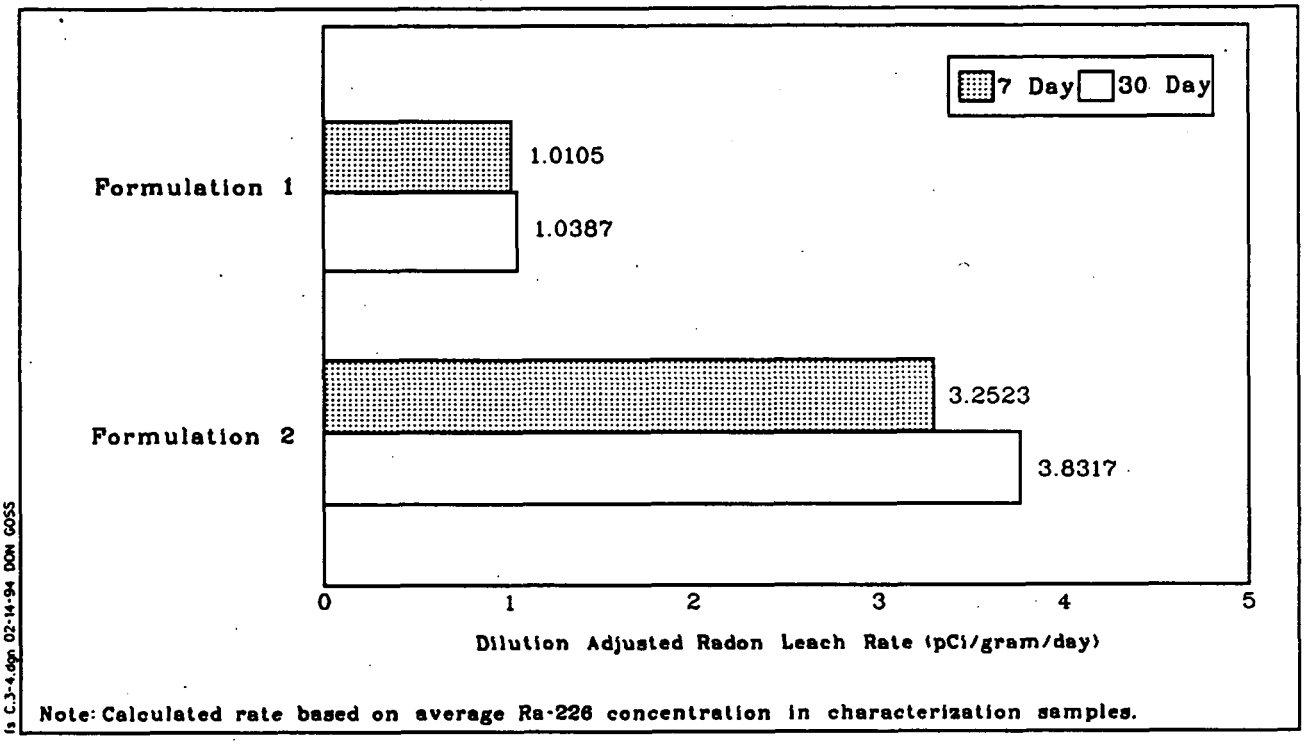

FIGURE C.3-4. WASTE PIT 1 STABILIZATION: COMPARISON OF DILUTION-ADJUSTED RADON LEACH RATES

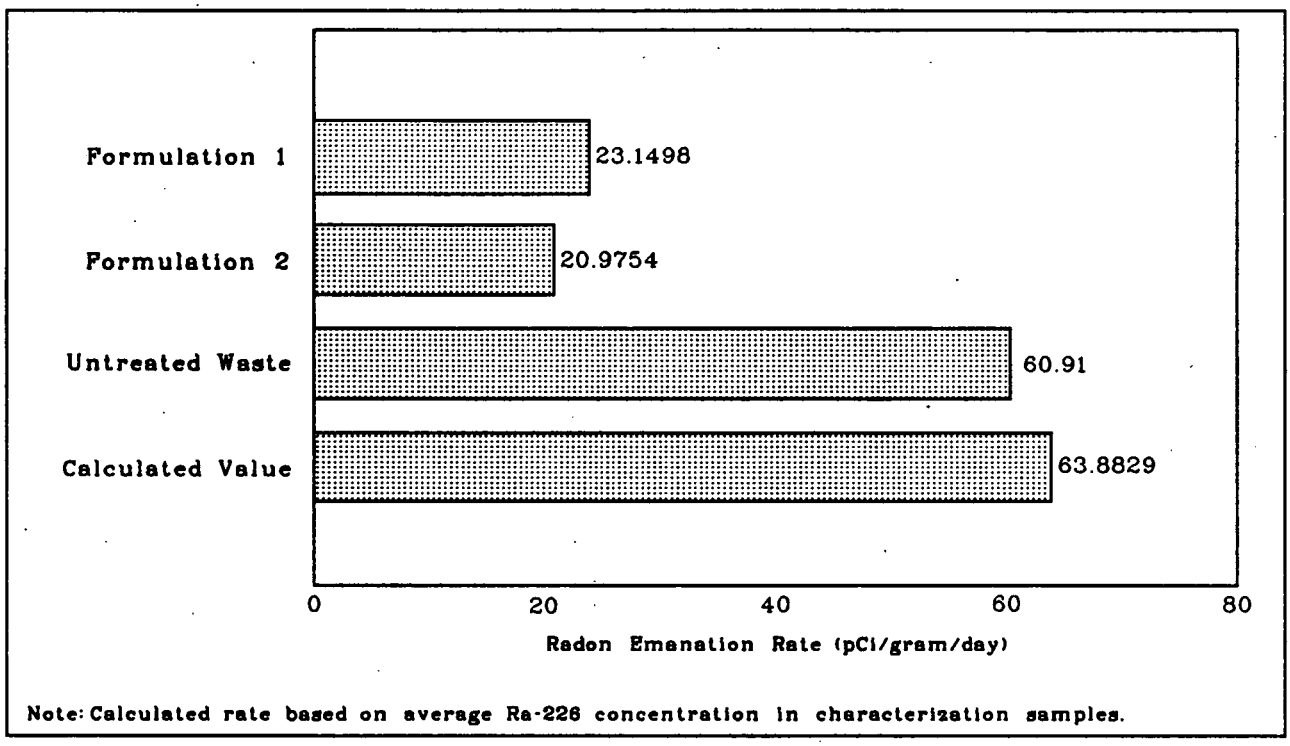

FIGURE C.3-5. WASTE PIT 2 STABILIZATION: COMPARISON OF DILUTION-ADJUSTED RADON EMANATION RATES

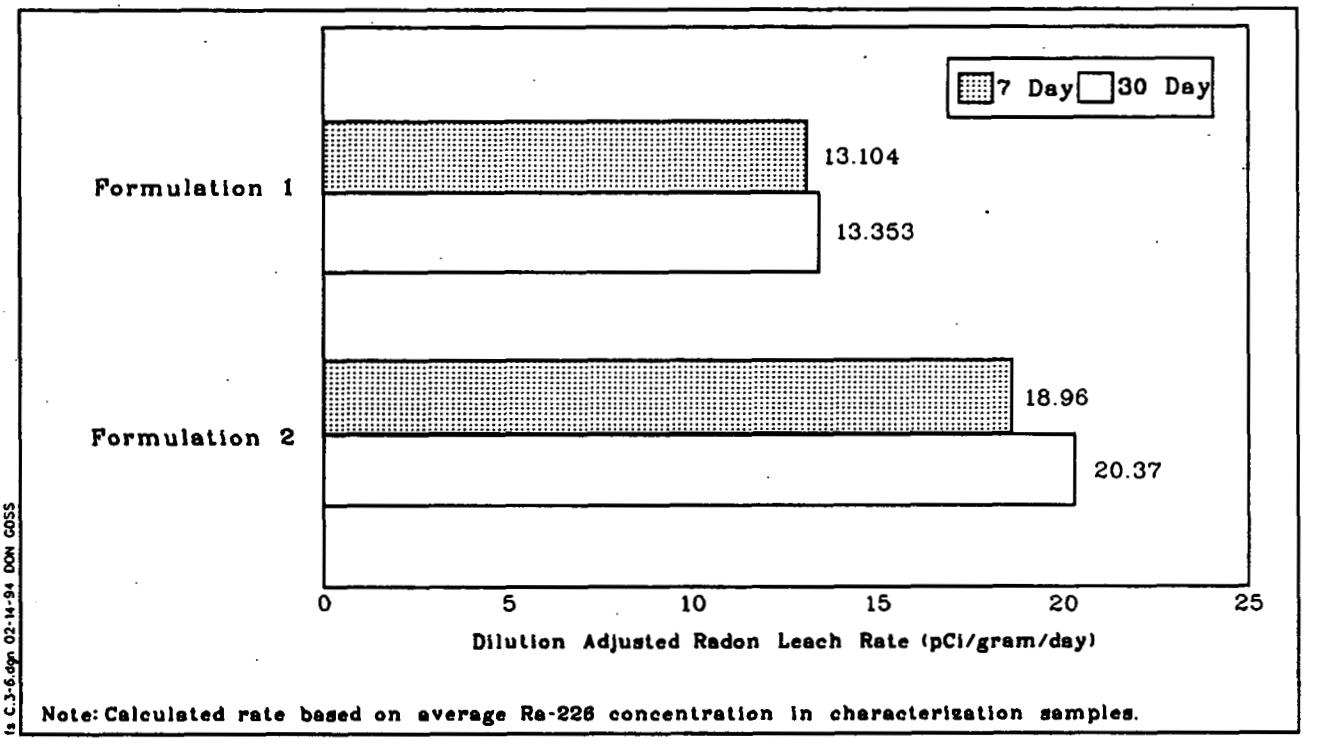

FIGURE C.3-6. WASTE PIT 2 STABILIZATION: COMPARISON OF DILUTION-ADJUSTED RADON LEACH RATES

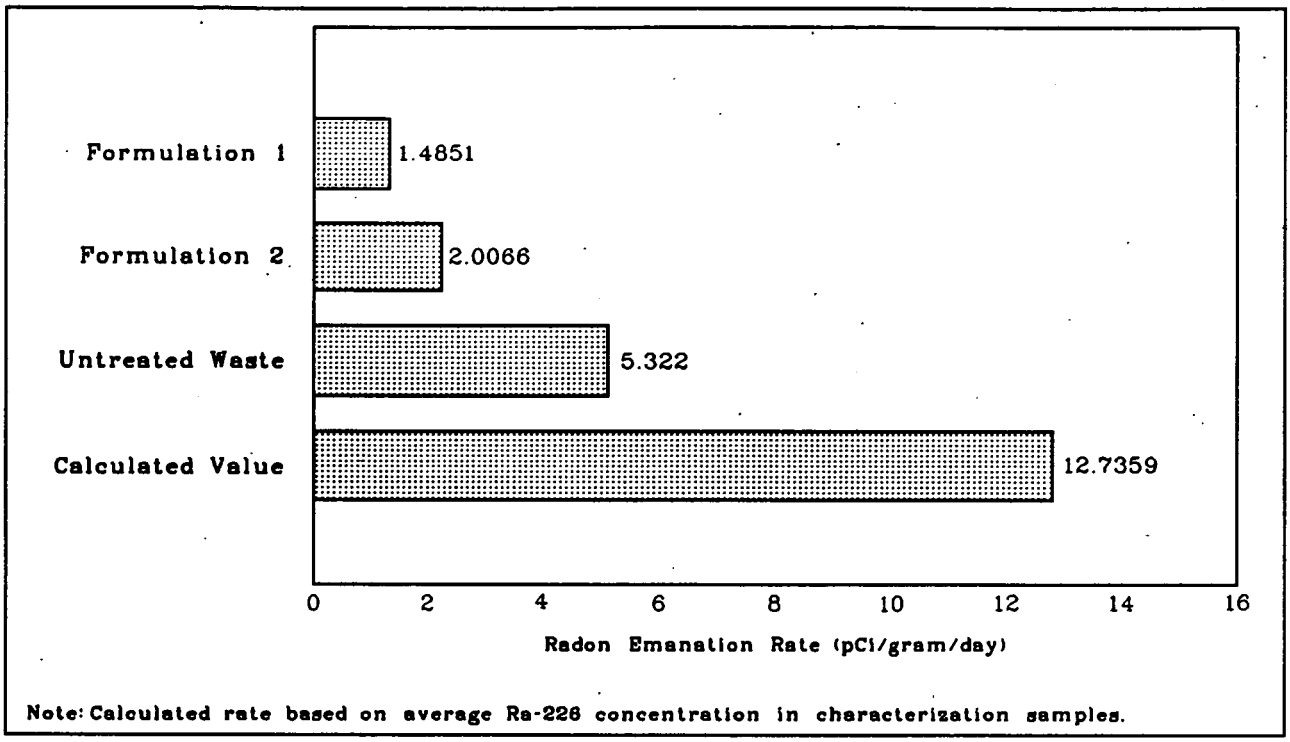

FIGURE C.3-7. WASTE PIT 3 STABILIZATION: COMPARISON OF DILUTION-ADJUSTED RADON EMANATION RATES

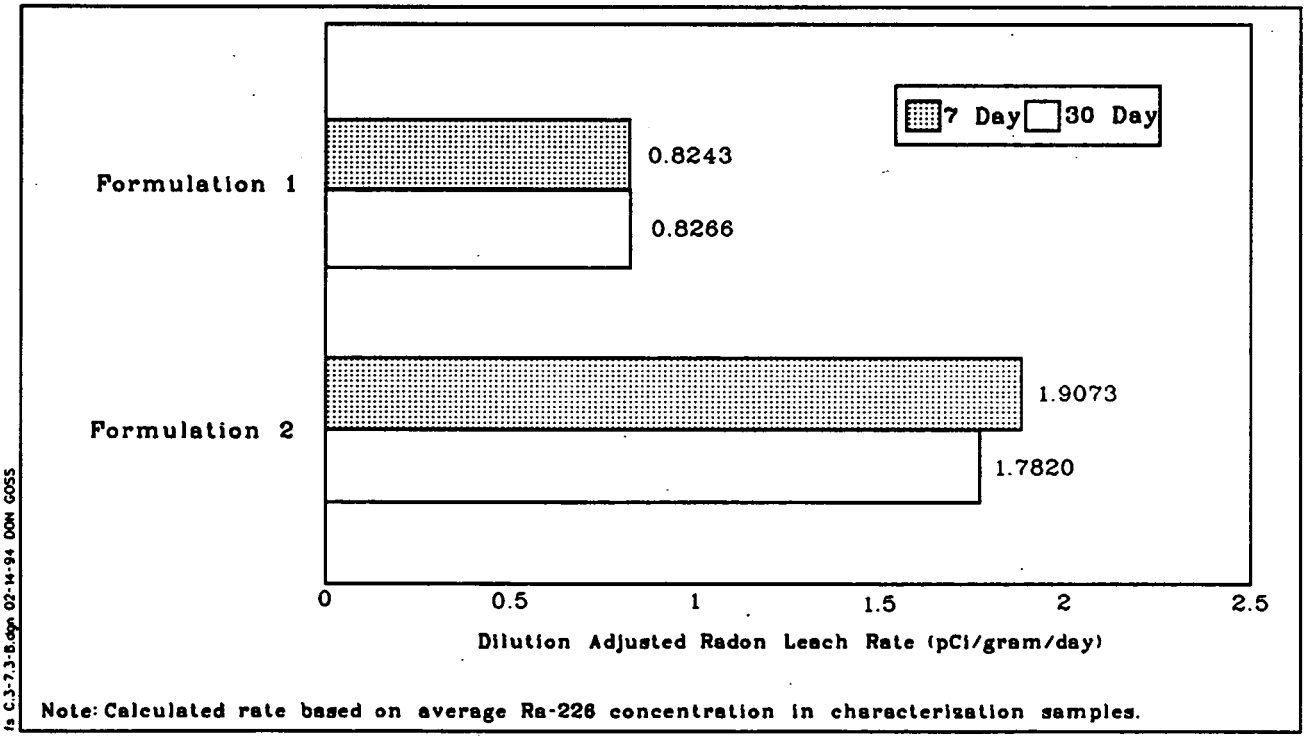

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FIGURE C.3-8. WASTE PIT 3 STABILIZATION: COMPARISON OF DILUTION-ADJUSTED RADON LEACH RATES

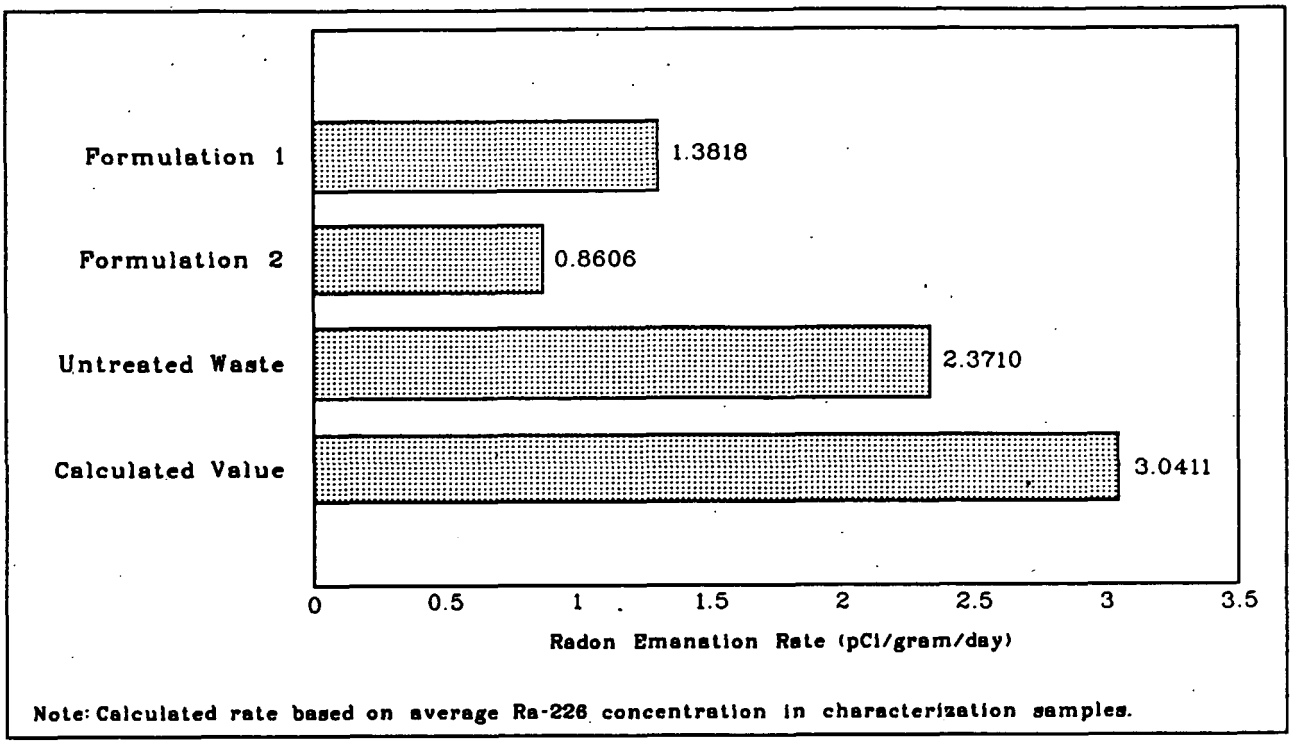

FIGURE C.3-9. WASTE PIT 4 STABILIZATION: COMPARISON OF DILUTION-ADJUSTED RADON EMANATION RATES

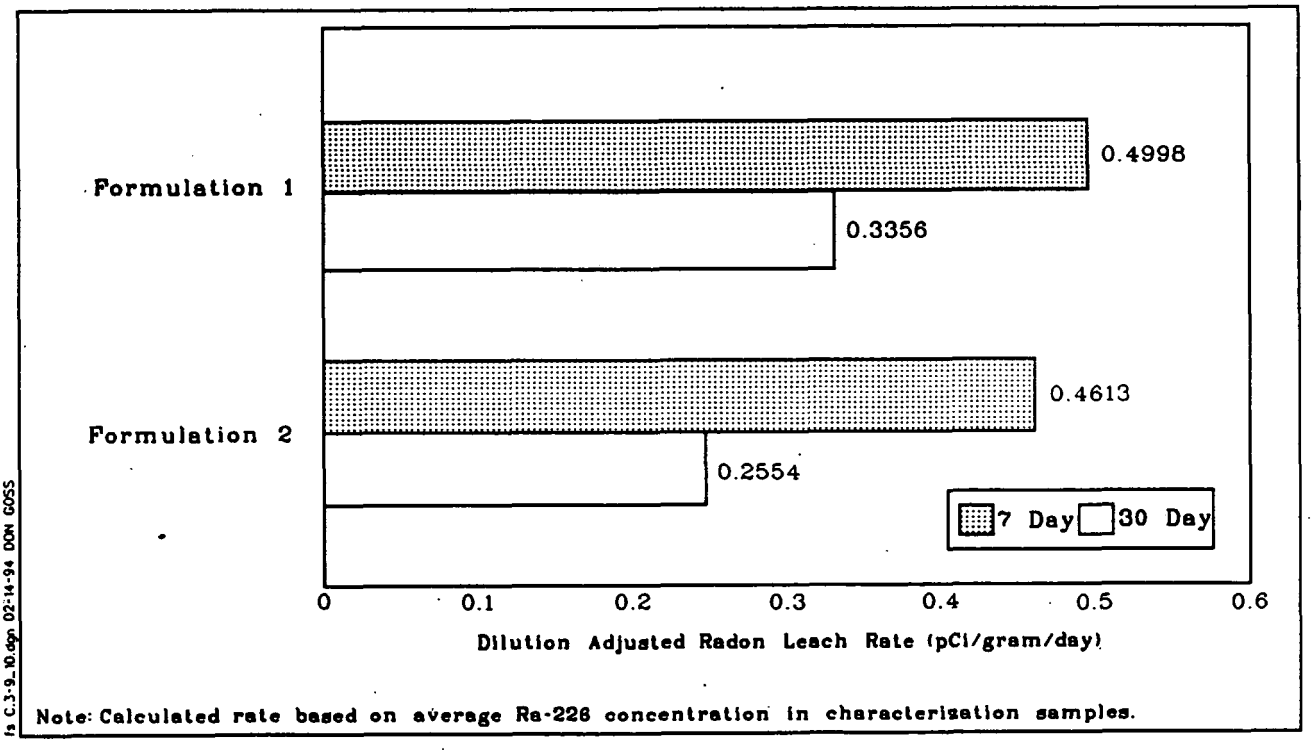

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FIGURE C.3-10. WASTE PIT 4 STABILIZATION: COMPARISON OF DILUTION-ADJUSTED RADON LEACH RATES

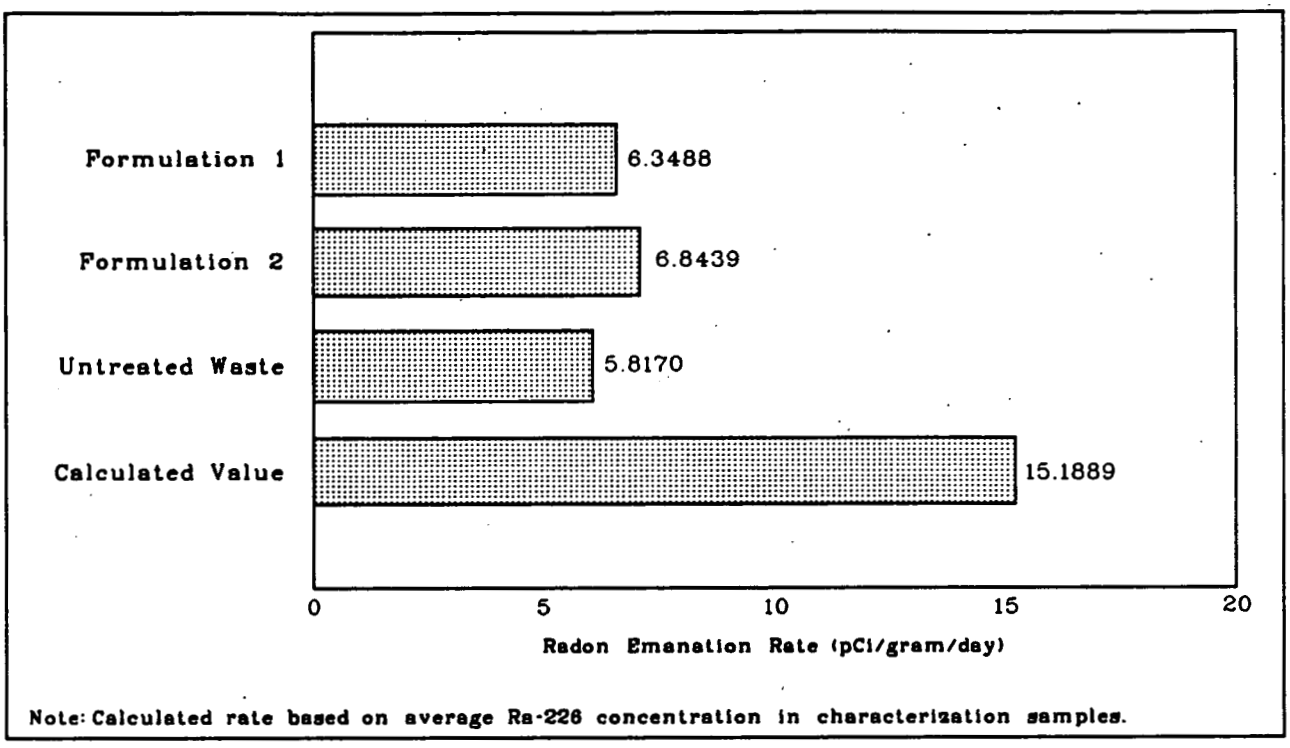

FIGURE C.3-11. WASTE PIT 5 STABILIZATION: COMPARISON OF DILUTION-ADJUSTED RADON EMANATION RATES

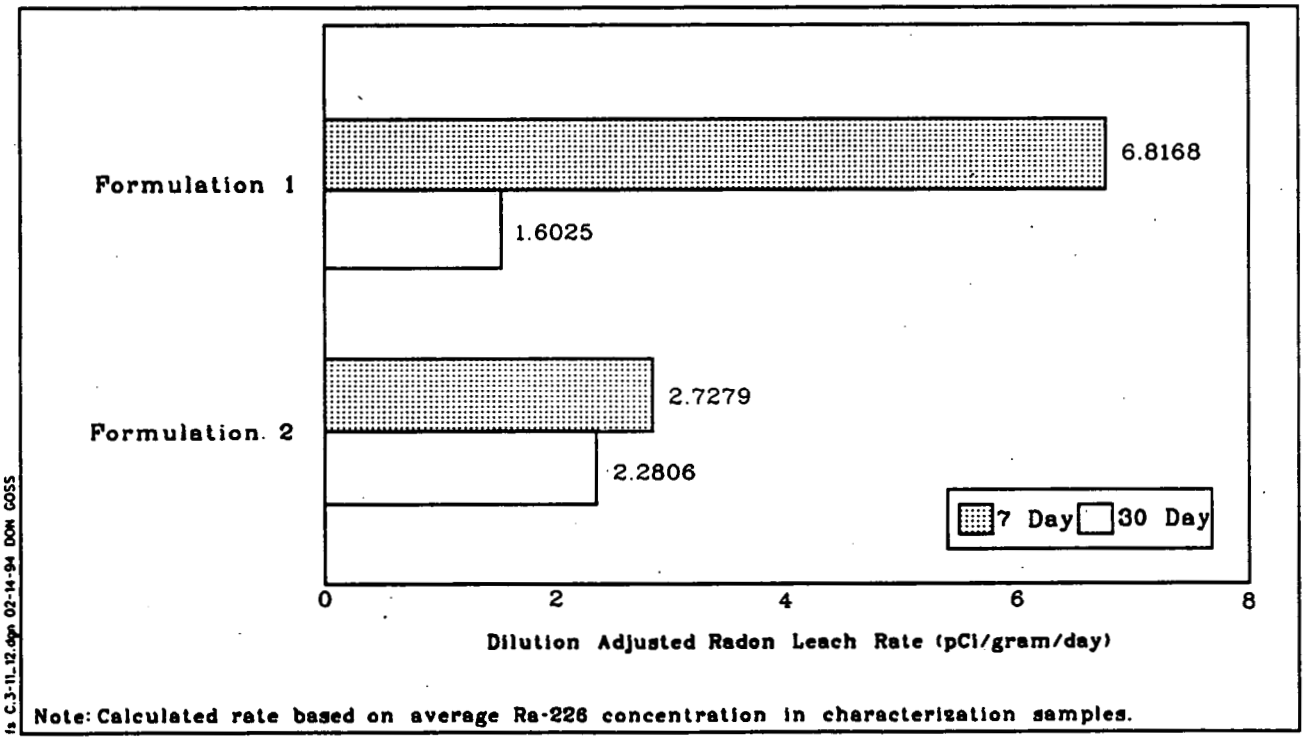

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FIGURE C.3-12. WASTE PIT 5 STABILIZATION: COMPARISON OF DILUTION-ADJUSTED RADON LEACH RATES

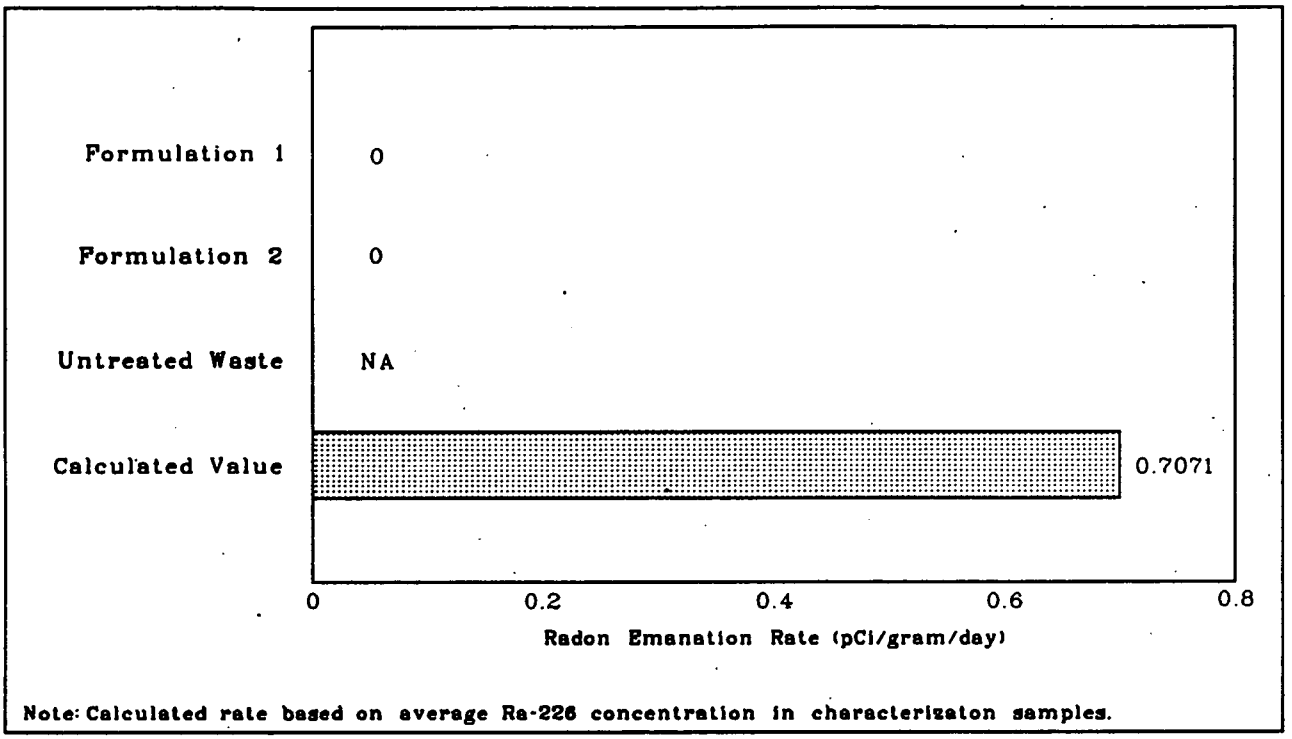

FIGURE C.3-13. WASTE PIT 6 STABILIZATION: COMPARISON OF DILUTION-ADJUSTED RADON EMANATION RATES

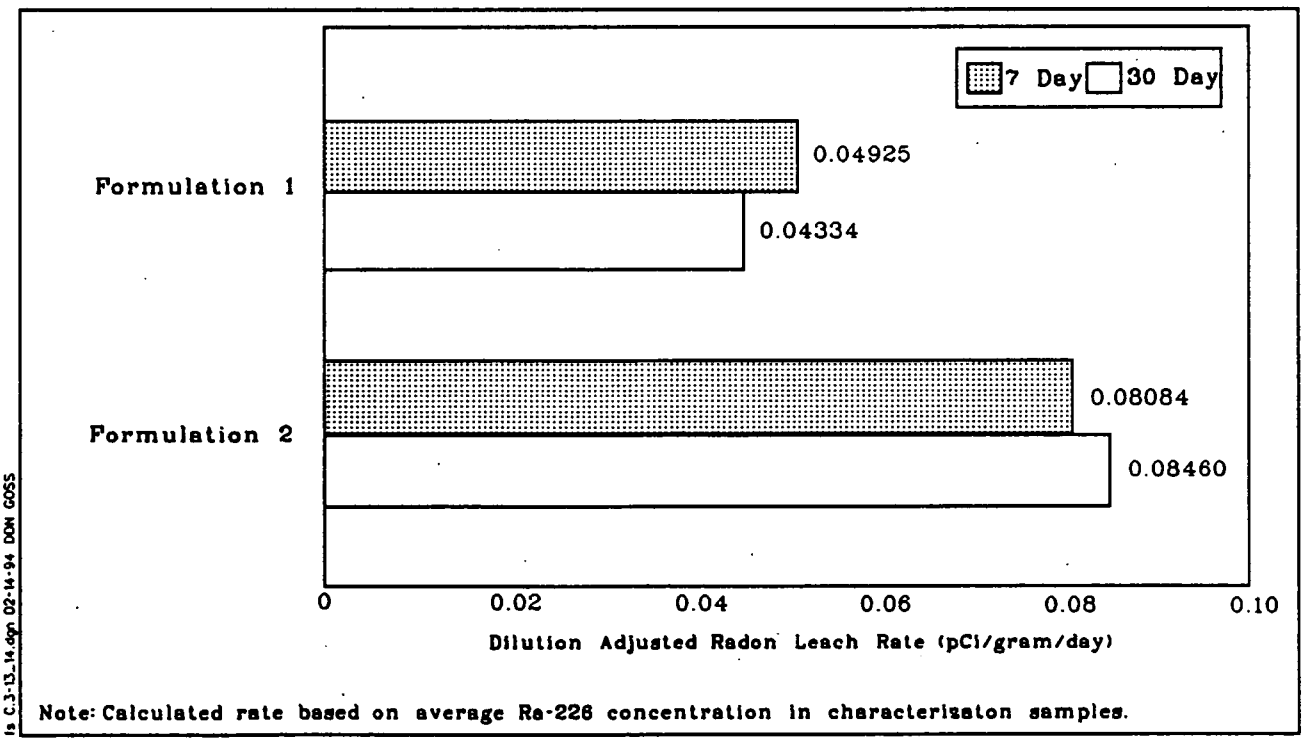

FIGURE C.3-14. WASTE PIT 6 STABILIZATION: COMPARISON OF DILUTION-ADJUSTED RADON LEACH RATES

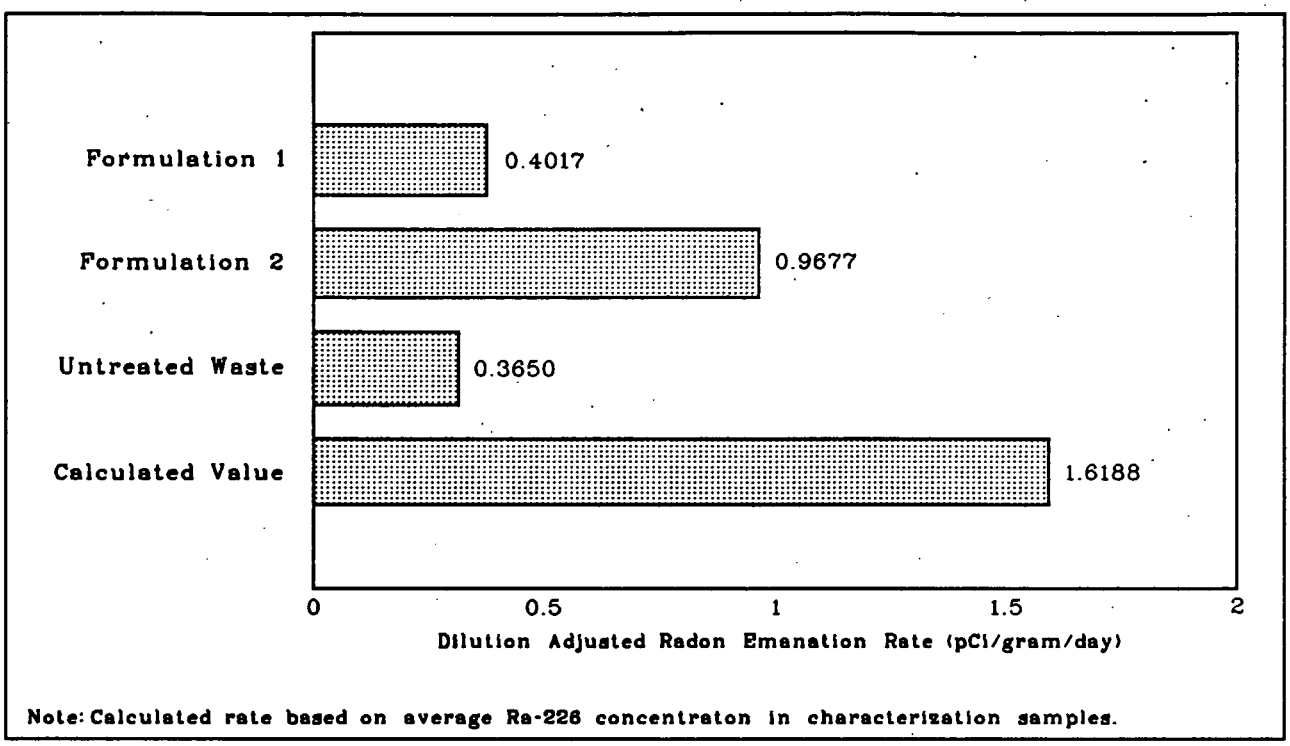

FIGURE C.3-15. BURN PIT STABILIZATION: COMPARISON OF DILUTION-ADJUSTED RADON EMANATION RATES

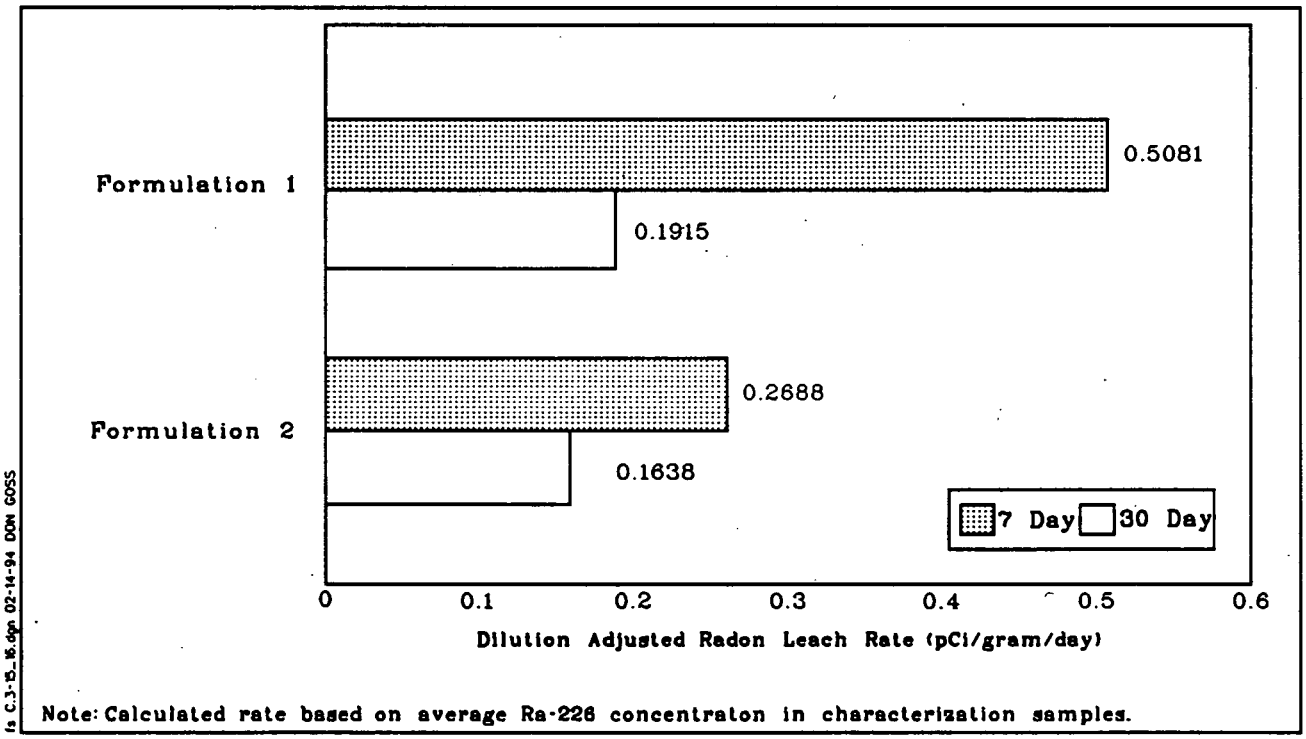

FIGURE C.3-16. BURN PIT STABILIZATION: COMPARISON OF DILUTION-ADJUSTED RADON LEACH RATES

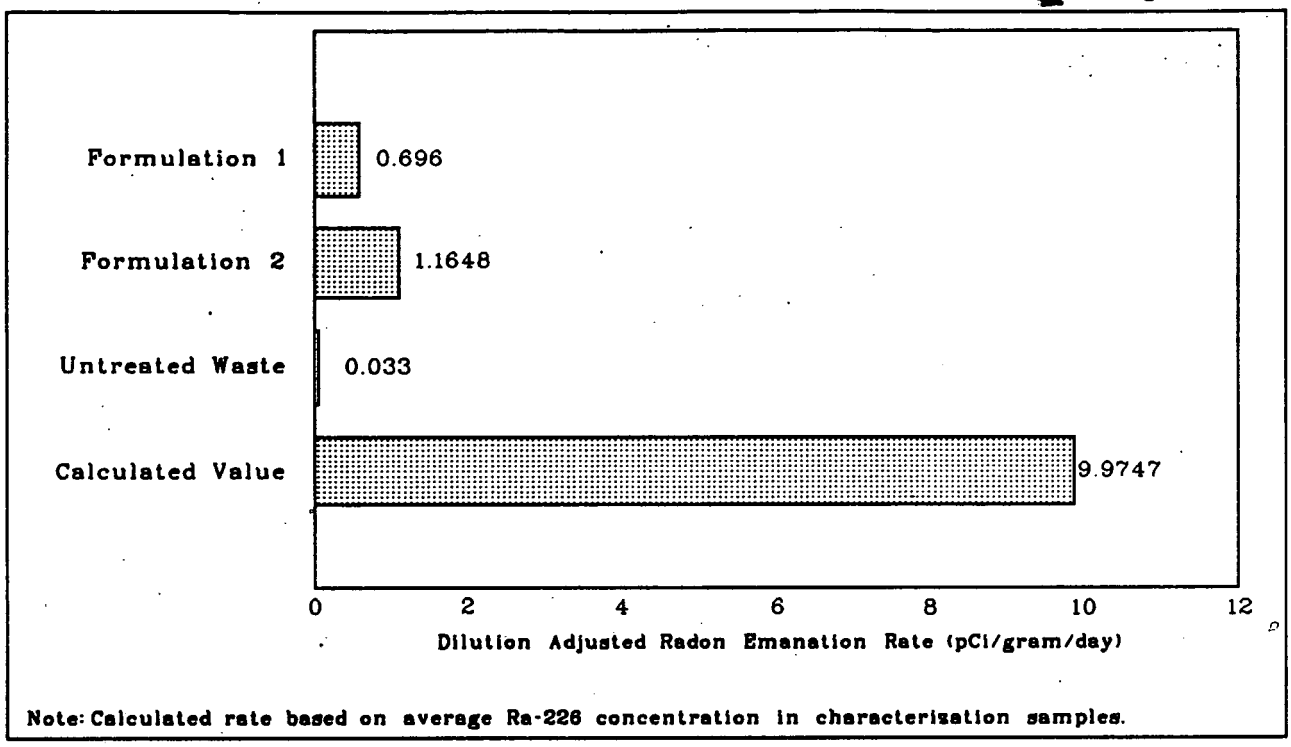

FIGURE C.3-17. CLEARWELL STABILIZATION: COMPARISON OF DILUTION-ADJUSTED RADON EMANATION RATES

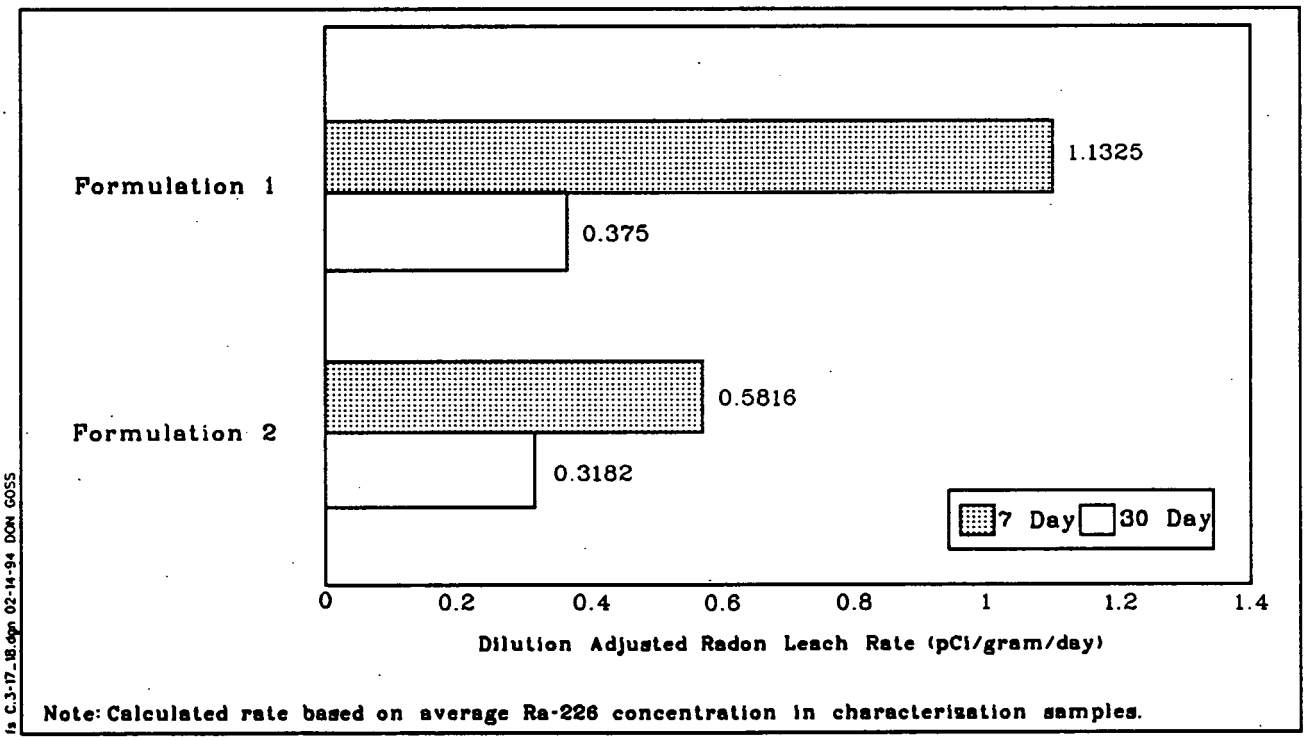

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FIGURE C.3-18. CLEARWELL STABILIZATION: COMPARISON OF DILUTION-ADJUSTED RADON LEACH RATES

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APPENDIX C

SECTION 4
THERMAL TREATMENT AND PARTICLE AGGLOMERATION

C.4.0 THERMAL TREATMENT AND PARTICLE AGGLOMERATION

C.4.1 INTRODUCTION

Thermal treatment and particle agglomeration studies are being carried out in support of the Operable Unit 1 RI/FS process currently underway at the FEMP. All treatability work is being performed based on work plans prepared in accordance with the EPA's "Guide for Conducting Treatability Studies Under CERCLA," Interim Final (EPA 1988) and Final (EPA 1992). Additional detail on the study may be found in the referenced work plan and the Treatability Study Report for Operable Unit 1, Final (DOE 1993).

C.4.2 TREATABILITY TEST METHODOLOGY

Initial Operable Unit 1 Treatability studies were designed to support evaluation of on-property disposal. When FERMCO became the Environmental Restoration Management Contractor (ERMC) for the site, a reassessment of the Leading Remedial Alternative for Operable Unit 1 determined off-site disposal was a potentially viable option for Operable Unit 1 wastes. This necessitated a reassessment of treatability options late in 1992. This reassessment required additional treatability studies to evaluate more cost effective treatment methods aimed at creating a potentially bulk shippable waste form capable of meeting waste acceptance criteria at off-site disposal sites.

Thermal treatment and particle agglomeration studies are being performed under the CRU1 Cooperative Remedy Screening Program (CRSP) Work Plan, University of Cincinnati, November 1993.

The primary goal of the study was to dry the waste to reduce moisture content and volume, agglomerate or solidify the waste to reduce dust, and package the waste for shipment without the need for containers.

Prior to evaluation of the stabilization methods to be screened by this program, the wastes were classified using a variety of physical and chemical characterization methods. A qualitative evaluation

of several stabilization methods was and is being performed. The following list identifies the range of screening possibilities within these treatment areas.

Thermal Processing

- Mechanical Dewatering (precedes drying to increase efficiency)
- Drying only (to various moisture contents)
- Drying followed by calcining
- Drying followed by calcining, and then clinkering
- Formation of a Portland cement derived from the pit waste

Particle Agglomeration

- Non-Thermal Processing - Low Strength Cement

  Phase I: Addition of purchased Portland cement or other pozzolan binder to form a low strength, soil-like matrix

  Addition of Portland cement or other binder to pit waste which has been dried

  Addition of Portland cement or other binder to pit waste which has been dried and calcined

  Addition of Portland cement or other binder to pit waste which has been dried, calcined, clinkered, and ground

  Phase II: Addition of a Portland cement (derived from the pit waste) to form a low strength soil-like matrix

  Addition of waste-derived Portland cement to raw pit waste which has been dried

  Addition of waste derived Portland cement to raw pit waste which has been dried and calcined

  Addition of waste derived Portland cement to raw waste which has been dried, calcined,clinkered, and ground

  Polymer Encapsulation, Pelletizing (using water or other binders), Briquetting, etc.

C.4.2.1 Thermal Processing

Thermal analyses of the waste will be performed using thermogravimetric analysis or similar thermal analysis method. These thermograms provide temperature/phase change data as well as compositional information. Based on the data generated, waste specific processing temperatures for drying,

calcining and clinkering will be selected. Based on the analysis, it is anticipated the temperatures required will be close to those for typical cement kiln feed. Ultimately, the wastes will be thermally treated in a laboratory scale tube furnace or rotary tube kiln. Residence times and feed rates will be estimated from the data generated for determining the processing temperatures.

C.4.2.2 Non-Thermal Processing

Two phases of non-thermal processing will be performed. The first phase involves the addition of Portland cement or other pozzolan binder to material produced by thermal processing. The second phase will utilize a Portland cement derived from the pit waste which will be added to each of the materials produced by thermal processing. In both phases, the waste material produced will consist of low-strength, soil-like material.

C.4.2.2.1 Phase I - Addition of Portland Cement or Other Pozzolan Binder

In Phase I, Portland cement (or other pozzolan binders) will be added to the waste material produced by thermal processing. Various binder amounts will be added separately to the dewatered, dried, calcined, clinkered, and ground clinkered waste materials. A maximum of three waste/binder ratios, utilizing three binders, will be studied for each waste material produced by thermal processing. Additionally, a maximum of three water/binder ratios will be studied.

C.4.2.2.2 Phase II - Addition of a Waste-Derived Portland Cement

Waste material processed (clinkered) at the upper end of the thermal treatment spectrum will be utilized in the Phase II. Clinkered material will be ground to form a low efficiency Portland cement. This waste-derived Portland cement will be added separately to each waste material produced by thermal processing to form a stable low-strength material. A maximum of three waste/binder and three water/binder ratios will be used. Small quantities of commercial binders may be utilized in this phase.

C.4.2.3 Polymer Encapsulation

Polyethylene will initially be used to assess polymer encapsulation. Polymer encapsulation involves adding dried wastes and polyethylene feed material into a heated mixing apparatus, then allowing the

mixed material to cool, producing a dimensionally stable waste form. An advantage of polymer encapsulation is that the encapsulating polyethylene material does not interact chemically with the dried waste. As heated, polymer encapsulation is an extremely viscous material. Particle size, density, and dryness of the waste appear to be the primary factors in successful encapsulation. A chemically inert surrogate material was created for use in the polymer encapsulation evaluation performed at various off-site vendor facilities. The properties were based upon particle size, density, and soil type analyses performed in the initial baseline characterization of the archived Operable Unit 1 wastes.

C.4.3 TEST OBJECTIVES AND DATA REQUIREMENTS

Data resulting from the study will be used to establish or identify the following:

- Technical applicability of treatment options
- Process data for support of bench and pilot scale design
- Compliance of technology with applicable or relevant and appropriate requirements (ARARs)
- Initial database for use in subsequent bench- and pilot-scale studies used in support of remedial design

Data generated includes:

- Physical and Chemical Product Characterization Data
- Product Characterization Data (such as leachate analysis)

The acquired data are intended to provide a qualitative assessment of the technical applicability of the treatment methods and technologies as applied to each waste pit.

C.4.4 DATA ANALYSIS AND INTERPRETATION

C.4.4.1 Analysis of Waste Stream Characteristics

This section discusses the waste stream characteristics and how these characteristics may impact thermal treatment and particle agglomeration. The waste pit contents vary greatly among and within each pit. The heterogeneity of the waste streams is a major factor in analyzing the applicability of a treatment technology for all or part of the waste pit material. The heterogeneity not only makes the

material difficult to characterize adequately, but also provides a significant challenge in identifying treatment processes which will be effective for all or most of the material types.

Characteristics of the waste pits which may affect thermal processing may vary considerably depending upon the type of equipment used and the drying temperature. For rotary drying at low temperatures, variations in waste contents will have little effect. The calcium content will likely be a processing factor at higher temperatures. The pH of the final waste material will have a significant impact on the leachability of the metals and radionuclides. The presence of fluoride will also be a factor at higher temperatures and may produce hydrogen fluoride gas, which is extremely corrosive. The organics present in the waste pits should not be a significant factor. At higher temperatures, they would need to be treated in the off-gas stream. Depending upon the type of thermal processing unit and its feed size requirement, the debris may or may not pose a problem.

C.4.4.2 Analysis of Treatability Study Data

Only preliminary results on soil classification of the waste pit materials and surrogate studies of particle agglomeration are included in this report. Data on baseline drying studies will be included in an addendum to this report to be issued in Spring 1994. Sufficient site historical experience drying process residues over the 40 years of plant operations, and extensive use of the various drying technologies throughout the industry, show that this treatment alternative is feasible and implementable for the FEMP pit wastes.

C.4.4.3 Thermal Treatment

Thermal treatment studies underway include physical characterization of each waste pit material and baseline crucible studies. The physical characterization is the first step in the thermal processing treatability study. Although numerical results have not yet been produced, many differences in the raw, the dried, and the heat treated wastes and soil became apparent as the testing proceeded. These differences are summarized in Table C.4-1. Moisture content in Table C.4-1 is defined as the weight of water/weight of dry solids x 100 percent.

Portions of the dried and the heat treated samples were set aside for further analysis. These analyses include TCLP on the raw, the dried, and the heat treated samples.

Physical characterization testing includes visual classification, natural moisture content, grain size distribution, Atterberg limits, hydrometer analysis, specific gravity, shrinkage factors, soil moisture-density relationships, unconfined compressive strength, direct shear, and possibly other tests. The purpose of physical characterization is to classify the pit wastes as to their expected engineering behavior under different moisture and stress environments as well as disposal environments. Engineering properties have been found to correlate well with the index and classification properties of a given soil deposit.

Waste pit materials were visually classified using the classifications in Table C.4-2. This table was developed by a University of Cincinnati geotechnical engineering professor as an outgrowth of ASTM D2488-90. The table does not cover all possible outcomes, but is meant to serve as a simple means to visually classify most soils in the laboratory or in the field. Results of the 55 visual classification tests performed are summarized as in Table C.4-1.

A summary of the laboratory data generated to date appears in Table C.4-3. It should be noted the visual classification summaries may need to be modified as further Atterberg limit determinations are made. Many samples are borderline in the USCS classification system, meaning they either have liquid limits near 50 percent which divides low from high plasticity, or their liquid limit plasticity index combination plots near the A-line which separates silts from clays on the plasticity chart.

Very little actual data are currently available. Based on the work completed to date, the pit wastes appear to be predominantly fine-grained (silts and clays) in nature. Only four of the 55 samples can be classified as sands. The gravel content found in the one-gallon cans is practically negligible. Waste Pits 3, 5 and 6 have relatively high water contents (107 to 620 percent). Most of the samples have been found to air-dry quickly. Extreme shrinkage has been observed with a number of samples, particularly those from Waste Pits 5 and 6. The pit wastes are amenable to standard ASTM soil classification testing.

C.4.4.4 Particle Agglomeration

Technical investigations into drying (thermal treatment) indicate the technology is a feasible alternative for treatment of the pit wastes. However, the end product of this type of treatment can be a fine, dusty material. The main purpose of this technology is to reduce dusting problems during handling for load-out, on-site storage, transportation, and off-site storage. Particle agglomeration is one method of eliminating dusting. The two types of particle agglomeration tested, using a surrogate soil, includes pelletizing and polymer encapsulation. The soils were made to resemble the particle size distribution of the wastes in Waste Pits 5 and 6.

C.4.4.4.1 Pelletizing

Agglomeration technology is a process of size enlargement or upgrading of otherwise finer particles. The forms of product, depending on the reason for agglomeration, can be spheres, pellets, irregular extrusions, or merely loosely bound aggregates or clusters.

Tests were performed at a vendor test facility using a disc pelletizer. Initial tests used water as the binder to create pellets from the surrogate waste. These tests were not successful in creating durable pellets. The pellets disintegrated upon discharge from the pelletizer. A water-based polymer was then tried as a binder to create pellets in three different size ranges. This polymer was diluted 50 percent with water to improve spraying properties. The smallest pellets created resembled coffee grounds. The next larger size resembled aquarium gravel, and the largest size were pellets about 2.0 to 2.5 centimeters in diameter. All three pellet forms virtually eliminated dusting. The smaller pellets or granules appeared to yield the best packing ratio. The composition of the waste material, with the exception of large, physically unsuitable material, appeared to have little effect on the agglomeration.

C.4.4.4.2 Polymer Encapsulation

Visits to three manufactures were scheduled to investigate equipment for polyethylene encapsulation and agglomeration. The purposes of these visits was to observe the use of the equipment with a surrogate waste matching the particle size characteristics of Operable Unit 1 pit waste. The surrogate waste had a moisture content of 6-8 percent. The three manufacturers visited were Draiswerke Inc.

(Allendale, New Jersey), Teledyne Readco (York, Pennsylvania), and Farrel Corporation (Ansonia, Connecticut).

At Draiswerke, Inc., the GELIMAT® Model G 40S 1-liter lab compounding unit was observed. This model was reported to create the least amount of dust of all of the GELIMAT® models. It is not designed for use with hazardous materials, but can be used with them if modifications are made (such as the addition of a HEPA-filtered exhaust system).

The test runs were made using 250-300 ml batches of surrogate waste and polyethylene beads from Chevron Chemical (PE 1409). A total of 35 batches were run, with waste loadings ranging from 50 percent to 92 percent by weight. The product exited the machine in a pile that was usually pressed into a pancake-like shape and placed in a container of water to cool. A typical batch took about 20 seconds to process. Eleven of the 35 batches were not pressed but were left loose so the size of the agglomerates formed could be seen.

Three of the batches had water added to them (6.5 percent by weight) to observe the effect of moisture on the process. The added water created a significant amount of steam and the pancake formed was generally smoother (less porous) than others in which water had not been added. The Draiswerke representative noted that the material inside the unit was fluxing at approximately 300 °F, well above the boiling point of water. Most of the water will be evaporated inside the compounding chamber and vented from the machine before the material fluxes and will not affect the final product significantly. The final three batches were run without any polyethylene. The highest waste loading achieved was 92 percent. At this waste loading, most of the surrogate waste was bound in the polyethylene and there were no signs of respirable fines on the surface of the final product. Several times during the course of the test runs, the GELIMAT® was purged and a relatively small amount of surrogate that had not been bound to polyethylene was expelled. This is viewed as a minor issue that can be resolved since the surrogate was not released with the polyethylene/waste matrix as respirable fines, but remained inside the unit. Surrogate waste (89 percent) and water (11 percent) were also run in the unit to see what kind of binding could be achieved. Although this resulted in a product not

bound by polyethylene, it did result in much larger waste particles and virtually eliminated any respirable fines.

Lab trials at Teledyne-Readco used the 2-inch continuous processor with a heating cooling jacket. Again, a surrogate waste was used and two different polymers were tested for their ability to encapsulate this surrogate. The surrogate used for these trials was spiked with 1 percent table salt (NaCl) so the leaching potential can be evaluated on the final products. The two polymers tested were polyethylene, PE 1409, and a polyethylene terephtalate (PET). A disk pelletizer was also tested to examine agglomeratization of the waste using a polymer-based binder.

A total of 25 waste loading/polymer combination runs were made using the continuous processor. The surrogate waste and polymers were fed through volumetric feeders into the solids inlet port of the processor. The polymer feed rate was kept constant while the surrogate waste feed rate was varied in order to provide samples of various waste loading. The speed of the machine was varied form 100 rpm to 300 rpm. The jacket temperature was varied from 105°C to 250°C.

The product exited the processor in a viscous state, similar to thick cake batter. It was collected and compressed into cylinders while still warm and moldable. At higher processing temperatures, the product tended to have a smoother surface finish. Using the PE 1409, the highest waste loading rate achieved was 88 percent. Using the PET polymer, a jacket temperature of 260°C was required and the highest waste loading rate was 80 percent. As with the batch mixer, most of the surrogate waste was bound in the polymer and there were no signs of respirable fines on the surface of the final product. One observation made concerning the final products was that the PET product was much more brittle and glossier than the PE product. Although no attempts were made to vary the moisture content of the surrogate, the continuous processor was able to vent the moisture that was present in the surrogate, estimated at about 6 percent. The material was being processed at a rate of about 45 kg/hr (100 lb/hr).

A disk pelletizer was also tested with the surrogate waste at Teledyne-Readco. Using both water and an acrylic binder, the waste was agglomerated into spheres of varying size; the longer the surrogate

was kept in the pelletizer, the larger the agglomerates. Using the acrylic binder and oven drying, the waste was formed into very hard agglomerates with no signs of waste on the surface.

A Banbury® batch mixer model BR1600 was tested at Farrel Corporation to observe how well it encapsulated the surrogate waste (spiked with NaCl) in polymer. The polymers tested with the BR1600 were polyethylene, PE 1409, and ethyl vinyl acetate (EVA). Initial trials determined the optimal batch size was 4.9 lbs. After this determination was made, a total of twelve batches were run using the BR1600.

The product exited the machine as a very thick substance and was collected on a pan. It was then placed, piecewise as it came out, in a cylindrical mold and compacted. Because of the low temperature of the exiting product, the final, molded product was stratified between the piecewise additions of product. After all of the encapsulated material exited the machine, a portion of the dry surrogate itself would exit. The stratified product and this expulsion of dry surrogate indicate the BR1600 was not operated at a sufficiently high temperature to successfully encapsulate the surrogate waste and form a fairly uniform product. A Farrel representative indicated a continuous process would be better for encapsulating the surrogate waste. Using the polyethylene polymer, the highest waste loading achieved was 80 percent. Using the EVA, 90 percent waste loading rate was achieved. These numbers, however, are over-estimates of the true loading rate since not all of the surrogate was encapsulated in the polymer, but was expelled dry. The samples made at Teledyne-Readco and Farrel will be subject to a leach test to obtain a general idea of their leach potentials.

C.4.4.5 Comparison to Test Objectives

The purpose of these studies is to determine whether drying the waste to a certain temperature for a specified period of time will produce a waste product which may be bulk handled and shipped and meet waste acceptance criteria at selected disposal sites. These waste acceptance criteria may include TCLP, moisture content, and free liquid content. Should further treatment be required to mitigate a dusting or handling problem which cannot be mitigated with engineering controls, agglomeration of the dried waste particles may be required. Agglomeration appears capable of creating a waste form which is essentially dust free and durable.

C.4.5 RECOMMENDATIONS AND CONCLUSIONS

C.4.5.1 Thermal Treatment

The potential robustness of a process is perhaps the most important consideration for evaluation of thermal treatment because the waste pit contents are extremely heterogenic in nature. Full characterization prior to excavation is not possible. The treatment process chosen must be robust enough to handle the wide variety of materials to be processed.

Drying may be used as a primary treatment for the waste pit material before shipment to an off-site disposal facility. Drying may also be used as a pretreatment for either vitrification or cement solidification treatment alternatives.

Thermal treatment has been used to treat residues from the processing of uranium for many years at the FEMP. Based on this experience and the extensive information available from industry on thermal treatment of residues the following conclusions were reached:

1) Waste from the waste pits can be effectively dried and packaged for shipment to an off-site disposal facility.

2) Thermal treatment of the waste will significantly reduce the volume.

3) High temperature drying (above the calcining temperature) will require more complex off-gas treatment due to the decomposition of organics and salts.

4) The dried waste will pass TCLP leach criteria (based on evaluation of the raw waste characterization).

5) A wide variation in the feed material will not significantly affect the thermal process at lower temperatures (below the calcining temperature).

The pit wastes contain large amounts of free water. The water is expected to be removed during the retrieval and feed preparation operations by selective excavation, pit dewatering, settling and decantation of the retrieved waste, and by mechanical removal. It is expected that the feed to the treatment plant will have a moisture content of 30 to 35 percent (dry weight basis) as a result of these operations.

To ensure full-scale implementability, the entire process would need to be tested in a pilot-scale test program. This program should include testing of dewatering during retrieval and feed preparation, and to establish parameters for drying and off-gas treatment. The advantages and disadvantages of higher temperature drying (i.e. creation of a clinkered material (to about 2600°F)) should also be evaluated.

To fully assess the process parameters for a drying process, the test program must determine the drying behavior of the waste (i.e., a drying profile as a function of time and temperature). This program will determine what the actual operating temperature, residence time, and dryer size should be for the materials to be dried. It will also provide data for determining off-gas treatment parameters.

Testing would also be required to determine the raw mixes that may produce stable clinkers for the production of low-quality Portland cement and magnesium-oxychloride cement from the waste pit material. Tests and a separate study should be performed to determine if the Operable Unit 2 lime sludge could be used as an additive for thermal treatment.

C.4.5.2 Particle Agglomeration

If drying is used as a primary treatment alternative, the dried material may pose a dusting problem for handling and shipping. Several methods for agglomeration of the dried waste have been investigated. These include pelletizing and polymer encapsulation.

This option is a combination of the previously described drying process followed by an agglomeration step using water or other additives as binders. Agglomeration technology is a process of size enlargement or upgrading of otherwise finer particles. The forms of product, depending on the reason for agglomeration, can be spheres, pellets, irregular extrusions, or merely loosely bound aggregates or clusters.

To date only tests with a surrogate material have been performed. Based on these surrogate tests and information available from studies at other DOE sites, the following conclusions were reached:

1) This technology is implementable. There is a long industrial history of agglomeration. The agglomeration equipment is reliable and easy to construct, operate, and maintain. Prospective technologies are readily available as are equipment vendors and specialists.
2) The agglomeration process may require the addition of water or other binders.
3) Agglomeration can successfully reduce the dusting hazard for dried waste.
4) Waste does not need to be completely dry for successful encapsulation or agglomeration.
5) High waste loadings in proportion to the binder can be achieved.
6) Chemical variations in the feed material have little or no effect on the polymer encapsulation process since the waste particles are microencapsulated and no chemical interaction occurs.

To prove technology applicability and implementability, further test work would be necessary. The testing should identify the appropriate technology and develop basic process parameters, including:

1) Feed size
2) Moisture content
3) Surface Requirements (ft^2/ton of feed)
4) Additives

This technology could be used to decrease dusting when handling and shipping the end product. The energy required for drying and encapsulation is moderately high, and depending on the amount of polymer required for treatment, the operation and maintenance costs could impact cost. Further testing should be performed to define the agglomeration process parameters and the agglomerated waste form requirements for transportation. Tests with actual pit waste would need to be performed at a bench scale. Additional pilot studies would also need to be performed.

TABLE C.4-1

SUMMARY OF WASTE CHARACTERISTICS

	Waste Pit 3	Waste Pit 5	Waste Pit 6	Soil
Sampling Notes	Clumps of grassy material, several small sticks, and many rocks in waste	Weak ammonia odor, few pieces of grassy material in waste	Few pieces of grassy material in waste	Rocks observed in raw sample
Wet Frisk[a] (counts per minute)	1,200	1,200	11,500	<20 above background
Wet Appearance	Very viscous, dark brown	Medium thickness, light brown, many air bubbles	Thin & grainy, drab olive green	Dark brown with malt colored powder interspersed
Average Moisture Content	110%	352%	169%	24%
Dry Frisk[a] (counts per minute)	2,000	4,000	20,000	<20 above background
Dry Appearance	Light to medium brown	Light pinkish brown with darker colored ring around edge, sticky	Light avocado with darker ring around edge	Light brown
Appearance after Being Heated to 400°C	Medium brown, same consistency as dried waste	Light orangish brown, same consistency as dried waste	Light pea greenish brown, same consistency as dried waste	Light to medium brown with orangish tint, same consistency as the dried soil
Appearance after Being Heated to 800°C	Light grey, easy to crush, softly clumped together, craters on surface	Medium to dark brown with white flecks, same consistency as dried waste	Bright yellow, same consistency as dried waste	Orangish brown, same consistency as the dried soil
Appearance after Being Heated to 1,000°C	Medium grey mottled with orange, layered, craters on surface hard, adhered to crucible	Very dark brown with few white flecks, clumped but easy to break and crush	Brown with slight reddish tint, shrunken from sides of crucible and very hard	Orange, agglomerated but easy to break and crush

[a] Note that the samples were frisked while in the evaporating dishes (wet and dry).

TABLE C.4-2

VISUAL CLASSIFICATION TESTS ON SOIL FRACTION LESS THAN 1/8-INCH SIZE

General Characteristics When Wet	Breaking or Dry Strength	Shine	Plasticity (Thread)	Shaking Reaction (Dilatancy)	Odor	Color (Wet)	USCS Symbol
Practically non-plastic, non-cohesive	None to slight, gritty	None to very dull	Very weak, easily crumbled	Moderate to quick	None	Gray, yellow, tan to reddish, blue	ML
Moderately plastic and cohesive	Significant to high, may be gritty	Medium to dull	Medium to tough, adheres to hand	None	Earthy	Dark brown, reddish, dark gray, tan	CL
Slightly plastic and cohesive	Slight, gritty	None to very dull	Soft, weak; adheres somewhat to hand	None to very slow	Decayed organic matter	Black, dark gray, dark brown	OL
Slightly plastic and cohesive	Slight to medium, powdered soil feels like talc	None to dull	Very soft, weak to medium	Slow to quick	None	Blue, pink, green, white, yellow, orange	MH

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TABLE C.4-2
(Continued)

General Characteristics When Wet	Breaking or Dry Strength	Shine	Plasticity (Thread)	Shaking Reaction (Dilatancy)	Odor	Color (Wet)	USCS Symbol
Very plastic and cohesive	High to very high, cannot be powdered by finger pressure	Very glossy	Very tough, very sticky to the hand	None	Strong earthy	Dark brown, red, blue, yellow	CH
Moderately to very plastic and cohesive	Moderate to high, may be fibrous	Medium to very glossy	Weak to medium, often soft and fibrous	None	Decayed organic matter	Black, dark brown, dark gray	OH
Fibrous highly organic, very plastic	Low to medium, fibrous when powdered	None to dull	Very soft, fibrous, slimy	None	Decayed organic matter	Black, dark brown, dark gray	Pt

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Table C.4-3

GEOTECHNICAL LABORATORY MATERIAL PROPERTY TESTING RESULTS

Sample Number	Pit	Moisture Content %	% Gravel	% Sand	% Fines	% < 2μ	G_s	Liquid Limit %	Plastic Limit %	PI %	pH of Solids In H_2O	Liquidity Index	Activity Index	USCS Symbol
1A	1	20.3	0.0	14.2	85.8			--	--	--		--		NP
2A	1	24.7	0.0	13.2	86.8			--	--	--		--		NP
3A	1	39.1	2.9	26.8	70.3			--	--	--		--		NP
4A	1	18.0	0.0	9.0	91.0			--	--	--		--		NP
5A	1	20.7	0.4	10.8	88.8	0.0	3.02	--	--	--	7.27	--	--	NP
6A	1	21.1	0.0	9.0	91.0			--	--	--		--		NP
7A	1	20.7	1.1	9.8	89.1			--	--	--		--		NP
8A	1	22.7	3.9	37.6	58.5			--	--	--		--		NP
9A	2	35.4	1.0	55.1	43.9			33.1	23.2	9.9		1.23		SM
10A	2	38.3	7.6	26.1	66.3	22.2	2.72	42.3	23.1	19.2	7.67	0.79	0.86	CL
11A	2	70.5	5.5	27.8	66.7	11.7	2.67	66.8	42.2	24.6	7.53	1.15	2.10	MH
12A	2	16.7	4.2	22.3	73.5			44.1	16.2	27.9		0.01		CL
13A	3	145.4	3.2	33.7	63.1			89.7	55.8	33.9		2.64		MH
14A	3	152.7	3.5	23.8	72.7			81.8	58.9	22.9		4.10		MH
15A	3	42.2	6.5	25.8	67.7	3.1	2.69	46.9	31.7	15.1	7.74	0.70	4.87	ML
16A	3	96.8	3.3	27.0	69.7	15.7	2.72	77.8	44.3	33.5	7.76	1.57	2.13	MH
17A	3	142.0	1.0	15.3	83.7			69.9	53.9	16.0		5.51		MH
18A	3	41.9	2.5	40.9	56.6			37.9	30.5	7.4		1.54		ML
19A	3	36.1	6.0	19.9	74.1			44.1	25.2	18.9		0.58		CL

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Table C.4-3
(Continued)

GEOTECHNICAL LABORATORY MATERIAL PROPERTY TESTING RESULTS

Sample Number	Pit	Moisture Content %	% Gravel	% Sand	% Fines	% < 2μ	G_s	Liquid Limit %	Plastic Limit %	PI %	pH of Solids In H_2O	Liquidity Index	Activity Index	USCS Symbol
21A	4	18.0	6.4	29.5	64.1	6.6	3.25	28.4	18.5	9.9	7.79	-0.05	1.50	CL
22A	4	23.3	0.0	12.0	88.8			--	--	--		--		NP
23A	4	22.2	0.8	15.2	84.0	8.4	3.02	--	--	--	7.73	--	--	NP
24A	4	10.1	13.4	24.7	61.9			33.9	16.7	17.2		-0.38		CL
25A	4	25.4	1.2	34.7	64.1			34.1	21.8	12.3		0.29		CL
26A	4	29.3	1.2	18.0	80.8			--	--	--		--		NP
30A	5	173.0	0.0	5.0	95.0			70.7	57.7	13.0		8.87		MH
31A	5	497.5	0.0	5.2	94.8			94.2	50.6	43.6		10.25		MH
32A	5	483.0	0.0	3.4	96.6			102.2	80.5	21.7		18.55		MH
33A	5	507.3	0.0	1.3	98.7			108.4	71.8	36.6		11.90		MH
34A	5	451.7	0.0	1.9	98.1			102.2	64.6	37.6		10.30		MH
35A	5	161.1	0.0	11.9	88.1	14.5	2.70	90.9	60.2	30.7	8.53	3.29	2.12	MH
36A	5	342.4	0.0	8.1	91.9			103.8	75.6	28.2		9.46		MH
37A	5	620.0	0.0	0.2	99.8			93.0	58.0	35.0		16.06		MH
38A	5	495.7	0.0	2.7	97.3		2.74	112.3	68.1	44.2	8.72	9.67	--	MH
39A	5	448.5	0.0	5.9	94.1			112.0	69.6	42.4		8.94		MH
40A	5	114.5	0.0	5.5	94.5			--	--	--		--		NP
41A	5	109.3	0.0	6.0	94.0	8.9	2.71	--	--	--	8.34	--	--	NP
57A	5	242.3	0.0	14.6	85.4			87.7	60.9	26.8		6.77		MH
58A	5	295.7	0.0	10.4	89.6	10.2	2.70	77.1	52.7	24.4	8.22	9.96	2.37	MH

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Table C.4-3
(Continued)

GEOTECHNICAL LABORATORY MATERIAL PROPERTY TESTING RESULTS

Sample Number	Pit	Moisture Content %	% Gravel	% Sand	% Fines	% < 2μ	G_s	Liquid Limit %	Plastic Limit %	PI %	pH of Solids In H_2O	Liquidity Index	Activity Index	USCS Symbol
43A	6	425.1	0.0	3.7	96.3			--	--	--		--		NP
45A	6	26.8	0.0	27.6	72.4	9.6	3.21	--	--	--	9.19	--	--	NP
45C	6	117.6	0.0	51.3	48.7			--	--	--		--		SM
46A	6	107.4	0.0	13.8	86.2	27.9	2.98	47.0	28.4	18.6	9.43	4.25	0.67	ML
47A	6	111.4	0.0	9.8	90.2	35.2	2.85	64.9	33.1	31.8	9.40	2.46	1.45	MH
49A	CW	53.4	3.3	31.1	65.6			43.9	25.6	18.3		1.52		CL
50A	CW	65.1	10.9	36.4	52.7			50.6	32.5	18.1		1.80		MH
51A	CW	61.9	0.0	51.5	48.5			45.0	28.0	17.0		1.99		SM
52A	CW	40.2	8.5	47.0	44.5			39.3	24.9	14.4		1.06		SM
53A	CW	35.4	0.0	39.4	60.6	22.3	2.69	35.1	18.0	17.1	8.35	1.02	0.77	CL
54A	CW	73.9	0.5	22.5	77.0			54.7	39.2	15.5		2.24		MH
55A	CW	71.7	1.8	23.7	74.5	23.8	2.78	52.4	38.0	14.4	8.24	2.34	0.61	MH
56A	CW	68.5	3.3	31.3	65.4			53.3	40.2	13.1		2.16		MH
27A	BP	25.5	2.6	26.2	71.2			41.3	24.7	16.6		0.05		CL
28A	BP	25.6	4.4	37.0	58.6			35.1	31.0	4.1		-1.32		ML
29A	BP	30.0	8.5	38.2	53.3	15.0	2.50	37.8	26.7	11.1	7.74	0.30	0.74	ML

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APPENDIX D

OPERABLE UNIT 1
PUBLIC HEALTH AND OCCUPATIONAL RISK CONSIDERATION

APPENDIX D

PUBLIC HEALTH AND OCCUPATIONAL RISK CONSIDERATION FOR OPERABLE UNIT 1 FEASIBILITY STUDY

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LIST OF ACRONYMS

Ac	actinium
ACGIH	American Conference of Governmental and Industrial Hygienists
AWWT	Advanced Waste Water Treatment
BEHP	bis(2-ethylhexyl)phthalate
BSL	Biodenitrification Surge Lagoon
Ca	exposure point concentration in air
CEDE	Committed Effective Dose Equivalent
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CF	conversion factor
CRARE	Comprehensive Response Action Risk Evaluation
CSF	cancer slope factor
COC	constituent(s) of concern
CPC	constituent(s) of potential concern
CT	central tendency
DOE	United States Department of Energy
ED	exposure duration
EPA	United States Environmental Protection Agency
FEMP	Fernald Environmental Management Project
FS	Feasibility Study
HEAST	Health Effects Assessment Summary Tables
HELP	hydrogeological evaluation of land performance
HEPA	high-efficiency particulate air
HI	Hazard Index
HQ	hazard quotient
IARC	International Agency for Research on Cancer
ICRP	International Commission of Radiological Production
ILCR	incremental lifetime cancer risk
IR	inhalation rate
IRIS	Integrated Risk Information System

LIST OF ACRONYMS
(Continued)

LOAEL	lowest observed adverse effect level
MCL	Maximum Contaminant Level
NA	not applicable
NCP	National Contingency Plan
ND	not detected
NE	northeast
NOAEL	no observed adverse effect level
NRC	Nuclear Regulatory Commission
NS	not selected
NTS	Nevada Test Site
NW	northwest
OAC	Ohio Administrative Code
O&M	operations and maintenance
OSHA	Occupational Safety and Health Administration
Pa	protactinium
PAH	polycyclic aromatic hydrocarbons
Pb	lead
PC	personal computer
PCB	polychlorinated biphenyls
PRG	Preliminary Remediation Goal(s)
PRL	Preliminary Remediation Level(s)
Po	polonium
RA	remedial action
Ra	radium
RCRA	Resource Conservation and Recovery Act
RfC	Reference Concentration
RfD	reference dose
RI	Remedial Investigation
RME	reasonable maximum exposure

LIST OF ACRONYMS
(Continued)

Rn	radon
RTS	Radon Treatment System
Ru	ruthenium
SE	southeast
SF	inhalation slope factor
SOWC	Southwest Ohio Water Company
SVOC	semi-volatile organic compounds
SW	southwest
Th	thorium
TCLP	Toxicity Characteristic Leaching Procedure
TLV	threshold limit value
TWA	time-weighted average
U	uranium
UCL	upper confidence level
UF	uncertainty factor
UMTRA	Uranium Mill Tailing Remedial Action Program
VOC	Volatile Organic Compounds

LIST OF MEASUREMENTS

Ci	curie
cm	centimeter
ft	feet
g	gram
hr	hour
in.	inch
kg	kilogram
km	kilometer
km^2	square kilometer
L	liter
lb	pound
m	meters
m^3	cubic meter
mg	milligram
mi	mile
mi^2	square mile
mL	milliliter
mm	millimeter
mrem	millirem
pCi	picocurie
sec	second
μg	microgram
μCi	microcurie
yd^3	cubic yard

D.1.0 INTRODUCTION

Operable Unit 1 of the Fernald Environmental Management Project (FEMP) site contains chemical and radiological material within stored waste inventories and environmental media that present potential risks to humans and to environmental resources. The nature and magnitude of these risks are evaluated as part of the remediation process to assist in the selection of remedial alternatives that are protective of human health and the environment.

As part of the Operable Unit 1 Remedial Investigation Report, a quantitative baseline risk assessment (baseline RA) was performed to evaluate the "no further action" alternative. The baseline RA estimated potential risks associated with current conditions at Operable Unit 1 and projected future risks based on the assumption that no further cleanup actions would be taken. Results of the baseline RA indicated that potential risks to human health associated with the "no further action" alternative are unacceptably high.

Having determined that remediation of Operable Unit 1 is required, this Feasibility Study (FS) was prepared. The FS provides detailed analysis of remedial alternatives based on criteria required by the U.S. Environmental Protection Agency (EPA), as discussed in the main text of the FS report. Part of the analysis and ultimate selection of alternatives includes evaluation of risks associated with implementation of the alternative (remedial action risk) and with the long-term effectiveness of the alternative in protecting human health and the environment (residual risk).

This appendix to the Operable Unit 1 FS report presents results of both remedial action risk evaluations and residual risk evaluations associated with the leading alternatives (4A, 4B, 5A and 5B). The risk evaluations were performed in support of Section 4.0 of the FS report, in which detailed analyses of the leading alternatives are presented.

Remedial action risks are those associated with construction and treatment activities performed during implementation of remedial action alternatives. Those potentially exposed to remedial action risks (receptors) are remediation workers, nonremediation workers, off-property residents at the FEMP site

boundary and the general public. Current land use (i.e., government ownership with access controls) is assumed to continue during remediation. Exposure scenarios for receptors include inhalation or resuspended dust, ingestion of and dermal contact with soil, direct radiation effects and physical injury.

Residual risks are potential risks projected to remain following completion of remedial action. For the purposes of this report, a period of 1000 years was used to evaluate long-term residual risks. It is assumed that the Fernald area will retain its rural agricultural character in the future; hence residual risks are evaluated for two scenarios: continued government ownership with some limited access controls and future private ownership. Receptors for the future government ownership with access controls (deed restrictions, fencing, etc.) scenario are an off-property farmer and child who live and farm adjacent to the FEMP property and an expanded trespasser on the Operable Unit 1 site. Receptors for the private ownership scenario are an on-property farmer and child who live and farm on the Operable Unit 1 site and the off-property farmer and child. Exposure scenarios evaluated quantitatively are use of groundwater for household and irrigation purposes and exposure to residual contaminants in surface soils. Potential residual risks are evaluated either quantitatively or qualitatively, as appropriate, based on exposure to groundwater or soil for each receptor considered.

This appendix includes summaries of remedial alternatives evaluation in Section 4.0 of the FS and of the baseline RA. It also contains information describing the toxicity, mobility and environmental persistence of the contaminants of concern (COCs) developed in the baseline RA. Finally, comparisons of remedial action and residual risks for the remedial alternatives evaluated in Section 4.0 of the FS are presented. Tables, figures and risk calculation spreadsheets are provided at the end of the appendix.

D.2.0 BACKGROUND

D.2.1 SITE HISTORY

The Feed Materials Production Center (FMPC) operated at the FEMP property from 1952 until 1989, providing high purity uranium metal products in support of United States defense programs. Uranium production operations were halted in 1989 to focus available resources on environmental restoration initiatives at the FEMP facility.

Identified environmental concerns include potential impacts on human health and the environment due to past releases of hazardous materials from the FEMP to air, water, and surrounding soils; continuing releases of hazardous materials from the facility; and the on-site accumulation of a large inventory of uranium process materials and low-level radioactive and hazardous wastes. Operable Unit 1, the focus of this risk evaluation, consists of the following FEMP facilities and associated environmental media:

- Waste Pits 1 through 6
- The Burn Pit and the Clearwell
- Miscellaneous structures and facilities. These structures and facilities include, but are not limited to, berms, liners, concrete pads, underground piping, utilities, railroad tracks, and fencing.
- Associated Environmental Media. These media include surface and subsurface soil, surface water, sediment, air, and flora and fauna of the immediate area. Groundwater remediation will be considered separately in Operable Unit 5. Potential risks from groundwater are analyzed as necessary to determine feasible remedial alternatives for the sources of groundwater contamination (i.e., waste pits, etc.) included in Operable Unit 1.

Significant concerns associated with waste materials include the presence of:

- Chemical constituents present in the waste material
- Radionuclides present in the waste material
- Emission of radon gas
- Potential for leaching waste materials into the underlying Great Miami Aquifer.

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D.2.2 OVERVIEW OF THE BASELINE RISK ASSESSMENT

During the Operable Unit 1 Remedial Investigation, an analysis was conducted to estimate the human health risks that could result from exposure to the hazardous wastes of Operable Unit 1 if no remediation is performed beyond that accomplished to date. This analysis is referred to as a baseline risk assessment.

The baseline risk assessment consists of five primary steps. First, the presence of chemical and radiological constituents that could potentially cause adverse health effects is determined; this is called Constituent of Potential Concern (CPC) determination and is discussed in Section D.2.2.1. The second step defines how the land will be used, how exposure will occur and how receptors, hypothetical inhabitants and visitors to the site, will be exposed; this is called exposure assessment and is discussed in Section D.2.2.2. In the third step, the hazardous effects of all CPCs are characterized; this step is termed toxicity assessment and is discussed in Section D.2.2.3. The next step of the baseline risk assessment is the hazard assessment where results of the first three steps are combined to determine health hazards for all receptors. This step is summarized in Section D.2.2.4. A semi-quantitative analysis of uncertainties and the effect of these uncertainties on the baseline risk assessment is the next step of the baseline risk assessment, and is presented in Section D.2.2.5. Finally, the conclusions presented in Section D.2.2.6 discuss the potential impact of the no action alternative on human health. The public is encouraged to review Section 6.0 and Appendix E of the OU1 RI Report (DOE, 1994) for detailed information on risks associated with Operable Unit 1.

D.2.2.1 Constituents of Potential Concern (CPCs)

CPCs are constituents that remain after a two-step statistical and toxicological screening process. That screening process focuses on the chemicals and radionuclides that are of concern to human health. In the first step, statistical analyses compared measured on-property concentrations of each remaining CPC to background concentrations of that constituent in the same media (soil, sediment, surface water, etc.). In the second step, each constituent detected in a given medium was reviewed for its toxicological significance, and those that were not likely to be of human health concern were excluded.

Three categories of CPCs were found: radionuclides, inorganic chemicals and organic compounds. Most of the 13 radioactive CPCs retained were of the uranium and thorium decay series. Inorganic CPCs included silver, arsenic, lead, copper and cyanide. Organic chemicals retained in the CPC list

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include PCBs, PAHs dioxins, furans and various organic solvents used at the FEMP. [Refer to Appendix E of the RI Report (DOE, 1994), Section E.2 for a complete listing of CPCs.]

D.2.2.2 Exposure Assessment

The exposure assessment identifies the sources and pathways of exposure and possible receptors under different land-use scenarios. First, sources of exposure are listed in section D.2.2.2.1. The current and future source terms are defined in the section D.2.2.2.2. Section D.2.2.2.3 describes land use scenarios used in the Operable Unit 1 baseline risk assessment and receptors considered for each scenario.

D.2.2.2.1 Sources of Exposure

The source terms identified were the waste pit materials in Waste Pits 1 through 6, the Burn Pit, and the Clearwell; surface water in Waste Pits 5 and 6 and the Clearwell; and surface soil within the Operable Unit 1 study area.

D.2.2.2.2 Source Terms

Two source term configurations were considered: the current and future source terms. The current source-term configuration considers the Waste Storage Area as it exists today.

The future source-term assumes that all maintenance activities within Operable Unit 1 were discontinued. As a result, the cap over Waste Pit 3 was assumed to partially fail, allowing 30 percent of the waste pit surface area direct exposure to pit contents. Caps and covers on Waste Pits 1, 2, and 4, and the Burn Pit remained intact. Water in Waste Pits 5 and 6 was assumed to evaporate, exposing waste pit contents over half of the surface area of each waste pit. The Clearwell is assumed to have remained filled with water. The surface-water-runoff-control system was assumed nonfunctional under the future source-term scenario as maintenance ceases.

D.2.2.2.3 Land Use Scenarios

Land-use scenarios addressed in the Operable Unit 1 Baseline Risk Assessment are: (1) current land use with access controls; (2) current land use without access controls; (3) future land use with access controls and; (4) future land use without access controls.

Under the first scenario (current land use with access controls), the site access restrictions historically provided by DOE were maintained and no further remedial actions were taken other than those

completed to date. The scenario further assumes that no members of the public are allowed access to the site and the integrity of the Waste Storage Area is maintained by inspections and repaired when necessary. Potential receptors for this scenario are a groundskeeper, an off-property farmer, and an off-property child.

The next land use scenario was current land use without access controls. Under this scenario, strict access controls were relaxed, increasing the likelihood of public trespass and livestock grazing on site. This scenario is considered for both the current and future source term as described in the previous section. Receptors considered under this scenario for the current source term are the trespasser and the off-property user of meat and milk products. Receptors considered under this land use scenario for the future source term are the off-property farmer, the off-property child, the Great Miami River User, the off-property user of meat and milk products, and the groundskeeper.

Two future land use scenarios are considered: future land use with and without access controls. For future land use with limited access controls (the government reserve), the government retains ownership of the site, but site maintenance and strict access controls were relaxed. Two receptors were evaluated under this scenario. They were the "expanded trespasser" and the "groundskeeper."

If the government were to relinquish all control over the site, unrestricted use of the site could permit exposure routes associated with development of residences, such as a home and farm, within the boundaries of Operable Unit 1. Access controls are assumed to be absent and no additional remedial actions were assumed. Receptors considered under this scenario are the RME resident farmer and child, the central tendency (CT) resident farmer, the off-property resident farmer and child, the home builder and the off-property user of meat and milk products.

D.2.2.3 Toxicity Assessment

Two human health hazards were addressed in the toxicity assessment for Operable Unit 1: cancer induction and non-carcinogenic toxicity. Cancer may be induced by exposure to a chemical carcinogen or from ionizing radiation from a radionuclide. Non-carcinogenic toxicity refers to organ tissue effects. These effects are numerous and range from systemic effects such as kidney or liver damage to localized effects such as skin or eye irritation.

Cancer risk is quantified by Incremental Lifetime Cancer Risks (ILCR) and is expressed in terms of the probability that a given receptor will develop cancer due to estimated exposures. For example, if

the receptor has an additional one chance in 10,000 of contracting cancer due to these exposures, the probability is expressed as a 10^{-4} (1/10,000) risk. Chemical intakes calculated in the exposure assessment are used in conjunction with the cancer slope factor (CSF) to determine the ILCR.

In the evaluation of potential exposures for the noncarcinogenic assessment, it was assumed that a dose threshold exists below which no toxic effect will occur. This threshold is used to develop an acceptable intake level (the reference dose [RfD]). To determine if Operable Unit 1 constituents may cause toxic effects, the estimated intake (calculated from the exposure assessment) was divided by the acceptable intake. This ratio is called the hazard quotient (HQ). When HQs for multiple CPCs are summed for a particular pathway, the resultant value is the hazard index (HI). If the ratio of estimated intake to the acceptable intake is greater than one, the site-related intake may increase the risk of non-carcinogenic toxic effects.

D.2.2.4 Risk Characterization Results

Tables D.2.2-1 through D.2.2-8 present summary results of the baseline risk assessment by land use. These results may be compared to the ranges of generally acceptable risk under CERCLA, which are an incremental lifetime cancer risk of 10^{-6} to 10^{-4} or a Hazard Index equal to or greater than one. A list of chemicals that contribute an ILCR greater than one in one million ($1x10^{-6}$) or a hazard quotient greater than 0.2 and were designated as constituents of concern (COCs) for the Feasibility Study is presented in table D.2.2-9.

D.2.2.4.1 Current Land Use

Current Land Use With Access Controls

Three of the receptors listed in Tables D.2.2-1 and D.2.2-2 - the groundskeeper, the off-property farmer, and the off-property child - were evaluated under the assumption that both active maintenance and access controls continue. The maximally exposed individual in this case is the groundskeeper, with ILCR approaching 10^{-4} (Table D.2.2-2). These risks are dominated by radiation exposures from isotopes of uranium, thorium, and radium in pit contents and surface soil. The hazard index of systemic toxic effects for the groundskeeper is less than one. Calculated risks to the off-property farmer are just over 10^{-6}, while calculated risks to the resident child are well below 10^{-6}. The HI for both the farmer and child are less than one, so no increase in risk of non-carcinogenic toxic effects is expected.

Current Land Use Without Access Controls

If access controls are relaxed, two additional receptors are assumed to become plausible - the trespassing youth and the off-property user of meat and milk. The greatest health effects are expected to occur to the off-property user of meat and milk products. Most of the total calculated risks to this receptor (about 10^{-3}) are from the uptake of PCBs by grazing cattle. Radionuclides contribute risks on the order of 10^{-4}. The HI for this receptor exceeds 1.0 (2.4), due primarily to antimony, cadmium, and uranium uptake by cattle. Impacts on the hypothetical trespassing youth are much lower (ILCR = 10^{-5} and HI = 0.5), so no increase in risk of non-carcinogenic toxic effects is expected.

Current Land Use Without Access Controls (Future Source Term)

Tables D.2.2-3 and D.2.2-4 present the ILCRs and HIs for the trespassing youth and the Great Miami River user evaluated under this exposure scenario. The trespassing youth incurs a ILCR of 10^{-4} and HI of 2, but impacts to the Great Miami River User were minimal.

D.2.2.4.2 Future Land Use

With Access Controls (Government Reserve)

Summaries of cancer risks and hazard indices for receptors evaluated under future land use with access controls are summarized in Tables D.2.2-5 and D.2.2-6. The groundskeeper was projected to incur cancer risks in the order of 10^{-3}. Hazard Indices for the groundskeeper and expanded trespasser were 2.1 and 3.8 respectively, both primarily due to contact with exposed pit material.

Without Access Controls

Summaries of cancer risks and hazard indices for receptors evaluated under future land use without access controls are summarized in Tables D.2.2-7 and D.2.2-8. All receptors were calculated to incur risks in excess of 10^{-4}. The greatest calculated risks are incurred by the hypothetical on-property farmer (ILCR = 10^{-1}). If domestic use of perched groundwater is included in the analysis, the risks approach one. Uranium and arsenic in groundwater dominate risks to this receptor. Similarly, predicted exposures to all receptors produce HI's exceeding 1. The highest HI, 6,100, is produced when the on-property farmer uses perched water. If this potential source is discounted, the highest HI is incurred by the resident child using groundwater from beneath the operable unit (1,600).

D.2.2.5 Summary of Uncertainties

It is generally recognized that uncertainty is inherent in quantitative risk assessment. The objective of the uncertainty analysis is to identify key site-related variables that contribute most to uncertainty, and to characterize the nature and magnitude of impact of these uncertainties on the conclusions of the risk assessment.

Table D.2.2-10 summarizes the semi-quantitative evaluation of uncertainty for the Operable Unit 1 Baseline Risk Assessment. Sources of uncertainty were identified for all steps of the risk assessment process: selection of CPCs, exposure assessment, toxicity assessment and risk characterization. The majority of uncertainties tended toward increased conservatism of the risk evaluation. Taken together, the uncertainties identified with site data, exposure parameters, fate and transport, toxicity assessment and risk characterization were judged high and could overestimate risk by two or more orders of magnitude).

D.2.2.6 Conclusion

Actual or threatened releases of hazardous substances from this site, if not addressed by the preferred alternative or one of the other active measures considered, present a potential future threat to public health.

D.2.3 DESCRIPTION OF WASTE PIT AREA AND EVALUATED POTENTIAL REMEDIAL ALTERNATIVES

D.2.3.1 Description of Waste Pit Area

Operable Unit 1 includes Waste Pit 1-6 wastes and associated caps, liners and soils, the Burn Pit wastes and associated materials, the Clearwell and associated materials and Operable Unit 1 area soils. The Waste Pit Area is located in the northwest corner of the facility. The specific features of Operable Unit 1 are provided in Section 1.0 of this FS/PP-EA. Waste Pits 1 through 6, located west of the former Production Area, contain a variety of liquid and solid wastes that were generated by eight separate operations plants at the site. Waste Pits 1 through 4 are covered with earth and waste residue from burned refuse. Section 1.0 of the RI Report for Operable Unit 1 provides a detailed description of wastes disposed in Operable Unit 1. A summary is included in Section 1.0 to this FS Report.

There are contaminated soils associated with each of the waste pits, the Burn Pit and the Clearwell. Operable Unit 1 will excavate the soils under and next to the pits to either a risk-based PRG level or

down to the Great Miami Aquifer strata. In addition for the purposes of this assessment, it is anticipated that the top 6 inches of soil across the Operable Unit 1 area, excluding soils north of the railroad tracks (unless they are shown to be contaminated), will be removed. If sampling reveals other hot spots either not related to a specific pit, or deeper than 6 inches in non-pit areas, these soils will also be excavated for eventual treatment and disposal.

D.2.3.2 Descriptions of Potential Remedial Alternatives

The role of the feasibility study is to analyze and select potential remedial alternatives. The elements involved in screening, evaluation and selection of alternatives are outlined in Figure D.2-1. The evaluation of remedial action and residual risks presented in this appendix in support of remedy selection focuses on risks associated with the four potential remedial alternatives, which are evaluated in detail in the feasibility study. The four alternatives analyzed in detail are briefly described in this section. A simplified conceptual flow diagram illustrating the steps involved in each of the four alternatives is shown in Figure D.2-2.

Description of Alternative 4A - Removal, Treatment (Vitrification), and On-Property Disposal

Alternative 4A requires the excavation of material in Waste Pits 1 through 6, the Burn Pit and the Clearwell, including the waste, caps, liners and soils below and adjacent to the liners, to health-based limits. Surface soils within the Operable Unit 1 boundary, outside the capped areas, would also be excavated to health-based limits. This surface soil excavation excludes the area north of the railroad track, unless contamination is found in this area. Excavated waste pit material would be dried and treated by vitrification for disposal in an aboveground disposal cell within the FEMP boundary. The waste pits would be backfilled with clean soil. The backfilled areas would, for conservatism, be covered with a infiltration limiting multilayer cover. The areas where surface soil is excavated would be graded and vegetated. Topsoil would be used to support vegetative growth, if required.

The pit waste, caps and liners would be dewatered and excavated with both mechanical and slurry systems. Waste would be transferred to a controlled stockpile where the waste streams could be blended and directed into a shredder which feeds the dryers. The shredder would homogenize and reduce the maximum particle dimension to less than 6 inches. The blended waste stream would be fed into a rotary dryer at a rate of 400 wet tons per day. The waste would then be size reduced to less than 1 cm (3/8 inch) in diameter and fed to one of four vitrifiers. Process gas from the dryer and vitrifier would be treated to meet the applicable regulations. The waste glass frit from the vitrifiers would be cooled and transferred to the on-property disposal cell by truck and placed in 12

inch lifts. The on-property disposal cell would incorporate design features from both the Resource Conservation Recovery Act (RCRA) and Uranium Mill Tailings Remediation Action (UMTRA) disposal cells to accommodate vitrified mixed waste, hazardous waste and radioactive waste.

Description of Alternative 4B - Removal, Treatment (Cement Stabilization), and On-Property Disposal

This alternative is identical to Alternative 4A, except that the waste would be treated using cement solidification instead of vitrification. The additional waste volume generated by cement solidification would also increase the size of the disposal cell.

Description of Alternative 5A - Removal, Treatment, and Off-Site Disposal at the Nevada Test Site (NTS)

The removal portion of this alternative is identical to Alternative 4A; however, the vitrification, on-property disposal, run-on/runoff control, monitoring, and access control technologies have been replaced by transportation and off-site disposal technologies. In this alternative, waste would be treated by drying to the extent necessary to meet the waste acceptance criteria of the off-site disposal facility.

This remedial alternative includes excavation, drying and off-site shipment and disposal at the NTS. The pit wastes, caps, and liners would be excavated with both mechanical and slurry systems. This waste would be dewatered and excavated and transferred to a controlled stockpile where the waste streams can be blended and directed into a shredder which feeds the dryers. The shredder would homogenize and reduce the maximum particle dimension to less than 15 cm (6 in.). This blended waste stream would be fed into the rotary dryer. The dryer output moisture content would be close to optimum for compaction and pass the liquid release test and must permit free flowing bulk material handling. The actual drying temperature and waste retention time would be finalized prior to actual process design. The dried waste would be transferred to an operational storage silo above the rail siding. The waste would be containerized in strong tight boxes, loaded onto flatbed rail cars, and disposed of at NTS. Rail shipment would be to a point near Las Vegas where the containerized wastes would be off-loaded onto trucks for the final leg of the trip to NTS.

Description of Alternative 5B - Removal, Treatment, and Off-Site Disposal at a Permitted Commercial Disposal Facility

This remedial alternative is identical to Alternative 5A except that dried material is placed in gondola railcars in bulk (i.e., no packaging) and shipped directly to a representative permitted commercial disposal facility located in Utah. Only rail transportation would be required for shipment to this

facility. Similar to Alternative 5A, the waste would be treated to the extent necessary to meet the waste acceptance criteria of the disposal facility.

D.2.4 REMEDIAL ACTIVITIES

The remedial action alternatives involve a range of different work activities and varying degrees of physical risk and potential exposure to Operable Unit 1 COCs. Remedial activities for the feasible remedial alternatives identified for Operable Unit 1 (Alternatives 4A, 4B, 5A and 5B) are identified below for each alternative.

- Alternative 4A - Removal, Vitrification, On-Property Disposal- Water extraction and transfer to AWWT facility; mechanical and slurry removal of waste and associated materials; waste segregation; stockpiling materials; crushing and shredding of materials; drying and vitrification of waste materials; run-on and runoff control construction; transfer and on-property disposal of frit in an engineered facility; surface soil excavation; monitoring of air, groundwater, leachate, surface water and sediment; and access controls are included in this remedial alternative.

  This alternative also includes remedial activities involved in the treatment and disposal facility construction and closure, decontamination and decommissioning of the treatment facility, disposal cell capping, and site restoration.

- Alternative 4B - Removal, Cement Solidification, On-Property Disposal- In this option, drying and vitrification processes of alternative 4A are replaced by cement solidification. The increased treated waste volume increases the size of the disposal cell, and processes for mixing and adding cement to the waste materials (i.e., the use of pugmill mixers) are substituted for the vitrification processes.

- Alternative 5A - Removal, Treatment, Off-Site Disposal at NTS- Off-site disposal at NTS involves waste material excavation via mechanical and slurry methods; material stockpiling, blending, shredding and drying; containerization and loading for transport; off-site shipment via rail and truck; and ultimate disposal.

- Alternative 5B - Removal, Treatment, Off-Site Disposal at a Permitted, Commercial Disposal Facility- Off-site disposal at a permitted commercial facility involves waste material excavation via mechanical and slurry methods; material stockpiling, blending, shredding and drying; bulk loading for transport; off-site shipment via rail; and ultimate disposal.

D.2.5 CONCEPTUAL MODELS

D.2.5.1 Conceptual Model for Remedial Action Risks

Remedial action risks are those risks associated with short-term exposures during implementation of remedial action alternatives from exposures over the duration of the remediation. The risks are

lifetime cancer risks associated with the exposure to chemical carcinogens and ionizing radiation, toxic effects associated with non-carcinogenic chemicals, and direct physical injuries associated with construction and transportation activities. This risk assessment estimates risks from exposures to three groups of individuals: remediation workers, non-remediation workers, and the general public. Remediation workers are those workers placed at risk through their direct involvement in a specific component of a remedial alternative. Non-remediation workers are all other workers within the FEMP. These workers include employees of the FEMP prime contractor and subcontractors. Nonremediation workers are placed at potential risk from the hypothetical airborne transport of contaminants from Operable Unit 1 to their work place. The general public living adjacent to the FEMP site are placed at potential risk from the hypothetical off-site atmospheric transport of airborne contaminants from Operable Unit 1. The general public living adjacent to the transport route for Operable Unit 1 waste materials are placed at potential risk from direct radiation associated with transport containers and the accidental release of waste material during transportation.

To estimate remedial action risks, phases of an alternative that may contribute to short-term risks have been identified. As a result, the assessment examines six distinct remedial alternative components. These components represent operations that have the potential for contributing to remedial action risks. Risks due to individual components comprising a remedial alternative are combined to develop an overall estimate for the risk associated with a remedial alternative. The following list presents the components and the alternatives that contain the component. Each component is briefly described below. This summary of the baseline risk assessment fully describes the exposure pathways.

Alternative Component	Alternative Containing Component
1. Excavation	Alternatives 4A, 4B, 5A, and 5B
2. Drying	Alternatives 4A, 4B, 5A, and 5B
3. Vitrification/Solidification	Alternatives 4A and 4B
4. On-Site Disposal	Alternatives 4A and 4B
5. Transportation	Alternatives 5A and 5B
6. Restoration	Alternatives 4A, 4B, 5A, and 5B

Excavation

Each alternative, except the no action alternative, includes excavating surface soils, pit covers, pit waste material, pit liners, and underlying soil and constructing ancillary facilities to support excavation. The exposure modes associated with excavation are direct radiation, inhalation of contaminants and immersion in contaminated air, and direct physical injury. The direct radiation exposure mode is defined as the mode where a receptor is impacted by ionizing radiation from a fixed

source. In the case of excavation, the fixed source is contamination in the surface soil. In contrast, immersion in contaminated air is defined as the mode where a receptor is exposed to ionizing radiation originating from contamination dispersed in air. Remediation workers, non-remediation workers, and members of the public are impacted from immersion during excavation. Direct physical injury is included as a risk measure since each alternative includes different mechanical operations and this measure serves as a distinguishing feature among the alternatives. Figure D.2-3 depicts the conceptual model for remedial action risks associated with excavation activities during remediation.

Drying

Each alternative, except the no action alternative, includes drying excavated material in a rotary dryer to remove excess water from excavated material. Exposure modes associated with drying are direct radiation, inhalation of contaminants and immersion in contaminated air, and direct physical injury. Remediation workers, non-remediation workers, and members of the public are impacted by the drying component. Direct physical injury is included as a risk measure since each alternative includes different mechanical operations and this measure serves as a distinguishing feature among the alternatives. Figure D.2-4 depicts the conceptual model for remedial action risks associated with drying.

Vitrification/Solidification

Alternatives 4A and 4B include stabilizing the excavated materials through vitrification (4A) or cement stabilization (4B). Exposure modes associated with the stabilization methods are direct radiation, inhalation of contaminants and immersion in contaminated air, and direct physical injury. Remediation workers, non-remediation workers, and members of the public are impacted by the exposure modes. Direct physical injury is included as a risk measure since each alternative includes different mechanical operations and this measure serves as a distinguishing feature among the alternatives. Figure D.2-5 depicts the conceptual model for remedial action risks associated with vitrification/solidification.

On-Property Disposal

Alternatives 4A and 4B consider disposal of excavated and stabilized material in an on-property disposal cell. Exposure modes associated with on-property disposal are direct radiation inhalation, and direct physical injury. Remediation workers are the only receptors impacted by on-property disposal exposure modes. Direct physical injury is included as a risk measure since each alternative includes different mechanical operations and this measure serves as a distinguishing feature

among the alternatives. Figure D.2-6 depicts the conceptual model for remedial action risks associated with this component.

Transportation

Alternatives 5A and 5B consider the transport and off-site disposal of the excavated material. Exposure modes associated with transportation are direct radiation, inhalation of contaminants and immersion in contaminated air, and direct physical injury. Remediation workers and members of the public are impacted by transportation exposure modes. Remediation workers have been divided into two groups: truck driver/train crew and waste package handler. Direct physical injury is included as a risk measure since each alternative includes different mechanical operations and this measure serves as a distinguishing feature among the alternatives. Figure D.2-7 depicts the conceptual model for remedial action risks associated with transportation.

Restoration

Each alternative, except the no action alternative, includes restoring excavated areas by backfilling with clean fill material. The exposure mode associated with this component is mechanical injury. Remediation workers are the only receptors impacted by this component. Direct physical injury is included as a risk measure since each alternative includes different mechanical operations and this measure serves as a distinguishing feature among the alternatives. Figure D.2-8 depicts the conceptual model for remedial action risks associated with this component.

D.2.5.2 Conceptual Model for Residual Risks

Residual risks are risks that potentially remain after remedial action has been completed. Figure D.2-9 depicts the conceptual model for residual risks following completion of Operable Unit 1 remedial alternatives. The conceptual model has been developed to identify potential residual exposure pathways associated with the Operable Unit 1 alternatives. It addresses potential risks from contaminants that may remain within the boundaries of Operable Unit 1, Operable Unit 1 materials disposed elsewhere within the FEMP boundaries, and residual Operable Unit 1 contaminants that may in the future migrate beyond the boundaries of Operable Unit 1. Exposure pathways describe the course a chemical or radiological contaminant takes from a source to an exposed individual. An exposure pathway consists of four elements:

- A source and mechanism of contaminant release
- A contaminant transport medium/mechanism
- A point of potential human contact
- An exposure route and receptor

Operable Unit 1 sources, release and transport mechanisms, exposure media/modes, and receptors are arrayed in Figure D.2-9 to depict potential residual exposure pathways. These pathways represent potential exposures considered in the assessment of residual risks that may follow completion of Operable Unit 1 remedial actions. The remedial action alternatives discussed in Section D.2.2 are designed to eliminate or mitigate these exposure pathways, as appropriate, through the use of treatment, containment, and/or property institutional control measures.

Two engineering measures, waste treatment and containment, eliminate or mitigate pathway segments at the source/release mechanism level. On-site disposal facility containment features serve to eliminate surface and subsurface release mechanisms, and stabilized waste forms mitigate leaching and airborne releases in the event of facility degradation. In the absence of disposal facility and/or waste form failures, there would be no risk to humans from materials disposed in these facilities.

While institutional control measures can mitigate release mechanisms (e.g., access controls to prevent containment system damage), they generally address exposure control at the exposure mode/receptor level. The remedial alternatives include some degree of continued Federal ownership and land use restrictions. Land use restrictions and access controls included in the remedial alternatives would mitigate exposure to certain media (e.g., groundwater from the Great Miami Aquifer).

The conceptual model does not include potential risks for off-property disposal endpoints (Alternatives 5A and 5B), nor does it consider the no action alternative endpoints which are included in the Operable Unit 1 Baseline Risk Assessment, as summarized in Section D.2.0. The conceptual model does not consider existing contamination which is to be distinguished from background levels in groundwater, surface water, sediment or soil not within the boundaries of Operable Unit 1, nor does it consider impacts on flora and fauna. These concerns are within the scope of Operable Unit 5, as specified in the Revised Risk Assessment Work Plan Addendum.

The conceptual model for potential residual risk exposure pathways includes the following elements which apply to all remedial alternatives:

- Disposal of waste material in engineered facilities on-property or off-site, which prevents unintentional access to wastes for the period of the residual risk evaluation (1000 years). It is reasonable to expect on-site disposal facilities to survive substantially intact because facility designs include several layers of cap material that collectively provide adequate thickness to prevent exposure of disposed waste material to wind erosion. The cap material retards diffusion of radon before release to the atmosphere. On-site disposal alternatives involve stabilization of primary radon

sources through cementation or vitrification, further mitigating potential radon release. Engineering measures are also included to prevent water erosion of and infiltration into disposed waste materials, therefore surface water runoff pathways and release of waste from disposal facilities to groundwater are not included in the calculation of potential residual risks for the Operable Unit 1 site.

- Contaminated surface soil will be excavated and removed from Operable Unit 1 for treatment and disposal. No residual risk for the Operable Unit 1 site is therefore associated with contaminated soil that is currently at the surface (0-6").

- Subsurface soils that are currently beneath pit areas will, after removal of pit waste, be covered with at least 20 feet of clean fill. Residual contaminants in these soils will therefore have an insignificant potential for re-exposure at the surface and a concomitant greatly reduced potential for exposure pathways involving external radiation, direct contact, resuspension of dust or runoff to surface water. Residual contamination in waste pit subsurface soils do have the potential, however, for release to groundwater through leaching. Groundwater exposure pathways are therefore included in the conceptual model for Operable Unit 1 residual risk.

- Subsurface soils in non-pit areas will be covered by 6 to 12 inches of clean fill. Residual contaminants in these subsurface soils may be released to groundwater and may also be re-exposed at the surface, for example through plowing by an on-site farmer. Groundwater and surface soil (external radiation, inhalation of resuspended dust, direct dermal contact, incorporation into crops and farm animals) exposure pathways are therefore included in the conceptual model for Operable Unit 1 residual risk.

D.2.6 ASSUMPTIONS FOR ANALYSIS OF REMEDIAL ACTION AND RESIDUAL RISKS

The assumed scope of analysis, exposure parameters, pathways and receptors, extent and type of remedial activity, COCs and other factors establish the complexity, usefulness and results of any risk evaluation. The following discussion highlights key assumptions used to develop the FS risk analysis.

D.2.6.1 Assumptions for Analysis of Remedial Action Risks

The assessments of remedial action risks required an number of assumptions for each element of the assessment, including exposure scenarios, receptors, exposure models, and exposure parameters. The assumptions are documented below:

1. During excavation, remediation workers operating heavy equipment are inside supplied air cabs and wear an appropriate level of personal protective equipment. These workers are protected from inhaling airborne contaminants and from direct radiation during routine work. The only remedial action risks they are subjected to are direct physical injury, e.g., in the event of a heavy equipment accident. Any impacts from the intake of contaminated material or exposure to direct radiation during a heavy equipment accident are considered negligible. The exposure duration is short and the concentrations and radiation fields within Operable Unit 1 are low.

2. At the end of excavation, remediation workers monitoring soil contamination levels are exposed to contaminated soil at soil action levels. The monitoring is assumed to take place at the end of remediation when the levels will be at or near the action levels.

3. During excavation, remediation workers monitoring soil contamination levels are dressed in Level B personnel protective equipment. This level of personal protection reduces exposure from inhalation by a factor of 50 and eliminates dermal contact with contaminants. These remediation workers are impacted by immersion in contaminated air only.

4. During all components of a given remedial alternative (i.e., excavation, drying, vitrification/solidification, on-property disposal, transportation, and restoration) the mechanical injury rate is constant. The one exception to this assumption is for truck drivers and train crews, whose injury rates are specific to those two operations.

5. Pit cap covers are contaminated to the same level as the surrounding surface soil. Pit liners and the 3 feet of underlying soil are contaminated to the same level as the waste within the pits.

6. Drying releases 50 percent of the volatile organic compounds (VOCs) and radon within the waste. The radon concentration within the soil is equal to the Ra-226 (i.e., the Rn-220 is in secular equilibrium with the Ra-226). The off-gas system contains all released particulate material and none of the VOCs and radon.

7. During drying, operators are not exposed to the off-gas plume, eliminating exposure from inhaling contaminants and dermal contact with contaminants.

8. Vitrifying and solidifying in concrete releases the remaining 50 percent of the VOCs and radon within the waste. The radon concentration within the soil is equal to the Ra-226 (i.e., the Rn-220 is in secular equilibrium with the Ra-226). The off-gas system contains any released particulate material.

9. During vitrification/solidification, operators are not exposed to the off-gas plume, eliminating exposure from inhaling and dermal contact with contaminants.

10. During restoration, the only risks are associated with mechanical hazards since backfilling will cover any residual contamination.

11. Non-remediation workers are assumed to have no respiratory protection (e.g., a respirator), but are protected from dermal contact by protective clothing.

12. During waste emplacement in the on-property disposal cell, remediation workers are inside heavy equipment and are protected form exposure to direct radiation from the waste material. This assumption is based on the low dose rates associated with the stabilized waste and the shielding provided by the equipment.

13. Nonremediation and off-site individual receptors are assumed to be along the airborne contamination plume centerline. The off-site individual resides at a location relative to the release towards which the wind blows the most in one year.

14. Operators of the dryer, vitrifier, and cement solidifier are not subject to mechanical hazards, since most of their operations will involve remote handling equipment.

15. Waste pit materials and liners are sufficiently wet so that pit material will not be resuspended during excavation. Surface soils and cap materials are available for resuspension.

16. Trucks transporting packages between the rail yard in Las Vegas and NTS are in constant use (i.e., go back and forth between Las Vegas and NTS). The mileage used in risk estimates is the round-trip mileage between Las Vegas and NTS.

17. Impacts from on-property transport (if any) and temporary stockpiling of waste material have been ignored. It is assumed that engineering controls and administrative practices will eliminate any significant (i.e., measurable) impacts.

18. There are no ingestion pathway risks associated with transportation accidents. Any significant crop contamination would trigger crop interdiction.

D.2.6.2 Assumptions for Analysis of Residual Risks

Evaluation of residual risks remaining after Operable Unit 1 remediation required a number of assumptions regarding future land use, receptors, exposure scenarios and exposure parameters. The assumptions listed below have been adopted from EPA guidance documents or have been used as the result of agreement between the FEMP and EPA.

1. Two future land use scenarios are considered: government ownership with some limited access controls and private ownership with a residential farm family on the property.

2. For the case of future government ownership with some limited access controls, evaluated receptors are an off-property farmer and child and an expanded trespasser.

3. For the case of future private ownership, evaluated receptors are an on-property resident farmer and child and an off-property farmer and child.

4. The on-property farmer and child are part of a farm family living on the Operable Unit 1 site, growing crops and raising dairy cows and using groundwater for routine household and agricultural purposes.

5. The off-site farmer and child are part of a family living and actively farming adjacent to the FEMP site boundary. Exposure to contaminants is through groundwater pathways and resuspended surface soil.

6. The expanded trespasser occasionally visits the Operable Unit 1 property for hiking, roaming or bird watching. Activities such as jogging, biking or ball playing will not be feasible because the land is undeveloped.

7. Adult exposure period (70 yrs) and child is (0-6 yrs) receptors are included in the risk analysis. FEMP has agreed with EPA to use a 70-year exposure period for adult residential exposure because residents in the Fernald area tend to remain in the area for their lifetime.

8. All current surface soil within the OU1 boundary not removed by pit remediation,excluding surface soils north of the railroad tracks (unless shown to be contaminated), will be removed to a depth of six inches. The subsurface soil at the six inch depth will be assumed to contain COCs at the soil action level to which the on-

property farmer and child are assumed to be exposed. This assumption leads to the following for the residual risk assessment:

- Surface water and sediment pathways are eliminated
- Surface soil pathways (dust, volatiles, radon) are included on the assumption that subsurface soil from non-pit areas is brought to the surface by some means (e.g., plowing).
- Subsurface soil contaminant percolation pathways are included

9. All pits are assumed to be excavated to three feet below the liner. This assumption includes pits in which the liner is close to or at the sand and gravel aquifer interface. This assumption is being made for costing purposes. Pit area soil below excavation levels is assumed to contain COCs at action level concentrations for groundwater risk assessment. It is also assumed that the disposal cell cap will remain intact for 1000 years. The caps over the excavated pit areas will also last 1000 years, but are not designed with intrusion barriers.

10. COCs were chosen based on Operable Unit 1 Baseline Risk Assessment results. Constituents with a greater than 10^{-7} Incremental Lifetime Cancer Risk (ILCR) or Hazard Quotient (HQ) of greater than 0.1 by all combined exposure pathways were considered COCs.

11. Groundwater COC input concentrations for the residual risk assessment are based on a groundwater modeling effort not ambient sampling data.

12. Resuspension factors used to evaluate particulate release due to remedial actions are from the Operable Unit 1 baseline RA for on-property and off-site receptors.

13. ILCRs calculated to be greater than 10^{-2} have not been recalculated using the equations in EPA's Risk Assessment Guidance for Superfund (RAGS).

14. Chronic Reference Doses (RfDs) are used for all risk calculations.

15. No credit is given for background concentrations in the PRGs or risk estimates.

16. The impact of Operable Unit 1 residual contaminant sources on perched groundwater in the sand lens beneath the waste pits (perched groundwater) and groundwater in the Great Miami Aquifer (GMA) is included in the Operable Unit 1 residual risk evaluation. By agreement with EPA, existing groundwater contamination is to be considered by Operable Unit 5.

D.2.7 CONSTITUENTS OF CONCERN

Not all constituents identified during the Operable Unit 1 RI pose significant health risks. The baseline RA evaluated constituents and exposure pathways to ascertain their potential present and future impacts on human health. In general, constituents that resulted in risks to a receptor of greater than 10^{-7} or which yielded a hazard quotient greater than 0.1 in the baseline RA were designated as constituents of concern (COC) to be considered in the selection of remedial alternatives. These COCs and the media in which the cancer risk level or HI was greater than 10^{-7} or 0.1, respectively, are

presented in Section 1.0 of this FS/PP-EA. These target levels were chosen as a screening tool and to protect against removal of those COCs summing to greater than 10^{-6}.

TABLE D.2-1

INCREMENTAL LIFETIME CANCER RISK SUMMARY
CURRENT LAND USE, CURRENT SOURCE TERM

Media	Groundskeeper	Off-property Farmer	Off-property Child	Trespassing Youth	Off-property User of Meat and Milk Products
Air					
Radiocarcinogenic Risk	5.9E-06	3.1E-06	1.6E-07	7.0E-07	NA
Chemical Carcinogenic Risk	3.0E-09	1.4E-07	7.4E-08	5.8E-10	NA
Total:[a]	5.9E-06	3.2E-06	2.3E-07	7.0E-07	NA
Surface Soil					
Radiocarcinogenic Risk	3.0E-05	NA	NA	1.0E-05	1.9E-04
Chemical Carcinogenic Risk	1.1E-05	NA	NA	9.1E-06	8.1E-04
Total:[a]	4.1E-05	NA	NA	1.9E-05	1.0E-03
Buried Pit Material					
Radiocarcinogenic Risk	4.7E-05	NA	NA	1.7E-05	NA
Chemical Carcinogenic Risk	NA	NA	NA	NA	NA
Total:[a]	4.7E-05	NA	NA	1.7E-05	NA
On-property Surface Water					
Radiocarcinogenic Risk	NA	NA	NA	NA	2.3E-04
Chemical Carcinogenic Risk	NA	NA	NA	NA	5.6E-06
Total:[a]	NA	NA	NA	NA	2.3E-04
Sum All Media					
Radiocarcinogenic Risk	8.2E-05	3.1E-06	1.6E-07	2.8E-05	4.2E-04
Chemical Carcinogenic Risk	1.1E-05	1.4E-07	7.4E-08	9.1E-06	8.1E-04
Total:[a]	9.4E-05	3.2E-06	2.3E-07	3.7E-05	1.2E-03

NA - Not applicable. Exposure route not evaluated for receptor.

[a] Radiocarcinogenic and chemocarcinogenic risks are not truly additive. A total is provided for reference only.

TABLE D.2-2
HAZARD INDEX SUMMARY
CURRENT LAND USE, CURRENT SOURCE TERM

Media	Groundskeeper	Off-property Farmer	Off-property Child	Trespassing Youth	Off-property User of Meat and Milk Products
Air	0.0E+00	2.1E-04	1.1E-03	0.0E+00	NA
Surface Soil	2.9E-01	NA	NA	4.8E-01	2.2E+00
On-property Surface Water	NA	NA	NA	NA	2.3E-01
Sum All Media	2.9E-01	2.1E-04	1.1E-03	4.8E-01	2.4E+00

NA - Not applicable. Exposure route not evaluated for receptor.

TABLE D.2-3

INCREMENTAL LIFETIME CANCER RISK SUMMARY
CURRENT LAND USE, FUTURE SOURCE TERM

Medium	Trespassing Youth	Great Miami River User
Air		
Radiocarcinogenic Risk	8.5E-05	NA
Chemical Carcinogenic Risk	4.3E-05	NA
Total:[a]	1.3E-04	NA
Surface Soil		
Radiocarcinogenic Risk	1.1E-04	NA
Chemical Carcinogenic Risk	7.4E-05	NA
Total:[a]	1.8E-04	NA
Buried Pit Material		
Radiocarcinogenic Risk	7.2E-06	NA
Chemical Carcinogenic Risk	NA	NA
Total:[a]	7.2E-06	NA
Paddys Run Surface Water		
Radiocarcinogenic Risk	6.6E-08	NA
Chemical Carcinogenic Risk	5.7E-08	NA
Total:[a]	1.2E-07	NA
Paddys Run Sediment		
Radiocarcinogenic Risk	3.5E-06	NA
Chemical Carcinogenic Risk	9.5E-06	NA
Total:[a]	1.3E-05	NA
Great Miami River Surface Water		
Radiocarcinogenic Risk	NA	2.5E-07
Chemical Carcinogenic Risk	NA	2.8E-08
Total:[a]	NA	2.8E-07
All Media		
Radiocarcinogenic Risk	2.0E-04	2.5E-07
Chemical Carcinogenic Risk	1.3E-04	2.8E-08
Total:[a]	3.3E-04	2.8E-07

NA - Not Applicable. Exposure route not evaluated for this receptor.

[a] Radiocarcinogenic risk and chemocarcinogenic risk are not truly additive. A total is provided for reference only.

TABLE D.2-4

HAZARD INDEX SUMMARY
CURRENT LAND USE, FUTURE SOURCE TERM

Medium	Trespassing Youth	Great Miami River User
Air	2.5E-01	NA
Surface Soil	1.5E+00	NA
Paddys Run Surface Water	3.9E-02	NA
Paddys Run Sediment	1.1E-01	NA
Great Miami River Surface Water	NA	4.2E-03
All Media	1.9E+00	4.2E-03

NA - Not Applicable. Exposure route not evaluated for this receptor.

TABLE D.2-5

INCREMENTAL LIFETIME CANCER RISK SUMMARY
FUTURE LAND USE (GOVERNMENT RESERVE)
FUTURE SOURCE TERM

Medium	On-property Groundskeeper	Expanded Trespasser
Air		
Radiocarcinogenic Risk	7.2E-04	1.3E-04
Chemical Carcinogenic Risk	2.2E-04	6.0E-05
Total:[a]	9.4E-04	1.9E-04
Surface Soil/Exposed Pit Material		
Radiocarcinogenic Risk	4.1E-04	2.5E-04
Chemical Carcinogenic Risk	2.1E-04	2.0E-04
Total:[a]	6.1E-04	4.5E-04
Buried Pit Material		
Radiocarcinogenic Risk	4.7E-05	2.6E-05
Chemical Carcinogenic Risk	NA	NA
Total:[a]	4.7E-05	2.6E-05
Paddys Run Surface Water		
Radiocarcinogenic Risk	NA	6.6E-08
Chemical Carcinogenic Risk	NA	5.7E-08
Total:[a]	NA	1.2E-07
Paddys Run Sediment		
Radiocarcinogenic Risk	NA	3.5E-06
Chemical Carcinogenic Risk	NA	9.5E-06
Total:[a]	NA	1.3E-05
All Media		
Radiocarcinogenic Risk	1.2E-03	4.1E-04
Chemical Carcinogenic Risk	4.3E-04	2.7E-04
Total:[a]	1.6E-03	6.8E-04

NA - Not Applicable. Exposure route not evaluated for this receptor.

[a] Radiocarcinogenic risk and chemocarcinogenic risk are not truly additive. A total is provided for reference only.

TABLE D.2-6

HAZARD INDEX SUMMARY
FUTURE LAND USE (GOVERNMENT RESERVE)
FUTURE SOURCE TERM

Medium	Groundskeeper	Expanded Trespasser
Air	6.2E-01	2.9E-01
Surface Soil/Exposed Pit Material	1.5E+00	3.4E+00
Paddys Run Surface Water	NA	3.9E-02
Paddys Run Sediment	NA	1.1E-01
All Media	2.1E+00	3.8E+00

NA - Not Applicable. Exposure route not evaluated for this receptor.

TABLE D.2-7

INCREMENTAL LIFETIME CANCER RISK SUMMARY
FUTURE LAND USE (AGRICULTURAL USE)
FUTURE SOURCE TERM

Media	On-property RME Farmer[b]	On-property RME Farmer[b] (User of Perched GW)	On-property CT Farmer	On-property Child	Off-property Farmer	Off-property Child	Homebuilder	Off-property User of Meat and Milk Products
Air								
Radiocarcinogenic Risk	4.8E-03	4.8E-03	3.5E-04	9.2E-05	2.2E-04	4.2E-06	5.1E-05	1.2E-05
Chemical Carcinogenic Risk	4.7E-03	4.7E-03	3.2E-04	1.2E-03	2.9E-04	7.4E-05	1.6E-05	7.7E-04
Total:[a]	9.5E-03	9.5E-03	6.8E-04	1.3E-03	5.1E-04	7.8E-05	6.7E-05	7.8E-04
Exposed Waste Pit Materials								
Radiocarcinogenic Risk	2.1E-02	2.1E-02	2.0E-03	1.6E-03	NA	NA	2.3E-05	NA
Chemical Carcinogenic Risk	9.4E-03	9.4E-03	5.8E-04	3.8E-03	NA	NA	4.7E-05	NA
Total:[a]	3.0E-02	3.0E-02	2.6E-03	5.4E-03	NA	NA	7.0E-05	NA
Surface Soil								
Radiocarcinogenic Risk	3.4E-04	3.4E-04	2.0E-05	4.6E-05	NA	NA	NA	1.9E-04
Chemical Carcinogenic Risk	9.1E-04	9.1E-04	5.5E-05	5.0E-04	NA	NA	NA	8.1E-04
Total:[a]	1.3E-03	1.3E-03	7.5E-05	5.4E-04	NA	NA	NA	1.0E-03
Buried Pit Material								
Radiocarcinogenic Risk	1.2E-03	1.2E-03	1.6E-04	2.5E-07	NA	NA	2.7E-06	NA
Chemical Carcinogenic Risk	NA	NA	NA	NA	NA	NA	NA	NA
Total:[a]	1.2E-03	1.2E-03	1.6E-04	2.5E-07	NA	NA	2.7E-06	NA
On-property Surface Water								
Radiocarcinogenic Risk	2.6E-04	2.6E-04	1.5E-05	4.1E-05	NA	NA	NA	2.6E-04
Chemical Carcinogenic Risk	6.1E-06	6.1E-06	4.0E-07	1.4E-06	NA	NA	NA	6.1E-06
Total:[a]	2.6E-04	2.6E-04	1.5E-05	4.3E-05	NA	NA	NA	2.6E-04
Groundwater								
Radiocarcinogenic Risk	2.3E-02	5.2E-01	1.6E-03	1.2E-03	1.7E-03	9.1E-05	NA	NA
Chemical Carcinogenic Risk	3.9E-02	9.1E-01	2.7E-03	9.4E-03	0.0E+00	0.0E+00	NA	NA
Total:[a]	6.2E-02	9.6E-01	4.3E-03	1.1E-02	1.7E-03	9.1E-05	NA	NA
All Media								
Radiocarcinogenic Risk	4.9E-02	5.3E-01	4.1E-03	3.0E-03	1.9E-03	9.6E-05	7.7E-05	4.6E-04
Chemical Carcinogenic Risk	5.4E-02	9.1E-01	3.7E-03	1.5E-02	2.9E-04	7.4E-05	6.3E-05	1.6E-03
Total:[a]	1.1E-01	9.6E-01	7.8E-03	1.8E-02	2.2E-03	1.7E-04	1.4E-04	2.0E-03

NA - Not applicable. Exposure route not evaluated for receptor.

[a] Radiocarcinogenic and chemocarcinogenic risks are not truly additive. A total is provided for reference only.

[b] Risks calculated and total summed based on the use of the 1-hit equation for calculating risks from higher doses (EPA 1989a).

TABLE D.2-8

HAZARD INDEX SUMMARY
FUTURE LAND USE (AGRICULTURAL USE)
FUTURE SOURCE TERM

Media	On-property RME Farmer	On-property RME Farmer (User of Perched GW)	On-property CT Farmer	On-property Child	Off-property Farmer	Off-property Child	Homebuilder	Off-property User of Meat an Milk Products
Air	8.4E+00	8.4E+00	4.3E+00	2.8E+01	5.2E-01	1.7E+00	1.1E+00	1.9E+00
Exposed Waste Pit Materials	2.3E+01	2.3E+01	9.8E+00	9.7E+01	NA	NA	7.3E+00	NA
Surface Soil	4.7E+00	4.7E+00	2.3E+00	2.5E+01	NA	NA	NA	2.2E+00
On-property Surface Water	3.3E-01	3.3E-01	1.5E-01	2.7E+00	NA	NA	NA	3.3E-01
Groundwater	5.0E+02	6.0E+03	2.7E+02	1.4E+03	3.1E+01	8.7E+01	NA	NA
All Media	5.4E+02	6.1E+03	2.9E+02	1.6E+03	3.2E+01	8.9E+01	8.4E+00	4.3E+00

NA - Not applicable. Exposure route not evaluated for receptor.

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TABLE D.2-9

OPERABLE UNIT 1
CONSTITUENTS OF CONCERN

	Sediment	Air	Surface Soil	Groundwater	Perched Water	Surface Water
RADIOLOGICAL COCs						
Cs-137	X	X	X			X
Np-237		X	X		X	
Pu-238		X	X	X	X	
Pu-239/240	X	X	X			
Ra-226 + 5 dtr		X				
Sr-90 + 1 dtr		X	X		X	X
Tc-99		X	X	X	X	X
Th-230		X	X	X	X	
Th-232 + 10 dtr	X	X	X		X	
U-234		X	X	X	X	X
U-235 + dtr	X	X	X	X	X	X
U-238 + 2 dtr	X	X	X	X	X	X
INORGANICS						
Antimony			X			
Arsenic	X	X	X			X
Beryllium	X	X	X			
Cadmium		X	X			
Chromium		X	X		X	
Cobalt		X				
Copper					X	
Lead	X		X	X	X	X
Manganese		X	X	X	X	
Molybdenum		X	X		X	
Mercury		X	X			
Nickel		X	X		X	
Silver		X	X		X	X

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TABLE D.2-9
(Continued)

	Sediment	Air	Surface Soil	Groundwater	Perched Water	Surface Water
Thallium	X	X	X			
Uranium		X	X	X	X	X
Vanadium		X	X			
PCBs						
Aroclor 1248		X	X			
Aroclor 1254		X	X			
Aroclor 1260		X	X			
PAHs						
Benzo(a)anthracene		X	X			
Benzo(a)pyrene		X	X			
Benzo(b)fluoranthene		X	X			
Benzo(k)fluoranthene			X	X		
Chrysene		X	X			
Indeno(1,2,3-cd)pyrene		X	X			
VOCs						
Tetrachloroethene						X
Pentachlorophenol			X			
Vinyl Chloride				X	X	
Polychlorinated Dibenzodioxins						
2378 Tetra CDD			X	X		
Hepta CDD			X	X		
Hexa CDD			X	X		
Octa CDD			X	X		
Polychlorinated Dibenzofurans						
Hepta CDF			X	X		
Hexa CDF			X	X		

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TABLE D.2-10

UNCERTAINTIES ASSOCIATED WITH ESTIMATED RISKS FROM OPERABLE UNIT 1

Source of Uncertainty	Magnitude[a]	Expected Direction[b]	Remark
Selection of CPCs:			
• Adequacy of database	Low to Moderate	Increases or decreases conservatism	CPCs may be underestimated. Principal constituents were identified.
Exposure Assessment:			
• Calculated exposure point concentrations - positive bias in sampling	Moderate	Increases conservatism	Source concentrations based on 95% UCL or maximum. Sampling was biased for radiological CPCs
- conservative modeling assumptions	High	Increases conservatism	Modeled concentrations were conservative.
• Determination of land uses - current scenario	Low	Increases conservatism	Scenario based on current environmental setting
- future scenario	High	Increases conservatism	Worst case scenario assumed.
• Assumptions for source terms - current source term	Low	Increases or decreases conservatism	Current source term assumes waste pits covered and surface water runoff treated.
- future source term	Moderate	Increases conservatism	Future source term assumes failure of Waste Pit 3 cap.
• Selection of receptors - current scenario	Low	Increases conservatism	Scenario based on current environmental setting.
- future scenario	High	Increases conservatism	Worst case scenario assumed.
• Determination of exposure factors	Low to moderate	Increases conservatism	Receptor and exposure pathway specific.

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TABLE D.2-10
(Continued)

Source of Uncertainty	Magnitude[a]	Expected Direction[b]	Remark
Toxicity Assessment:			
• Dose-response assessment			
- chemical CPCs	High	Increases conservatism	Dose-response based on animal data.
- radiological CPCs	Low	Increases conservatism	Dose-response based on human data.
internal	Moderate to high	Increases conservatism	Conservative assumptions made for external exposure.
external			
• Other OU1 CPCs	Low	Increases conservatism	PAHs pose low risk.
- dose-response for PAHs	Low	Increases conservatism	PCBs pose relatively low risk.
- dose-response for PCBs	Low	Increases conservatism	Furans/dioxins relatively low risk.
- dose-response for dioxins/furans	Low to moderate	Increases conservatism	Assumptions for indoor Rn-222 differ from those made for the CSF.
- dose-response for Rn-222 (indoors)			
Risk Characterization:			
• Additivity	Low to moderate	Increases conservatism	Health effects dominated from few CPCs and exposure pathways.
• Failure to consider antagonism	Unknown	Increases conservatism	Data unknown.
• Failure to consider synergism	Unknown	Decreases conservatism	Data unknown.
• Failure to consider segregation of HIs	Low	Increases conservatism	HIs dominated by few CPCs and exposure pathways.
Overall	High	Increases conservatism	High uncertainty from combining low, moderate, and highly uncertain parameters.

[a] Magnitude is assessed qualitatively based on professional judgment and includes the following:
Low-impact risk by a factor of 10 or less.
Moderate-impact risk by a factor of 10 to 100.
High-impact risk by a factor of 100 or more.
[b] Direction is assessed qualitatively where an increased conservatism increases final health effects and a decreased conservatism decreases final health effects calculated in risk assessment.

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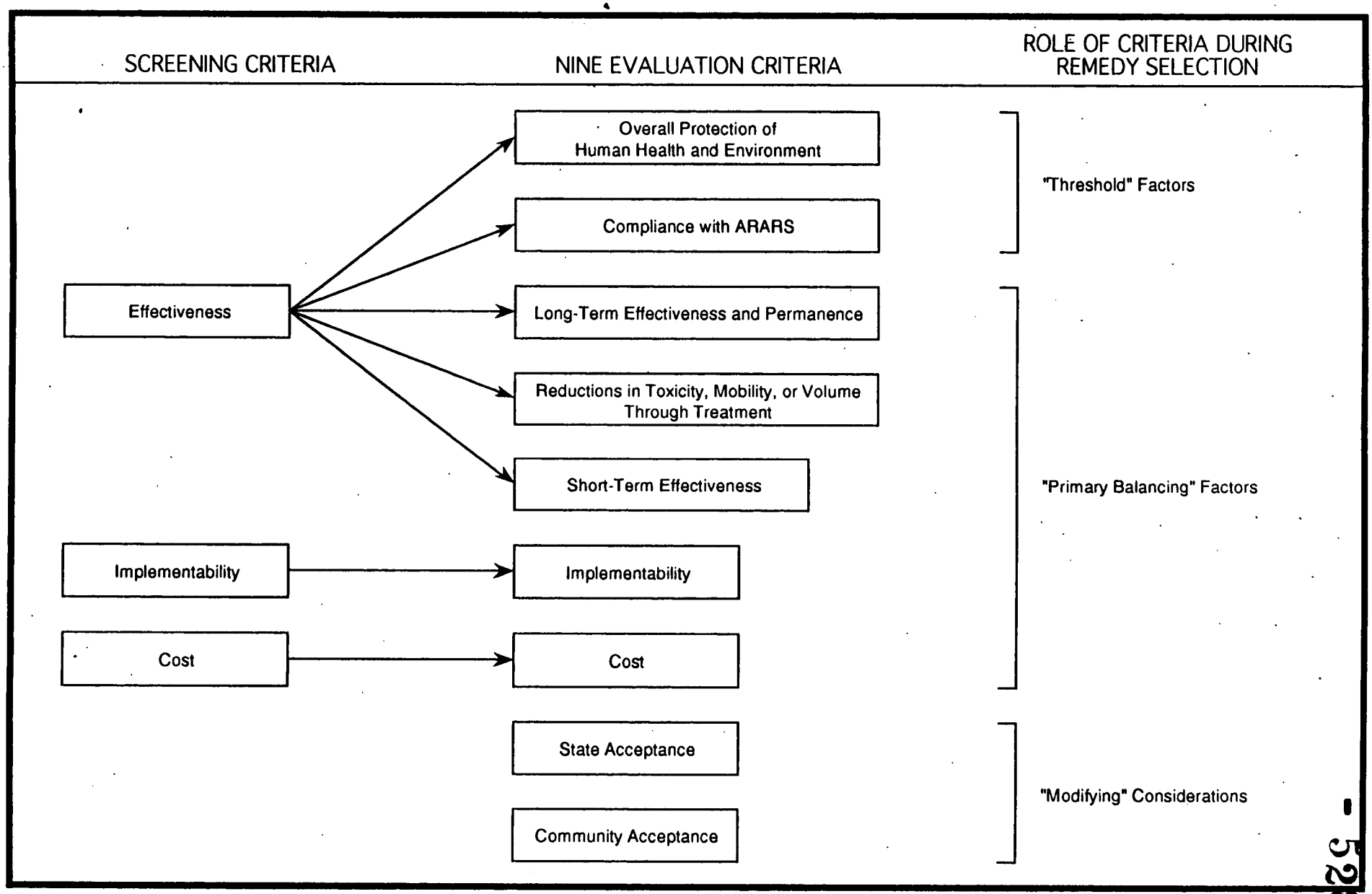

FIGURE D.2-1
OPERABLE UNIT 1
RELATIONSHIP OF SCREENING CRITERIA TO THE NINE EVALUATION CRITERIA

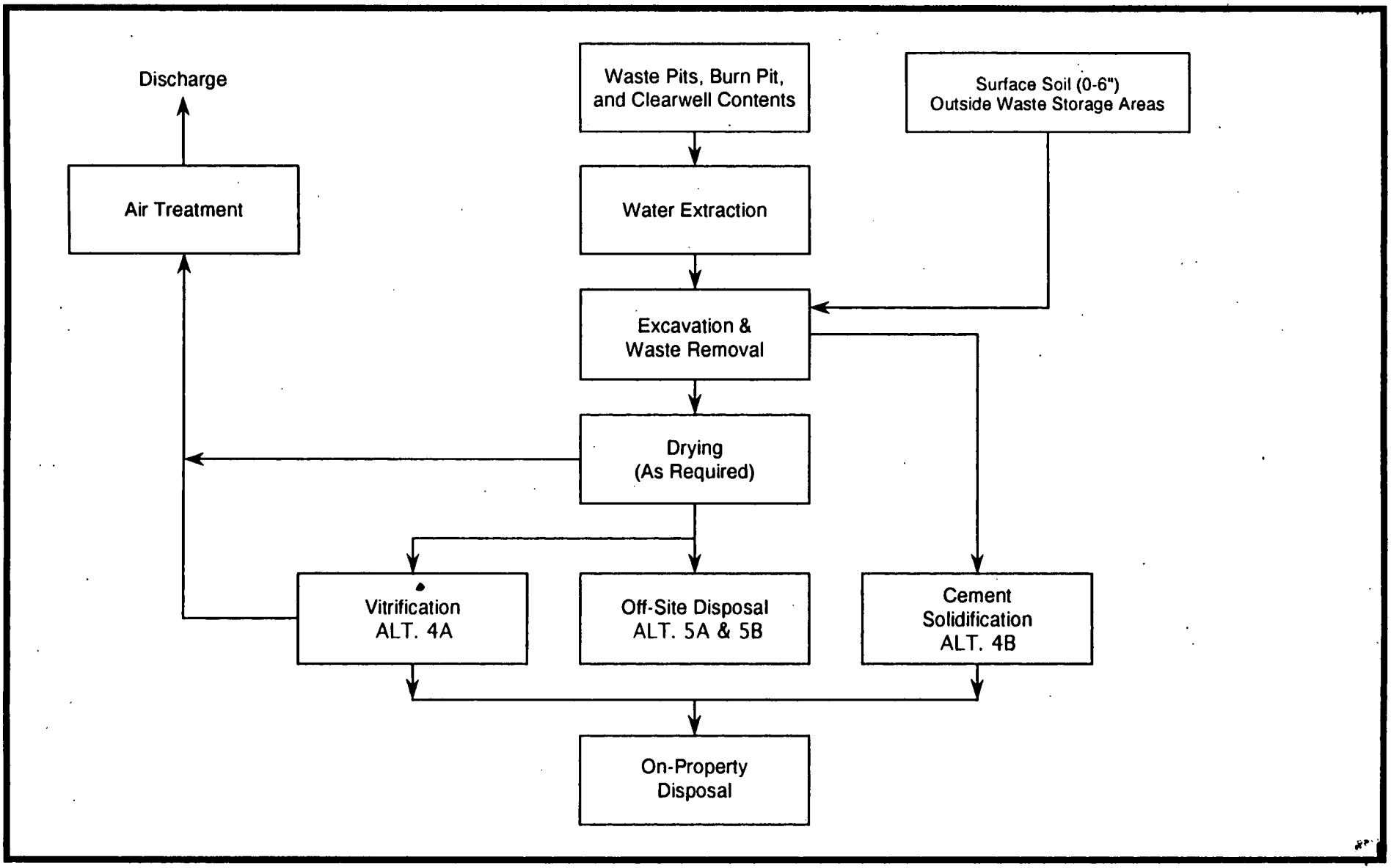

FIGURE D.2-2
OPERABLE UNIT 1
ALTERNATIVES 4A, 4B, 5A AND 5B - REMOVAL, TREATMENT, AND DISPOSAL CONCEPTUAL FLOW DIAGRAM

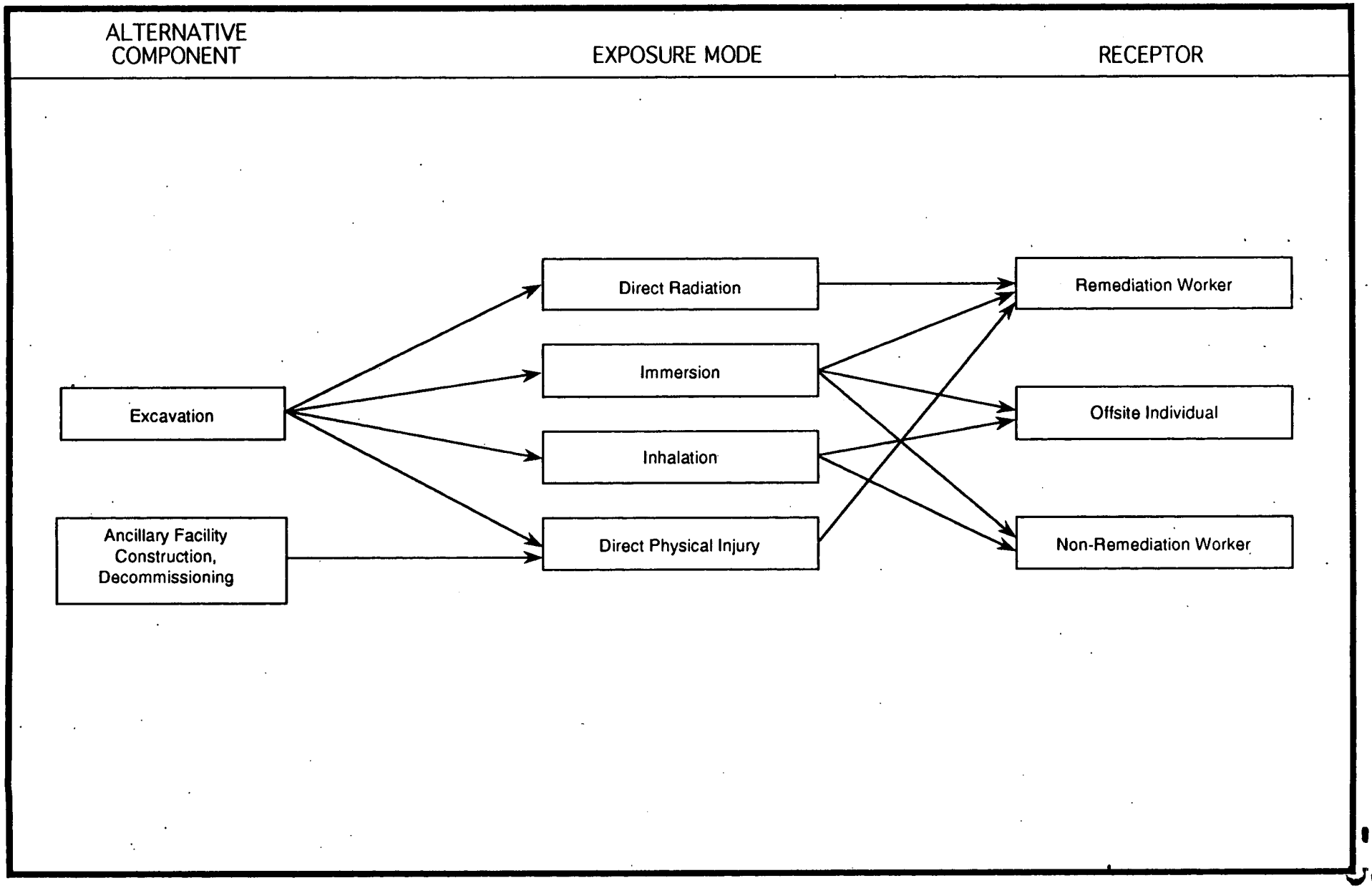

FIGURE D.2-3
OPERABLE UNIT 1
CONCEPTUAL MODEL FOR REMEDIAL ACTION RISKS - EXCAVATION

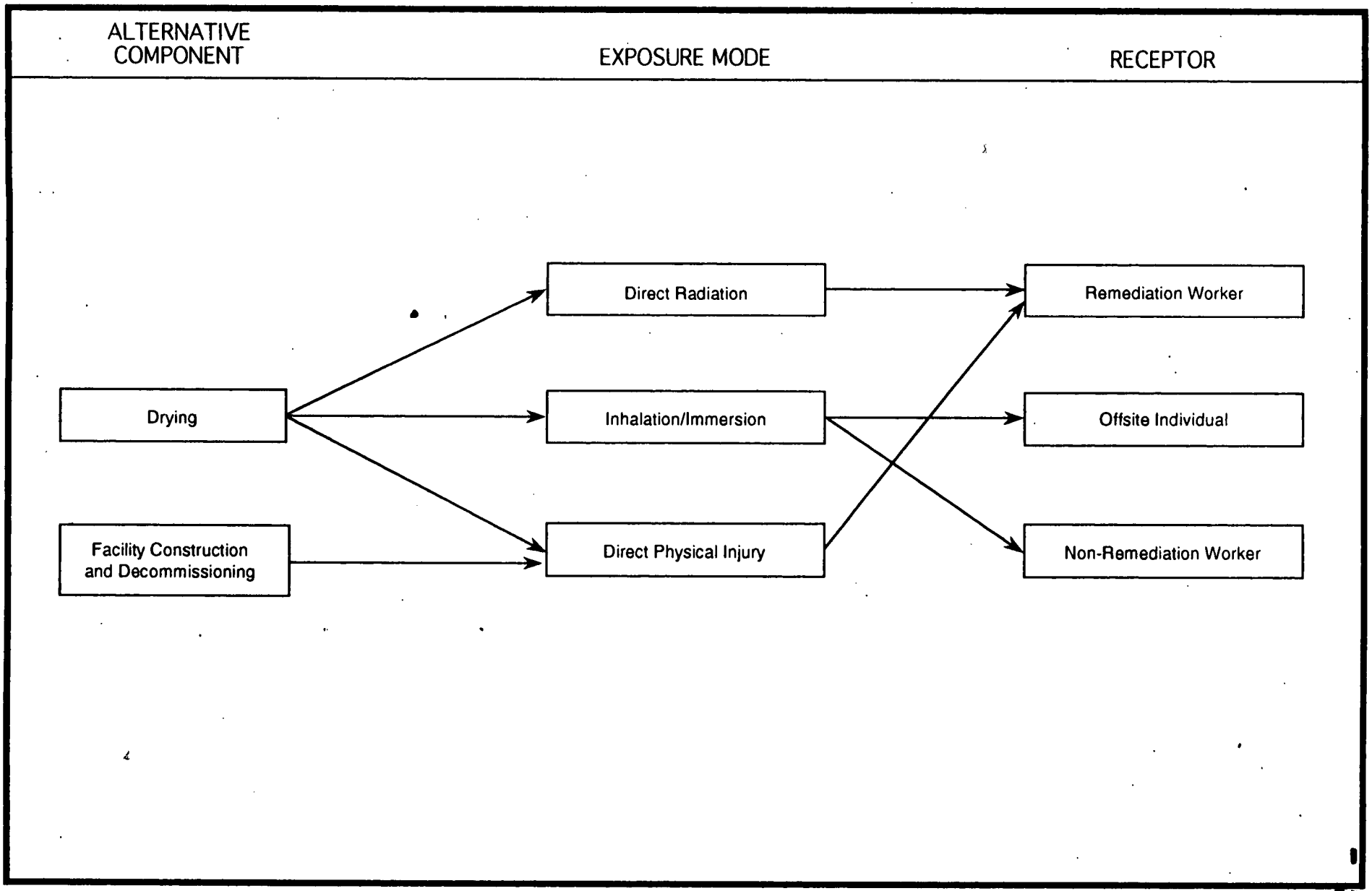

FIGURE D.2-4
OPERABLE UNIT 1
CONCEPTUAL MODEL FOR REMEDIAL ACTION RISKS - DRYING

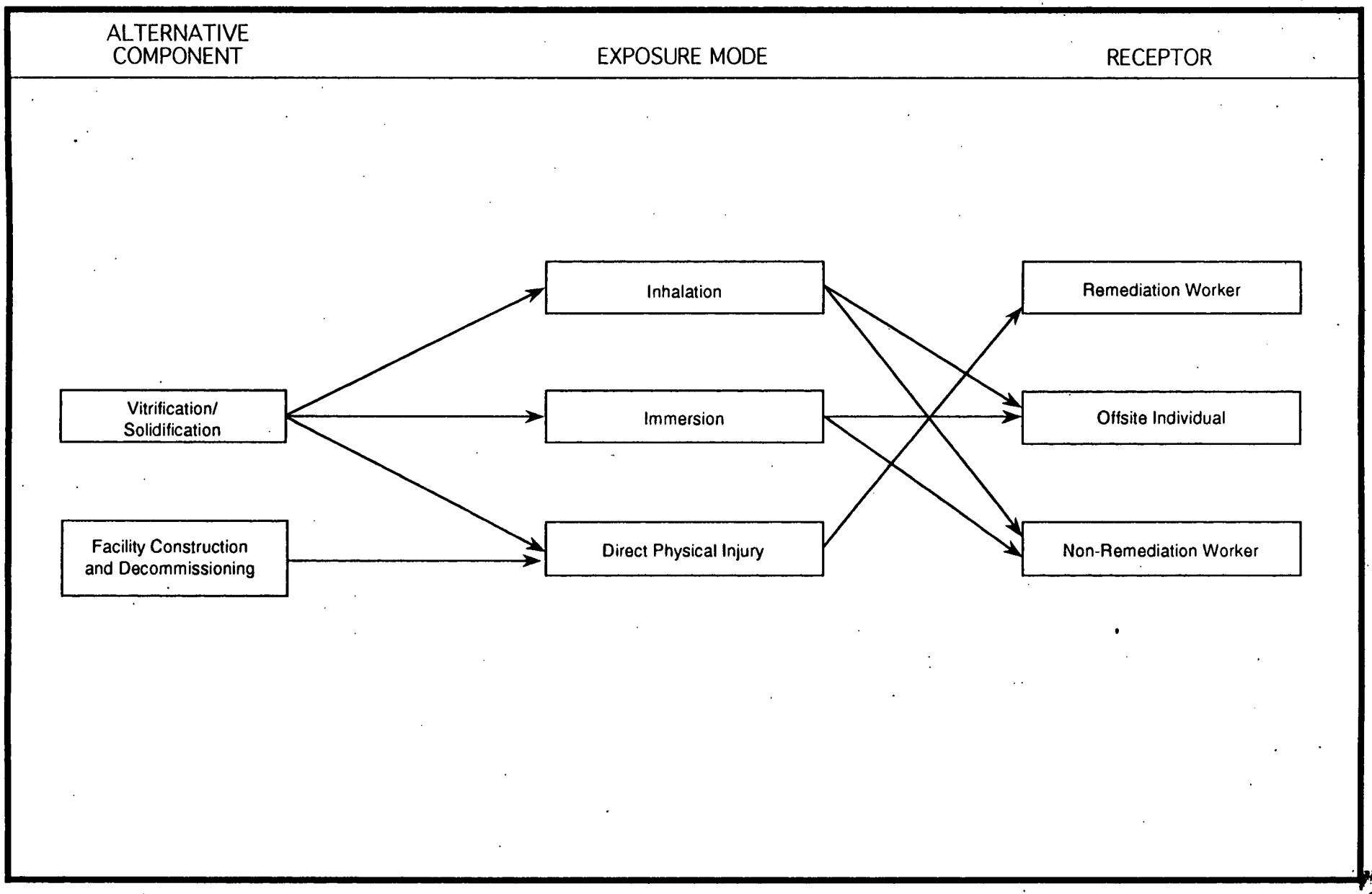

FIGURE D.2-5
OPERABLE UNIT 1
CONCEPTUAL MODEL FOR REMEDIAL ACTION RISKS -
VITRIFICATION/SOLIDIFICATION

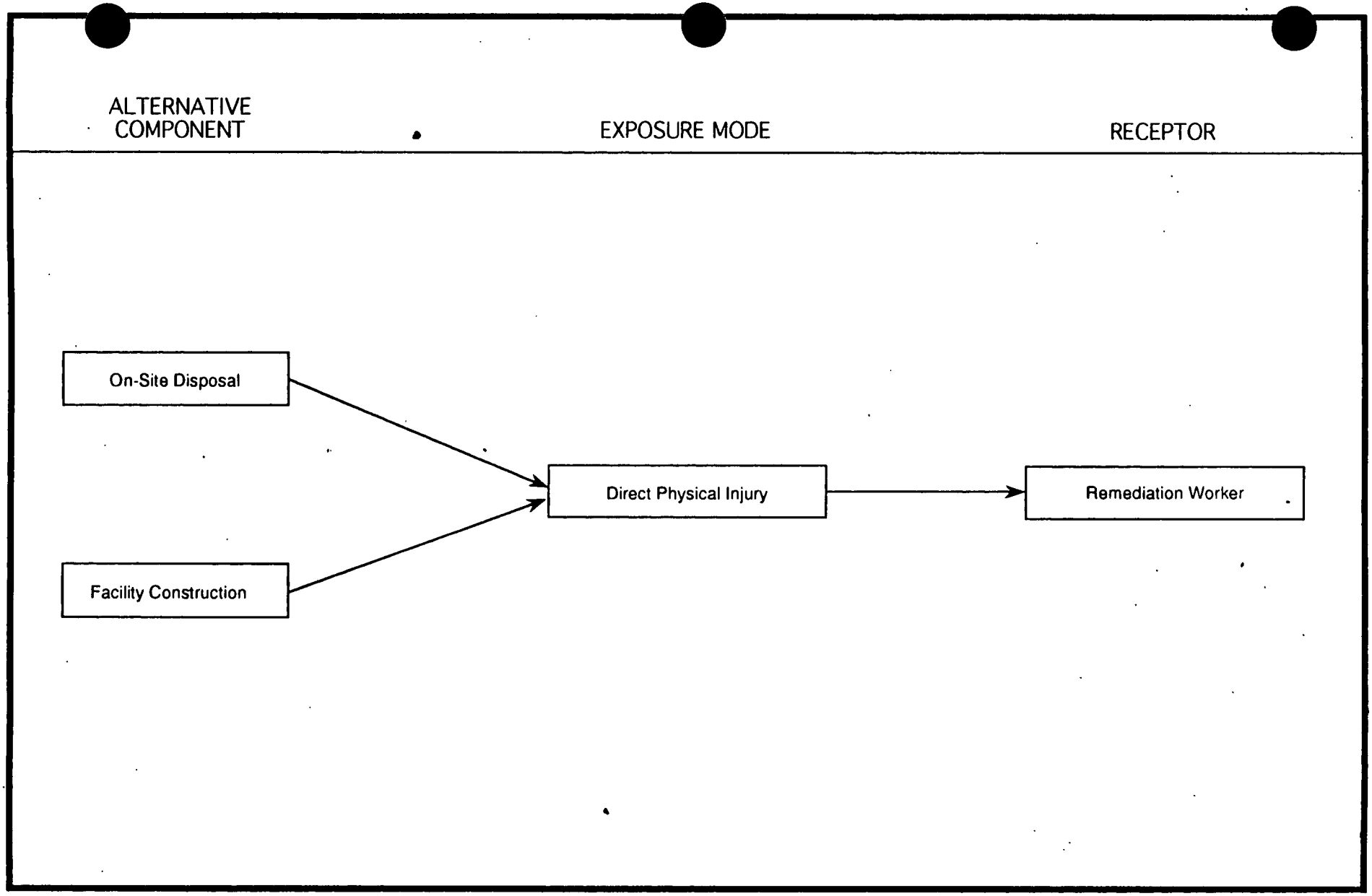

FIGURE D.2-6
OPERABLE UNIT 1
CONCEPTUAL MODEL FOR REMEDIAL ACTION - ON-SITE DISPOSAL

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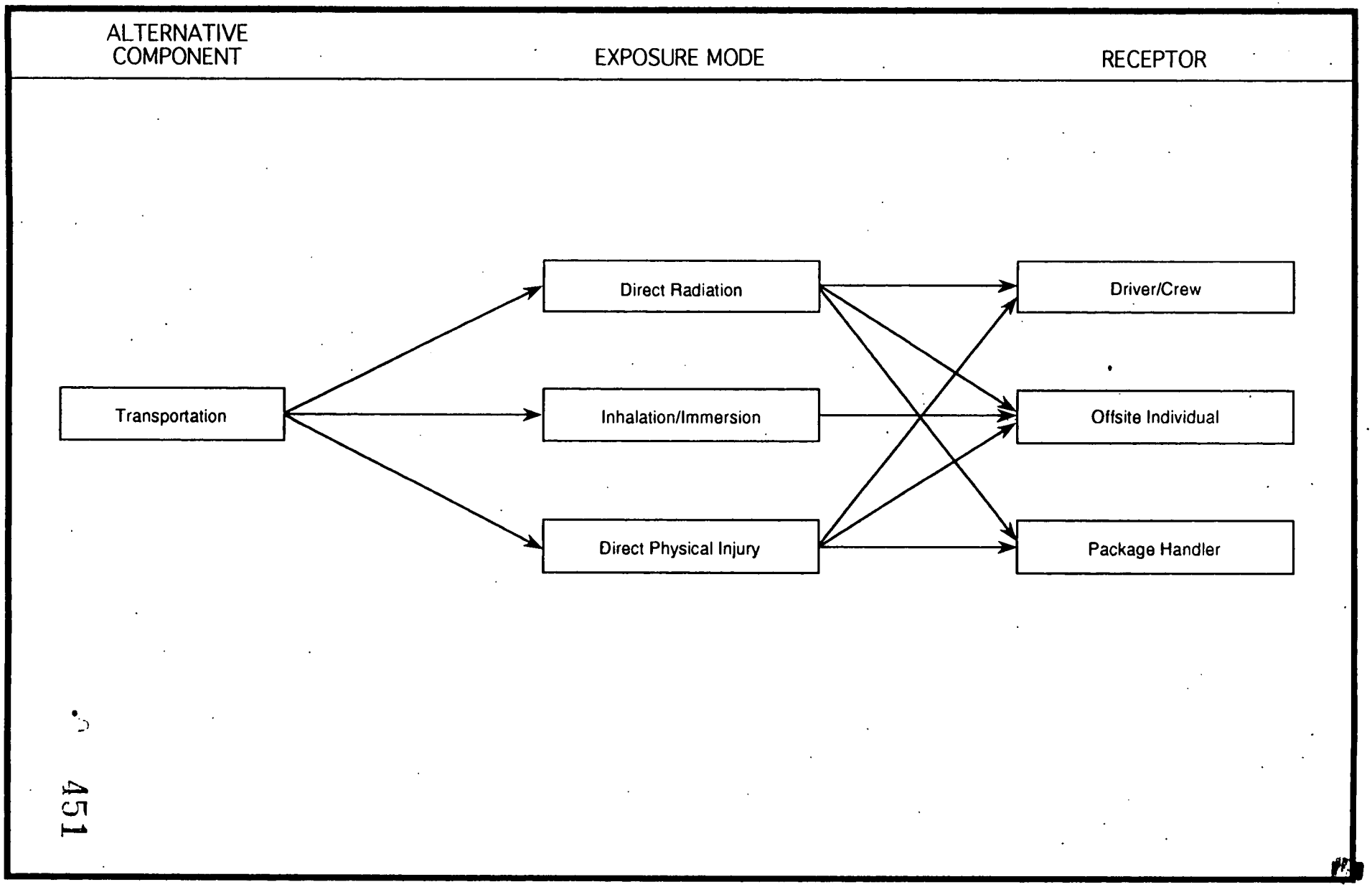

FIGURE D.2-7
OPERABLE UNIT 1
CONCEPTUAL MODEL FOR REMEDIAL ACTION RISKS - TRANSPORTATION

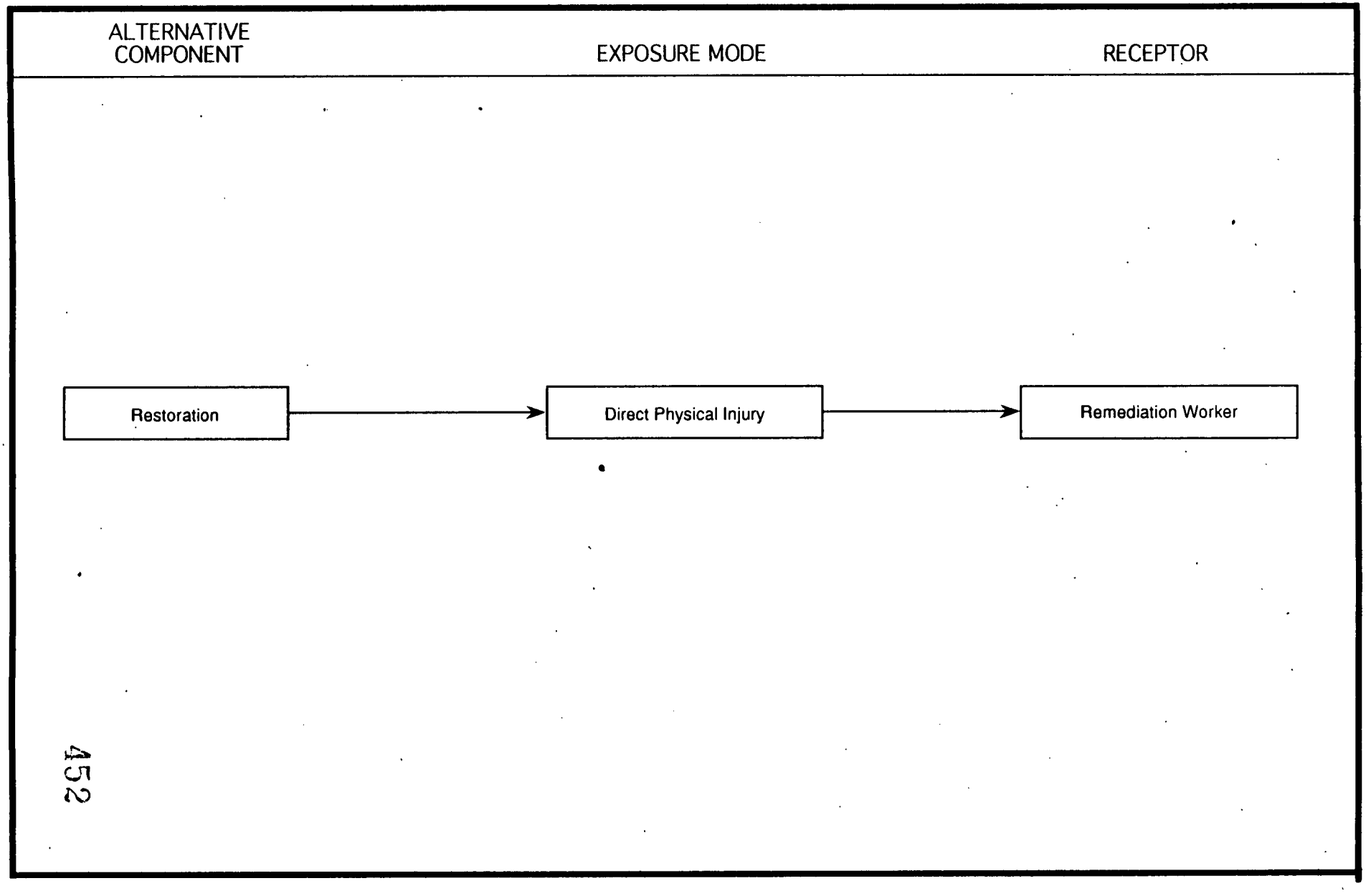

FIGURE D.2-8
OPERABLE UNIT 1
CONCEPTUAL MODEL FOR REMEDIAL ACTION RISKS - RESTORATION

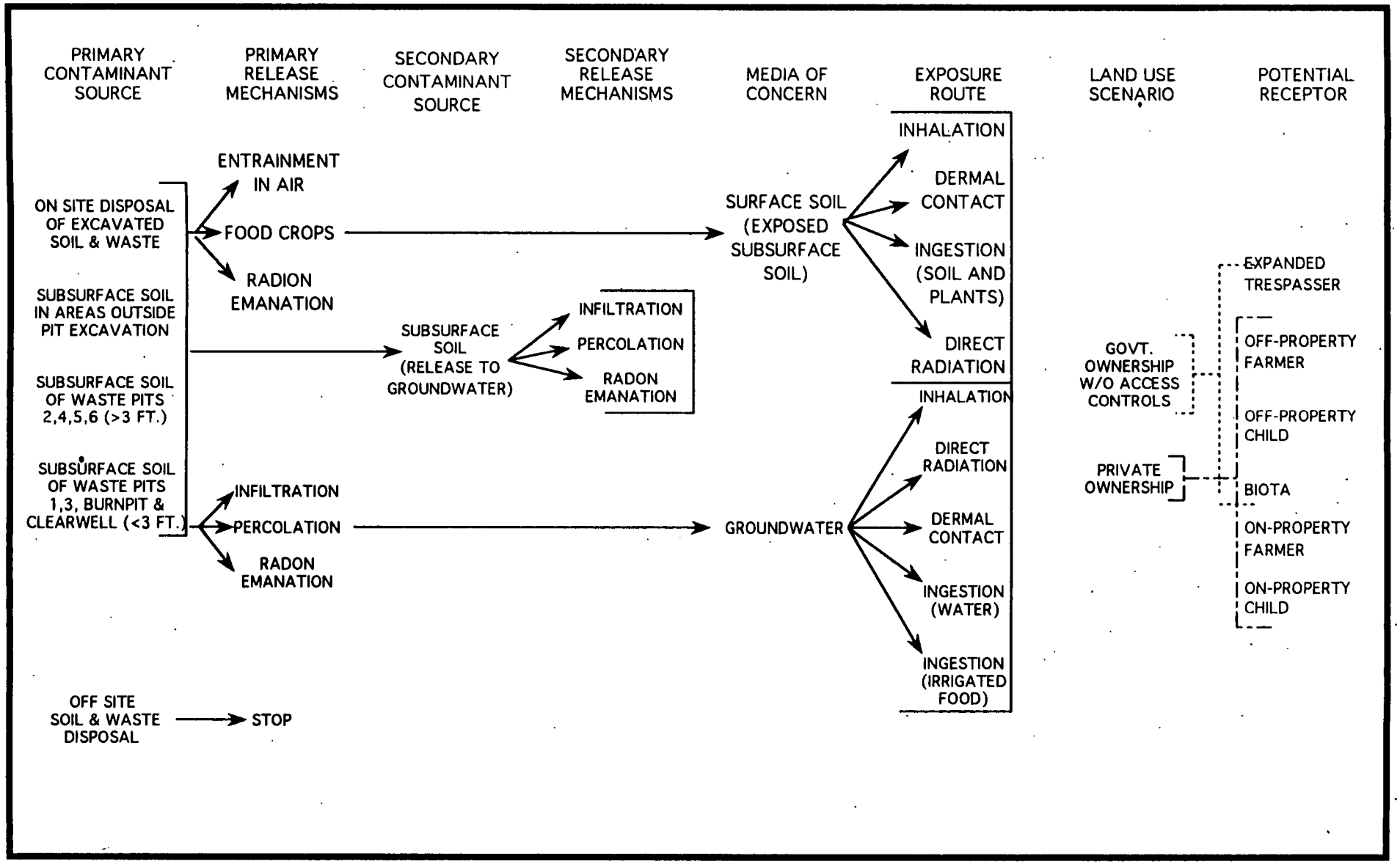

FIGURE D.2-9
OPERABLE UNIT 1
CONCEPTUAL MODEL FOR RESIDUAL RISK - EXPOSURE PATHWAYS

D.3.0 EXPOSURE PATHWAY ANALYSIS

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D.3.1 EXPOSURE SCENARIOS

D.3.1.1 Remedial Action Exposure Scenarios

Each of the six conceptual models presented in Section 2.5.1 represents a series of exposure scenarios. This section describes those scenarios by alternative component. These scenarios encompass the remedial actions that pose a short-term risk to remediation workers, nonremediation workers, and off-site individuals. Also, these scenarios include all activities that pose a risk, including facility construction, operation, and decommissioning.

Excavation

During excavation, heavy equipment removes contaminated surface soil, pit covers, pit waste, pit liner, and underlying soil for ultimate disposal. This remedial activity has a potential to suspend dust containing contaminants into the air. Remediation workers monitoring soil contamination levels are exposed to ionizing radiation from immersion in the contaminated air. The airborne contaminants are transported to non-remediation workers on-property and to off-site individuals living at the fenceline. The non-remediation workers and off-site individuals inhale chemical contaminants and radionuclides and are exposed to ionizing radiation from immersion in the contaminated air. Remediation workers monitoring soil contamination levels are also exposed to direct radiation from contamination in the soil. Finally, remediation workers are exposed to mechanical hazards during excavation and construction of ancillary facilities.

Drying

During drying, VOCs and radon are released through the off-gas system. The airborne contaminants are transported to non-remediation workers on-property and to off-site individuals living at the fenceline. The non-remediation workers and off-site individuals inhale chemical contaminants and radionuclides and are exposed to direct radiation from immersion in the contaminated air. Operators are exposed to direct radiation from contaminated soil in the dryer. Operators are not exposed to ionizing radiation from immersion in the contaminated air, since the contaminants are released from a stack. Finally, remediation workers are exposed to mechanical hazards during construction of the facility.

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Vitrification/Solidification

During vitrification or solidification in cement, VOCs and radon are released through the off-gas system. The airborne contaminants are transported to non-remediation workers on-property and to off-site individuals living at the fenceline. The non-remediation workers and off-site individuals inhale chemical contaminants and radionuclides and are exposed to direct radiation from immersion in the contaminated air. Operators are not exposed to direct radiation from contaminated waste in the vitrification and solidification systems since they will not have access to the equipment. Also, operators are not exposed to ionizing radiation from immersion in the contaminated air, since the contaminants are released from a stack. Finally, remediation workers are exposed to mechanical hazards during construction and decommissioning of the facility.

On-Property Disposal

During on-property disposal (for Alternatives 4A and 4B), remediation workers are exposed to direct radiation from waste material in the disposal cell. Also, remediation workers are exposed to mechanical hazards during construction of the facility and waste emplacement.

Off-Site Waste Transportation

Following drying, the excavated material is placed into shipping packages and loaded onto a rail car (for Alternatives 5A and 5B). Two off-site disposal sites are considered: NTS and a representative permitted, commercial disposal facility in Utah. For transport to the permitted commercial disposal facility, the material is placed into gondola rail cars and shipped directly by rail to the facility. For transport to NTS, the material is placed into steel containers and loaded onto flatbed rail cars. The packages are transported by rail to Las Vegas, Nevada. In Las Vegas, the packages are transferred to trucks and transported to NTS (since NTS does not have a rail spur). During loading of the material and packages, remediation workers (package handlers) are exposed to direct radiation from the material. These workers are also placed at risk from mechanical hazards. During transport, truck drivers and train crews are exposed to radiation from the material. Individuals living on the transportation route or sharing the transportation route are exposed to direct radiation. For transport to NTS, package handlers are exposed to direct radiation and mechanical hazards from the transfer of packages from the train to trucks. Finally, members of the public are exposed to direct radiation from air and ground contamination and inhale contaminants following a postulated transportation accident.

Restoration

Following removal of contaminated material in Operable Unit 1, the areas are backfilled with clean soil. Remediation workers are placed at risk from mechanical hazards associated with the backfilling equipment.

D.3.1.2 Residual Exposure Scenarios

In the event they are released to the environment, COCs can travel by several transport pathways and reach media to which receptors may be exposed. The following subsections briefly summarize transport and exposure pathways, which are discussed in more detail in the Risk Assessment Work Plan Addendum (DOE 1992). As discussed in Section D.2.5.2, surface water releases are eliminated from the scope of the conceptual model.

The impact of Operable Unit 1 residual contaminant sources on perched groundwater in the sand lens beneath the waste pits (perched groundwater) and groundwater in the Great Miami Aquifer is included in the scope of the Operable Unit 1 conceptual model (existing contamination in groundwater is within the scope of Operable Unit 5). Potential sources of contaminant leaching to perched groundwater and the aquifer include the residual soils in Waste Pits 1-6, Burn Pit and Clearwell, and in non-waste pit areas as well as treated wastes in the on-property disposal cell. Potential exposure pathways from contaminants in groundwater following transport to receptors include ingestion of drinking water, ingestion of fruits and vegetables irrigated with groundwater, ingestion of animal products from cattle raised on groundwater and feed crops irrigated with groundwater, dermal contact with groundwater while bathing, and inhalation of VOCs from use of groundwater in the home. All surface soils will be replaced with clean fill or caps. However, it is assumed here that the potential exists for on-site subsurface soils to be brought to the surface. Although unlikely, surface soil exposure pathways (incidental ingestion, inhalation of particulates and volatiles, and dermal contact) are included.

Exposure scenarios combine postulated future land uses with release and transport mechanisms to define potentially exposed individuals. Exposure scenarios are developed in this risk assessment for the purpose of modeling potential receptor exposure to Operable Unit 1 COCs. The Risk Assessment Work Plan Addendum (DOE 1992) defines land use and receptor combinations to be considered, as appropriate, in FEMP risk assessments.

The relevant land uses for consideration in the assessment of potential long-term risks following completion of Operable Unit 1 remedial actions are:

- Future land use with continued federal ownership with some limited access controls
- Future land use with private ownership and on-property residence and farming.

Federal ownership and land use restrictions can be used to supplement engineering measures considered under the alternative to prevent or mitigate potential exposures to Operable Unit 1 COCs. Land use restrictions mitigate potential exposure to on-site disposal facilities and soils with residual concentrations of COCs. As specified in Ohio Administrative Code (OAC) 3734.02, hazardous and solid waste disposal facilities must include a protective covenant to restrict mining, drilling, and residential uses. The sections that follow provide summary descriptions of the Risk Assessment Work Plan Addendum receptor/land use combinations and their adaptation to the Operable Unit 1 residual risk assessment.

D.3.2 RECEPTORS

D.3.2.1 Receptors for Remedial Action Risks

Receptors for remedial action risks are described below. Each description includes the alternative components that apply to that receptor.

Remediation Workers

Remediation workers are those individuals that are placed at risk from the tasks that they themselves are performing. For example, an individual operating excavation equipment within Operable Unit 1 is placed at risk by the excavation operations and would be a remediation worker receptor. In contrast, an individual performing remediation work within Operable Unit 4 who might be exposed to resuspended material from Operable Unit 1 would not be a remediation worker receptor (see non-remediation worker receptor, below). The level of risk to which these individuals are exposed depends on their proximity to the waste, level of personnel protective equipment, length of time of exposure to the hazard, and the type of hazard. In addition, all remediation workers will be working under a health and safety plan, which will control and restrict exposure through personal protective equipment, engineering controls, and duration of exposure. As a general principle, remediation workers are not considered in FEMP risk assessments because of this coverage, as stated in the FEMP Risk Assessment Work Plan Addendum (FEMP 1992). Evaluation of specific remediation worker impacts have been performed to compare impacts from alternatives.

Truck Driver/Train Crew

Truck driver and train crew receptors are a subcategory of remediation worker. They have been broken out since the model used to assess impacts from transporting contaminated material (see Section 3.3.1 for model description) develops estimates for impacts specifically for these individuals. The magnitude for these impacts depends on the level of contaminants in the transported waste, the degree of shielding provided by transport containers, their proximity to the waste shipments, and the duration of transport, including stops.

Package Handlers

Package handler receptors are another subcategory of remediation worker. They have been broken out separately since they are associated with transportation risks and truck drivers and train crew were identified separately. The level of risk to which these individuals are exposed depends on their proximity to the waste, the dose rate from packages, and the duration of their handling tasks.

Nonremediation Workers

Nonremediation worker receptors are those FEMP employees exposed to hazards associated with the remediation of Operable Unit 1 but are not involved with the remediation of Operable Unit 1. For example, an individual performing remediation work within Operable Unit 4 who might be exposed to resuspended material from Operable Unit 1 would be a nonremediation worker receptor. The level of risk to which these individuals are exposed depends on the extent to which airborne contaminants are transported to their work area and the duration of their exposure.

Off-Site Individuals

The off-site individual receptors vary in character based on the exposure scenario. For those scenarios where contaminants are dispersed in the air and carried to the FEMP site boundary, these individuals are located at the fenceline, i.e., the location of the "off-property farmer." For transportation scenarios, the off-site individuals live along the transport route or, in the case of truck transport, share the roadway with the trucks. The transportation model assessed collective and maximum individual risks from exposure to contaminants during transport.

D.3.2.2 Receptors for Residual Risks

Residual risks are evaluated for receptors involved in two land use scenarios:

Future Land Use With Continued Federal Ownership With Some Limited Access Controls

Under this land use scenario, the federal government maintains ownership of the property and restricts future residential, farm development, or industrial use but does not maintain physical barriers to prevent entry. Potential receptors include off-site farmer and child receptors and the expanded trespasser. This scenario assumes that a farm family lives immediately adjacent to the FEMP property boundary and is exposed through groundwater and surface soil pathways.

Future Land Use With Private Ownership

Under this land use scenario, there are neither access controls nor continued federal ownership. A farm family is assumed to reside on and farm the Operable Unit 1 property. A farm family is also assumed to be living and farming immediately adjacent to the FEMP property boundary. This scenario includes exposure routes that require development time such as establishing a home and farm operations on property.

Receptor exposure scenarios for the two land use scenarios are summarized in Figure D.3-1 and as follows:

- On-Property Resident Farmer Receptor - This scenario assumes that a farmer resides on the property and conducts agricultural activities. Typical activities may include food and feed production, livestock production, and general farm work. The receptor is assumed to not intrude into the disposal facility or the soils beneath the waste pits. It is assumed, however, that farming or other processes will bring non-pit area subsurface soils to the surface resulting in potential receptor exposure to surface soil pathways.
- On-Property Resident Child Receptor - This exposure is similar to the resident farmer with modifications of exposure parameter values to reflect values typical of a child. The exposure routes for this receptor include those listed for the resident farmer and assumed no intrusion into the disposal facility. Exposure to surface soil pathways is also assumed to occur.
- Off-Site Farmer and Child Receptors - This scenario assumes that a farm family lives immediately adjacent to the FEMP property boundary and is exposed through groundwater pathways. The off-site farmer and child exposures are the same for both land use scenarios.
- Expanded Trespasser - The expanded trespasser is an individual trespassing on the site as a youth and (later) as an adult. This exposure scenario assumes that subsurface soils are brought to the surface by some means such that surface soil exposure pathways are relevant. Groundwater and produce ingestion exposure pathways are not included in this exposure scenario.

Exposure routes identified for the on-property resident farmer and the on-property resident child are quantitatively evaluated for the private land use scenario. Groundwater exposure pathways include

ingestion of drinking water, inhalation of volatiles released from water during household use, dermal contact while bathing, ingestion of vegetables and fruits irrigated with contaminated groundwater, and ingestion of meat and milk from cattle drinking contaminated groundwater, receiving one-half of their daily ration from forage grown under irrigation with contaminated groundwater. Groundwater modeling results for each remedial alternative are presented in the next section. Soil exposure pathways for the on-property farmer and child residents (assuming subsurface soil is brought to the surface by some means) include incidental ingestion, inhalation of particulates and volatiles from soil, dermal contact, external (direct) exposure to radionuclides, ingestion of fruits and vegetables grown in the soil, and ingestion of meat and milk from cattle, receiving one-half of their daily ration from forages grown in the soil.

For the expanded trespasser, the relevant soil exposure pathways include incidental ingestion, inhalation of particulates and volatiles from soil, and dermal contact. Exposure to on-property subsurface soil is included for private ownership receptors using the unlikely assumption that the farmer plows the soil deeply enough to bring residual concentrations (at soil action levels) to the surface.

D.3.3 EXPOSURE MODELS

D.3.3.1 Exposure Models for Remedial Action Risks

This section presents the exposure models used to estimate the remedial action risks. The section has been divided into subsections for each alternative component-exposure mode-receptor combination.

Excavation-Direct Radiation-Remediation Worker

During excavation, the remediation worker is exposed to direct radiation from radionuclides in the soil. The magnitude of the exposure for each radionuclide is given by the following equation:

$$H_{E,i} = C_{s,i} \times ESD \times DCF_{s,i} \times T_1 \times UCF_1 \times \rho$$

where:

$H_{E,i}$	=	Effective dose equivalent from radionuclide i, mrem
$C_{s,i}$	=	Soil concentration for radionuclide i, pCi/g
ESD	=	Effective soil depth, m
$DCF_{s,i}$	=	Dose conversion factor for radionuclide i in soil, mrem/yr per $\mu Ci/m^2$
T_1	=	Fraction of one year exposed to soil, yr
UCF_1	=	Unit Conversion Factor, 10^{-6} $\mu Ci/pCi$
ρ	=	density of soil, g/m^3

$DCF_{s,i}$ is based on organ-specific conversion factors published by the Department of Energy (DOE, 1988). Calculation of $DCF_{s,i}$ is discussed in the following paragraphs. This equation is summed over all organs.

DOE (1988) performs dose conversion factor (DCF) calculations and reports $DCF_{s,i}$. As stated in the assumptions, soil concentrations are assumed to equal soil PRGs. The values used are PRGs that predict a risk of 10^{-4} for the most limiting exposure scenario (i.e., the scenario with the lowest soil concentration).

The PRGs are taken from Section 2 of the FS (Table 2-5) and are:

Radionuclide	Concentration (pCi/s)
Ra-228	0.82
Sr-90	1.6
Tc-99	1.7
Th-228	0.43
U-238	45

For those radionuclides without PRGs, surface soil concentrations will be used.

$$DCF_{s,i} = \sum wf_k \times DCF_{s,i,k}$$

where,

wf_k = Organ weighing factor for organ k
$DCF_{s,i,k}$ = Dose conversion factor for exposure to contaminated soil for organ k, radionuclide i

Risk from exposure to ionizing radiation is expressed in incremental lifetime fatal cancers for the nonremediation and off-site individual receptors (and dose equivalent for the remediation worker receptor). The risk is calculated by the following equation. The effective dose equivalent is summed for all radionuclides.

$$ILCR = \sum H_{E,i} \times CRF$$

where:

ILCR = Incremental lifetime cancer risk
CRF = Cancer risk factor for radionuclides, ILCR/mrem

The cancer risk factors used to translate dose equivalent to incremental lifetime cancer risk are based on a number of studies sponsored by national and international radiation protection organizations. The results of these studies present cancer risk factors in terms of the risk of contracting a fatal cancer per

unit of dose equivalent delivered to the body. This presentation of risk for exposure to ionizing radiation during remediation differs from the presentation for carcinogenic chemicals, which is in terms of the risk of contracting any cancer.

Excavation-Direct Physical Injury-Remediation Worker

Risk of mechanical injury, both for injuries and fatalities, is based on a risk conversion factor developed by the Department of Labor. This conversion factor translates hours worked to risk from a mechanical hazard using the following equation:

$$\text{Risk} = \text{MHRF} \times T_2$$

where:

MHRF = mechanical hazard risk factor, injuries or fatalities per person-hour worked
T_2 = Person-hours worked during excavation

Excavation-Inhalation/Immersion-Remediation Worker

It is assumed that remediation workers are not exposed through the inhalation pathway because they wear personnel protective equipment or working in climate-controlled cabs. A remediation worker is exposed to direct radiation from immersion in contaminated air. The risk is calculated in a similar fashion to direct radiation exposure from soil.

The magnitude of immersion exposure for each radionuclide is given by the following equation:

$$H_{E,i} = C_{a,i} \times DCF_{a,i} \times T_1 \times UCF_1$$

where:

$H_{E,i}$ = Effective dose equivalent from radionuclide i, (mrem)
$C_{a,i}$ = Air concentration for radionuclide i, pCi/m^3
$DCF_{a,i}$ = Dose conversion factor for immersion for radionuclide i in air, mrem/yr per μCi/m^3
T_1 = Fraction of one year exposed to contaminated air, yr
UCF_1 = Unit conversion factor (10^{-6} mCi/pCi)

The concentration of a radionuclide in air is based on a dust loading factor for soil and the concentration of the radionuclide the soil. The following equation provides the expression for the air concentration of the ith radionuclide. This concentration in soil is the volume weighted average concentration for surface soils, caps, pit wastes, and liners.

$$C_{a,i} = DL \times C_{s,i}$$

where:

DL = dust loading factor for construction, g of soil/m^3 of air

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$DCF_{a,i}$ is based on organ-specific conversion factors published by the Department of Energy (DOE, 1988). $DCF_{a,i}$ is calculated by the following equation. This equation is summed over all organs. DOE (1988) performs this calculation and reports $DCF_{a,i}$.

$$DCF_{a,i} = \sum wf_k \times DCF_{a,i,k}$$

where:

$DCF_{a,i,k}$ = Dose conversion factor for immersion in air for organ k, radionuclide i

The risk from exposure to ionizing radiation is measured in incremental lifetime fatal cancers (see ILCR previously given). The effective dose equivalent is summed over all site-related radionuclides.

Excavation-Inhalation/Immersion-Nonremediation Worker

The risk from immersion for the non-remediation worker is calculated identically to the remediation worker. The only difference is the estimated time of exposure, with the non-remediation worker exposed for a different period of time, T_3. The air concentration would be reduced through atmospheric dispersion during transport to the nonremediation worker's exposure point. However, this analysis does not take credit for reduced concentration due to dispersion.

The nonremediation worker is assumed not to have respiratory protection. The worker can be exposed by inhaling airborne contaminants. The risk from this exposure mode is calculated similarly to the immersion pathway. However, both radionuclides and chemical contaminants must be considered. The next two equations present the formulation for calculating dose equivalent from inhaling radionuclides, followed by the formulation for calculating intake of chemical contaminants.

$$H_{E,i} = C_{a,i} \times IR \times IDCF_i \times T_3 \times UCF_1$$

where:

$H_{E,i}$ = Effective dose equivalent of radionuclide i (mrem)
$C_{a,i}$ = Concentration of radionuclide in air
IR = Inhalation rate, m^3/hr
$IDCF_i$ = Inhalation dose conversion factor for radionuclide i, mrem/μCi
T_3 = Exposure time, hours
UCF_1 = Unit conversion factor (10^{-6} mCi/pCi)

and $$IDCF_i = \sum wf_k \times IDCF_{i,k}$$

where,

$IDCF_{i,k}$ = Dose conversion factor for inhalation for organ k, radionuclide i

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For chemical contaminants, the intake equation from air for chemical now is:

$$I_{a,n} = C_{a,n} \times IR \times T_3 / (BW \times AT)$$

where,

T_3 = exposure at time (hrs)
$I_{a,n}$ = Intake from air of chemical contaminant n, mg/kg-day
$C_{a,n}$ = Concentration of chemical contaminant n in air, mg/m^3
BW = Body weight, kg
AT = Averaging time, days

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It must be remembered that radiological risks are expressed as "fatal" cancers while chemical risks are "total" cancers. Calculation of risks from radionuclide intake is discussed in the preceding paragraphs. For carcinogenic and noncarcinogenic chemicals, the relevant risk equations follow. Carcinogenic risk is summed over all carcinogenic chemicals. Noncarcinogenic impacts (hazard index) are summed over all noncarcinogenic chemicals.

For carcinogenic risk:

$$Risk = \sum I_{a,n} \times SF_n$$

where:

SF_n = Cancer slope factor for carcinogen n, (mg/kg-day)$^{-1}$

For non-carcinogenic chemicals, the hazard index (HI) is:

$$HI = \sum I_{a,n} / RfD_n$$

where,

HI = Hazard Index
RfD_n = Reference dose for noncarcinogen n, mg/kg-day

In some cases, unit intake factors instead of cancer slope factors were presented in the Operable Unit 1 remedial investigation and have been used in this analysis. In these cases, the risk is the ratio of the air concentration for a contaminant to the unit risk factor, adjusted for the difference in exposure duration. The unit risk factors are based on a 70-year continuous exposure while remedial risks are over a shorter time period.

Excavation-Inhalation/Immersion-Off-site individual

The risk from immersion for the off-site individual is calculated identically to the non-remediation worker. The only difference is the estimated time of exposure. The off-site individual is assumed to be exposed for a different period of time, T_4. The air concentration would be reduced through

dispersion as the contaminants are transported to the receptor's exposure point. However, this analysis does not take credit for this reduced concentration. The inhalation exposure is also calculated the same as for the non-remediation worker. Again, the only difference is exposure time, which is T_4. Cancer risks and hazard quotient are calculated the same as for the non-remediation worker.

Drying-Direct Radiation-Remediation Worker

The direct radiation exposure to a dryer operator is calculated by a personal computer-based computer code, SUPERSHIELD. SUPERSHIELD is produced by Shonka Research Associates, Inc. and contains a version of ISOSHIELD, a widely used shielding code. SUPERSHIELD uses a series of menus to develop the input data set. Information required by the code includes source-to-receptor geometry, source configuration, shield configuration, shield material, source strength, and build-up calculational method. The code output is an estimate of the dose equivalent rate at the receptor point. For the exposure from the dryer, the source strength is based on the concentration of radionuclides in the excavated soil. For this calculation, a weighted average concentration is used. The source and shield configurations and shield material are based on the layout of the dryer and the location of the operator. The dose rate developed by the code is multiplied by the exposure time for the operator, T_5 (in hours), to estimate the dose equivalent. The ILCR equation previously provided is used to estimate the risk from the dose equivalent estimate. The computer code sums the contribution from each radionuclide, so the summation in that equation is not needed.

Drying-Direct Physical Injury-Remediation Worker

Mechanical hazard impacts are calculated identically to the impacts for the Excavation-Mechanical Injury-Remediation Worker pathway. The only difference is the total person- hours for constructing the drying facility, which is T_6.

Drying-Inhalation/Immersion-Nonremediation Worker

The immersion and inhalation impacts for this exposure are calculated similarly to the excavation-inhalation/immersion pathways. However, the air concentration is calculated differently. The contaminants are released through a short stack event and a Gaussian plume dispersion model is used to estimate the concentration at the receptor location. The following equations describe the calculation of air concentration. The second equation, used to calculate the centerline plume concentration, was taken from the AIRDOS-EPA computer model (Moore *et al.*, 1979), which is discussed in the Risk Assessment Work Plan Addendum (but the computer model was not run). It is

summed over all stability classes. Dose equivalent, intake, risk, and hazard index are calculated as described for the Excavation-Inhalation/Immersion-Nonremediation Worker.

$C_a = RR \times (\chi/Q)$

where:

RR = release rate of contaminant, pCi/sec (radionuclides) or mg/sec (chemicals)
χ/Q = Gaussian dispersion factor, sec/m^3, where:
$\chi/Q = \Sigma FRAC \times \exp[-\frac{1}{2}(H/\sigma_z)]/(2 \times \pi \times \sigma_y \times \sigma_z \times \mu)$

where:

FRAC = fraction of time for a given stability class
H = release height, m
σ_z = vertical dispersion coefficient, m
σ_y = horizontal dispersion coefficient, m
π = 3.1415...
μ = mean wind speed, m/sec

Release rates equal the total amount of the contaminant released over the total time for the operation.

Drying-Inhalation/Immersion-Off-Site Individual

The immersion and inhalation impacts for this exposure are calculated the same as for the Drying-Inhalation/Immersion-Non-Remediation Worker pathway. As with the excavation alternative component, the exposure time for the off-site individual is different than for the non-remediation worker. Dose equivalent, intake, cancer risk, and hazard index are calculated as described for the Excavation-Inhalation/Immersion-Off-site Individual.

Vitrification/Solidification-Direct Physical Injury-Remediation Worker

Mechanical hazard impacts are calculated identically to the impacts for the Excavation-Mechanical Injury-Remediation Worker pathway. The only difference is the total person hours for constructing the vitrification and cement solidification facilities, which are T_7 and T_8, respectively.

Vitrification/Solidification-Inhalation/Immersion-Nonremediation Worker

Inhalation/immersion impacts are calculated identically to the impacts for the Drying-Inhalation/Immersion-Non-Remediation Worker pathway.

Vitrification/Solidification-Inhalation/Immersion-Off-Site Individual

Inhalation/immersion impacts are calculated identically to the impacts for the Drying-Inhalation/Immersion-Off-site individual pathway.

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Transportation

The magnitude of the transportation impacts is calculated by the TRANSNET computer model system. The TRANSNET system is operated by Sandia National Laboratory and includes routing models (HIGHWAY and INTERSTATE for truck transport and INTERLINE for rail transport) and an impact model (RADTRAN 4). For this analysis, the route yielding the shortest distance between Fernald and the disposal site is used.

In order for RADTRAN to assess the impacts from direct radiation, a dose rate one meter away from the truck or rail car must be calculated. For this analysis, SUPERSHIELD is used to estimate the dose rate.

RADTRAN also assesses the impacts from releases of material from a transportation accident. The code uses as input data radionuclide concentration and release fractions to assess these impacts. Default values for exposure from this release are used.

The magnitude of the impacts from a transportation accident depends on the severity of the accident, the dispersibility of the waste material, and the density of the surrounding population. The only emergency response considered in the analysis for this feasibility study is crop interdiction. It is assumed that there is not ingestion pathway impacts following an accident since authorities would interdict any contaminated crops. No other emergency responses are considered.

The dose equivalent estimates are converted to risk values using the ILCR equation. The code sums the contributions from all radionuclides, so the summation in this equation is not needed.

Mechanical hazards are based on miles traveled. The following equation presents the calculation for the mechanical hazard impacts for both workers and members of the public.

$$\text{Risk} = RCF_m \times DST_m$$

where,

RCF_m = Risk conversion factor for worker or member of the public for transportation mode m (truck or rail), fatalities or injuries per mile

DST = Distance traveled by transportation mode m (truck or rail), miles

Risks to package handlers are assessed similarly to other remediation workers. Dose rates are calculated by SUPERSHIELD and direct radiation impacts are calculating using an exposure time,

T_{11}. For mechanical hazards, T_{12} and T_{13} are used for the person-hours worked loading trains to NTS and a permitted commercial disposal facility, respectively.

For transport of waste containers between the Las Vegas rail yard and NTS, the roundtrip mileage is used for DST. This mileage is appropriate since it is assumed that trucks transporting waste packages are in constant use between the rail yard and NTS (i.e., the trucks travel back and forth between the rail yard and NTS until all packages are offloaded).

On-Site Disposal-Direct Physical Injury-Remediation Worker

Mechanical hazard impacts are calculated identically to the impacts for the Excavation-Mechanical Injury-Remediation Worker pathway. The only difference is the total person- hours worked, which is T_9 for disposal of vitrified waste and T_{10} for disposal of cementitious waste.

Restoration-Direct Physical Injury-Remediation Worker

Mechanical hazard impacts are calculated identically to the impacts for the Excavation-Mechanical Injury-Remediation Worker pathway. The only difference is the total person- hours worked, which is T_{14}.

D.3.3.2 Exposure Models for Residual Risks

Two primary sources are considered to contribute to potential exposure pathways for residual risks: groundwater and surface soil. Residual contaminants in groundwater and soil are also assumed to be incorporated into agricultural products ingested by receptors.

Numerical groundwater models were used to predict potential movement of residual and disposed constituents from Operable Unit 1 source terms to receptor locations. The transport models provide the only means of predicting potential groundwater constituent concentrations at receptor locations in the future under assumed conditions. The models were used to develop groundwater concentrations as follows:

- The model is used to estimate leachate and PRG concentrations
- The model is also used to predict the Great Miami Aquifer concentrations for a subset of COCs
- The hydrogeological evaluation of landfill performance (HELP) model is used to estimate exfiltration rates.

Non-pit area subsurface soils that are, in the future, brought to the surface are assumed to be contaminated with Operable Unit 1 COCs at PRG concentrations. For inhalation of particulates, resuspension factors developed in the baseline RA have been used to calculate potential exposure.

D.3.4 EXPOSURE PARAMETERS

Exposure parameters used in the remedial action and residual risk assessment are summarized in the following sections. The Risk Assessment Work Plan (DOE 1992) is the primary source for these values; other values are used in accordance with EPA guidance and/or FEMP direction.

D.3.4.1 Exposure Parameters for Remedial Action Risks

This section presents parameter values for the models discussed in Section D.3.3.1. Each presentation includes the parameter, the value or values for the parameter, parameter units, and a reference for the parameter values. Many of the parameter values are from the Risk Assessment Work Plan Addendum (DOE 1992).

Table D.3-1 presents most of the noncontaminant-specific parameters. Table D.3-2 presents the values for the 11 time parameters (T_1 through T_{11}). Table D.3-3 presents risk factors. Table D.3-4 presents organ weighing factors. Table D.3-5 presents cancer slope factors for carcinogenic chemicals (COCs). Table D.3-6 presents reference dose values for the noncarcinogenic chemicals. Table D.3-7 presents the direct soil, immersion, and inhalation dose equivalent factors. Table D.3-8 presents formulations for vertical and horizontal dispersion coefficients. Tables D.3-9 and D.3-10 present measured soil concentrations for radionuclides and chemicals, respectively. Tables D.3-11 through D.3-13 present calculated radionuclide concentrations in vitrified waste, dried, and cementitious waste forms. Table D.3-14 presents transportation analysis parameters.

Table D.3-2 presents durations for exposure to contaminants and mechanical hazards. T_1 reflects the assumption that an individual monitors the soil at the end of excavating each pit. It is assumed that the individual is monitoring the soil for 5 days for each pit (45 days total), 5 hours per day. For T_2, the total person-hours have been taken from the cost estimate for excavation. For T_3, the exposure time is based on a nonremediation worker exposed for one hour a day, 250 days per year, for the 4 years of excavation. For T_4, the off-site individual spends 5.7 hours a day outside and is exposed 11 percent of 250 days per year, for 4 years. The 11 percent is the maximum percent of the time wind blows in a given direction at the site. T_5 is based on 24 person-hours per day (3 eight-hour shifts with one operator per shift - from the operational scenario) exposed 10 percent of the time to material

in the dryer system over 250 days per year and 5 years (to dry all material). For T_6, the total person hours have been taken from the cost estimate for constructing the drying facility. For T_7, the total person hours have been taken from the cost estimate for constructing the vitrification facility. T_8 is based on the total person hours taken from the cost estimate for constructing the cement stabilization facility. T_9 is based on the total person hours taken from the cost estimate for constructing the on-site disposal facility. For T_{10}, a package handler is assumed to spend one-tenth of his time within one meter of the package. The time is based on the person hour estimate for technicians in the cost estimate for loading the trains to NTS. The gondola cars are loaded by conveyer and minimal (e.g., cover placement) contact is anticipated, so no impact to a package handler is assessed. T_{11} and T_{12}, the total person-hours for package handling, is based on the total person hours taken from the cost estimate for loading the trains for NTS and the commercial facility, respectively.

Unit risk factors for inhalation of PCBs, dioxins, and furans that appear in Table D.3-5 were derived based on the oral cancer slope factors for those chemicals. The oral cancer slope factors, in units of inverse milligrams per kilogram-day, were multiplied by 20 cubic meters of air per day (daily inhalation rate) and 0.001 milligrams per microgram. The inverse of the product is the unit risk factor. For example, for PCBs (e.g., Aroclor 1348, Aroclor 1254, and 2379-TCDF):

$$(7.7 \text{ kg-day/mg} \times 20 \text{ m}^3 \text{ /day} \times 0.001 \text{ mg/ug/70 kg})^{-1} = 450 \text{ ug/m}^3$$

Tables D.3-5 and D.3-6 provide cancer slope and reference dose factors for chemicals. Subsequent tables with chemical data include only those chemicals for which either cancer slope factors (or unit risk factors) or reference dose values exist.

The bulking factor used to calculate the cementitious waste concentrations in Table D.3-13 were taken from the Operable Unit 1 Treatability Study (DOE 1993). This study presented bulking factors for each pit waste material. A volume weighted average bulking factor was calculated. This factor, 80 percent, was calculated by summing the product of the bulking factor for each pit and the waste volume for each pit and dividing the sum by the total waste volume for all pits.

Table D.3-14 presents transportation analysis parameters. For all RADTRAN 4 parameters not presented in the table, default values were used.

D.3.4.2 Exposure Parameters for Residual Risks

Residual exposure parameters for the various potential receptors and exposure pathways are included in Table D.3-15. The on-property farmer (adult) and child resident residual risks are based on exposure to subsurface soil (presumed to be brought to the surface by plowing or other means), groundwater, and produce (fruits and vegetables, meat, and milk) affected by subsurface soils and groundwater. The off-site farmer and child resident residual risks are based on exposure to groundwater and produce (fruits and vegetables, meat, and milk) affected by groundwater. Exposure parameters for the on-property and off-site receptors are the same (i.e., on-property and off-site adult exposure parameters are the same, and on-property and off-site child exposure parameters are the same). Residual risks to the expanded trespasser are based on exposure to subsurface soils that are brought to the surface by some means. The primary differences between the on-property and off-site calculations involve the relevant media (no soil exposure pathways except inhalation for the off-site residents) and the groundwater exposure point concentrations. Parameters used in actual risk calculations are documented on spreadsheets for each potential receptor/pathway analysis. The spreadsheets are attached to the end of this Appendix.

TABLE D.3-1
NONCONTAMINANT-SPECIFIC EXPOSURE PARAMETERS

Parameter	Value	Units	Reference
Effective Soil Depth - ESD	1	m	DOE, 1988
Dust Loading (Remediation Worker) - DL	6×10^{-5}	g/m^3	RAWPA
Dust Loading (Non-Remediation Worker) - DL	2.8×10^{-5}	g/m^3	RAWPA
Dust Loading (Off-Site Individual) - DL	2.5×10^{-6}	g/m^3	RAWPA
Soil Density - ρ	1.7×10^{6}	g/m^3	RAWPA
Inhalation Rate - IR (Worker)[a]	3	m^3/hr	RAWPA
Inhalation Rate - IR (Off-Site Individual)	0.83	m^3/hr	RAWPA
Body Weight - BW	70	kg	RAWPA
Averaging Time - AT (Carcinogens)	25550	days	RAWPA
Ave. Time - AT (Noncarcinogens)	T_3 or T_4	See Table D.3.4.1-2	RAWPA
Stack height - H	0	m	Assumption
Average wind speed - μ	4.1	m/sec	OU1 RI, Figure E.3.1

[a] This value is based on 50 percent moderate work (2.1 m^3/hr) and 50 percent heavy work (3.9 m^3/hr).
[b] Risk Assessment Work Plan Addendum.

TABLE D.3-2
EXPOSURE DURATION PARAMETERS

Parameter	Value	Units	Reference
T_1	0.026	years	See supporting text
T_2	306370	person-hours	See supporting text
T_3	1000	hours	See supporting text
T_4	627	hours	See supporting text
T_5	3000	person-hours	See supporting text
T_6	168063	person-hours	See supporting text
T_7	102100	person-hours	See supporting text
T_8	125647	person-hours	See supporting text
T_9	1781329	person-hours	See supporting text
T_{10}	2303909	person-hours	See supporting text
T_{11}	4160	person-hours	See supporting text
T_{12}	171750	person-hours	See supporting text
T_{13}	88950	person-hours	See supporting text
T_{14}	171460	person-hours	See supporting text

TABLE D.3-3
UNIT RISK FACTORS

Parameter	Value	Units	Reference
CRF	1.25×10^{-4}	Per person/rem	OU4 FS
MHRF (injury)	3.4×10^{-5}	Injuries per person/hour	RAWPA
MHRF (fatality)	5.0×10^{-7}	Fatalities per person/hour	RAWPA
RCF (train worker injury)	4.6×10^{-6}	Injuries per mile	RAWPA
RCF (train worker fatality)	4.6×10^{-8}	Fatalities per mile	RAWPA
RCF (truck worker injury)	6.8×10^{-6}	Injuries per mile	RAWPA
RCF (truck worker fatality)	1.8×10^{-6}	Fatalities per mile	RAWPA
RCF (train public injury)	4.1×10^{-8}	Injuries per mile	RAWPA
RCF (train public fatality)	2.1×10^{-9}	Fatalities per mile	RAWPA
RCF (truck public injury)	1.2×10^{-7}	Injuries per mile	RAWPA
RCF (truck public fatality)	1.3×10^{-8}	Fatalities per mile	RAWPA

TABLE D.3-4
ORGAN WEIGHTING FACTORS

Organ or Tissue	Weighting Factor
Gonads	0.25
Breasts	0.15
Red Bone Marrow	0.12
Lungs	0.12
Thyroid	0.03
Bone Surfaces	0.03
Remainder[a]	0.30

[a] Remainder means the five other organs with the highest dose equivalent (excluding skin, lens of eye, and extremities). The weighting factor for each such organ is 0.06.

SOURCE: U.S. Dept. of Energy (DOE), 1988a, "Internal Dose Conversion Factors," DOE/EH-0071, Washington, DC.

TABLE D.3-5
INHALATION UNIT RISK AND CANCER SLOPE FACTORS

Contaminant of Concern	Unit Risk Factor, $\mu g/m^3$ or Cancer Slope Factor, kg-day/mg
Antimony	NV[a]
Arsenic	0.0043 $\mu g/m^3$
Barium	NC[b]
Beryllium	8.4 kg-day/mg
Boron	NV
Cadmium	6.1 kg-day/mg
Cobalt	NV
Copper	NC
Manganese	NC
Molybdenum	NV
Mercury	NC
Nickel	0.84 kg-day/mg
Silver	NC
Thallium	NV
Uranium	NA[c]
Vanadium	NV
Zinc	NC
Aroclor 1248	450. $\mu g/m^3$
Aroclor 1254	450. $\mu g/m^3$
2379-TCDF	450. $\mu g/m^3$
HpCDD	0.023 $\mu g/m^3$
HpCDF	0.023 $\mu g/m^3$
HxCDD	0.023 $\mu g/m^3$
HxCDF	0.023 $\mu g/m^3$
OCDD	0.023 $\mu g/m^3$
OCDF	0.023 $\mu g/m^3$
Pentachlorophenol	NV
Tetrachloroethane	0.003 kg-day/mg
Benzo(b)anthracene	6.1 kg-day/mg
Benzo(a)pyrene	6.1 kg-day/mg
Benzo(b)fluoranthene	6.1 kg-day/mg
Chrysene	6.1 kg-day/mg
Indeno(123cd)pyrene	6.1 kg-day/mg

TABLE D.3-5
(Continued)

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[a] NV - No values.
[b] NC - Noncarcinogen.
[c] NA - Not applicable. Uranium carcinogenesis is due to radiation.

SOURCE: U.S. Dept. of Energy (DOE), 1994, "Draft Final Remedial Investigation Report for Operable Unit 1," DOE, Fernald Field, Office, Fernald, OH (Table E.4-2).

TABLE D.3-6
INHALATION REFERENCE DOSE VALUES

Contaminant of Concern	Reference Dose, mg/kg-day
Antimony	NA[a]
Arsenic	NA
Barium	1.43×10^{-4}
Beryllium	NA
Boron	NA
Cadmium	NA
Cobalt	3×10^{-7}
Copper	NA
Manganese	1.14×10^{-4}
Molybdenum	NA
Mercury	NA
Nickel	NA
Silver	NA
Thallium	NA
Uranium	NA
Vanadium	NA
Zinc	NA
Aroclor 1248	NA
Aroclor 1254	NA
2379-TCDF	NA
HpCDD	NA
HpCDF	NA
HxCDD	NA
HxCDF	NA
OCDD	NA
OCDF	NA
Pentachlorophenol	NA
Tetrachloroethane	NA
Benzo(b)anthracene	NA
Benzo(a)pyrene	NA
Benzo(b)fluorathene	NA
Chrysene	NA
Indeno(123cd)pyrene	NA

TABLE D.3-6
(continued)

[a] NA - No toxic effects.

SOURCE: U.S. Dept. of Energy (DOE), 1994, "Draft Final Remedial Investigation Report for Operable Unit 1," DOE, Fernald Field Office, Fernald, OH (Table E.4-2).

TABLE D.3-7
DOSE EQUIVALENT FACTORS

Radionuclide	Direct Radiation from Soil Dose Factor, mrem/yr per $\mu Ci/m^2$	Inhalation Dose Factor, rem/μCi (Solubility Class)[a]	Immersion Dose Factor, mrem/yr per $\mu Ci/m^3$
Sr-90	6.75×10^{1} [b]	1.3 (Y)	0.0
Tc-99	6.26×10^{-5}	7.5×10^{-3} (W)	2.65×10^{-3}
Cs-137	6.11×10^{1} [c]	3.2×10^{-2} (D)	3.06×10^{3} [c]
Rn-220	5.38×10^{-2}	0.0	1.95
Ra-226	7.6×10^{-1}	7.9 (W)	3.43×10^{1}
Th-228	2.77×10^{-1}	2.5×10^{2} (W)	9.89
Th-230	9.07×10^{-2}	3.2×10^{2} (W)	1.96
Th-232	6.66×10^{-2}	1.6×10^{3} (W)	9.33×10^{-1}
U-234	8.07×10^{-2}	1.3×10^{2} (Y)	7.65×10^{-1}
U-235	1.71×10^{1}	1.2×10^{2} (Y)	7.70×10^{2}
U-238	6.46×10^{-2}	1.2×10^{2} (Y)	6.19×10^{-1}
Np-237	3.24	4.9×10^{2} (W)	1.15×10^{2}
Pu-238	8.58×10^{-2}	4.6×10^{2} (W)	4.41×10^{-1}
Pu-239/240	8.20×10^{-2} [d]	5.1×10^{2} (W)	4.32×10^{-1} [c]

[a] D = Day, W = Week, Y = Year
[b] Includes Y-90 and Y-90m
[c] Includes Ba-137m
[d] Based on Pu-240

SOURCE: U.S. Dept. of Energy, 1988a, "Internal Dose Conversion Factors," DOE/EH-0071, Washington, DC (for inhalation).

U.S. Dept. of Energy, 1988b, "External Dose Conversion Factors," DOE/EH-0070, DOE, Washington, DC (for direct soil and immersion).

TABLE D.3-8
DISPERSION COEFFICIENT FORMULATION

Pasquill Class	Horizontal Dispersion Coefficient, σ_y (m)	Vertical Dispersion Coefficient, σ_z (m)	Stability Class Frequency FRAC[b]
A	$0.22 \bullet x^a / [1 + (0.0001 \bullet x)]^{1/2}$	$0.20 \bullet x$	0.09
B	$0.16 \bullet x / [1 + (0.0001 \bullet x)]^{1/2}$	$0.12 \bullet x$	0.04
C	$0.11 \bullet x / [1 + (0.0001 \bullet x)]^{1/2}$	$0.08 \bullet x / [1 + (0.0002 \bullet x)]^{1/2}$	0.04
D	$0.08 \bullet x / [1 + (0.0001 \bullet x)]^{1/2}$	$0.06 \bullet x / [1 + (0.0015 \bullet x)]^{1/2}$	0.33
E	$0.06 \bullet x / [1 + (0.0001 \bullet x)]^{1/2}$	$0.03 \bullet x / [1 + (0.0003 \bullet x)]$	0.27
F	$0.04 \bullet x / [1 + (0.0001 \bullet x)]^{1/2}$	$0.016 \bullet x / [1 + (0.0003 \bullet x)]$	0.22

[a] The parameter "x" is the downwind distance in meters.
[b] From Operable Unit 1 Remedial Investigation Report, Figure E-3-1.

SOURCE: U.S. Dept. of Energy (DOE), 1994, "Draft Final Remedial Investigation Report for Operable Unit 1," DOE, Fernald Field Office, Fernald, OH (Table E.4-2).

Moore et al., 1979, "*AIRDOS-EPA: A Computerized Methodology for Estimating Environmental Concentrations and Dose to Man from Airborne Releases of Radionuclides*," prepared for U.S. Environmental Protection Agency by Oak Ridge National Laboratory, Oak Ridge, TN.

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TABLE D.3-9
RADIONUCLIDE SOIL CONCENTRATIONS

Radionuclide	Pit Concentration, pCi/g								
	1	2	3	4	5	6	Burn	Clearwell	Surf. Soils
Sr-90	4.7	3.99	5.2	99.4	20.1	5.5	0.5	22.3	1.7
Tc-99	15	618	521	197	2070	167	52.3	523	8.7
Cs-137	1.1	3.6	ND	ND	76	108	ND	406	1
Ra-226	86.7	850	306	36.6	112	4.4	34.2	118	1
Th-228	131	697	554	2320	42.9	1.5	12.9	54.9	5.5
Th-230	5460	18400	8570	1520	6810	47.6	3810	4760	74.9
Th-232	131	268	396	708	45.1	1.1	13.2	36.9	4.3
U-234	902	11500	1110	4100	930	5060	1560	797	60.1
U-235	179	5520	51.8	898	53.9	1840	101	349	6.8
U-238	10400	11900	1300	44500	903	20600	1800	1360	245
Np-237	ND[a]	ND	2.1	0.4	46	3.4	0.6	2.2	0.5
Pu-238	ND	0.1	1	0.5	3.6	1.3	0.5	0.4	0.4
Pu-239/240	ND	0.6	14	0.4	9.7	14.3	0.4	0.4	0.1

[a] ND = Not Detected.

SOURCE: U.S. Dept. of Energy (DOE), 1994, "Draft Final Remedial Investigation Report for Operable Unit 1," DOE, Fernald Field Office, Fernald, OH.

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TABLE D.3-10

CHEMICAL SOIL CONCENTRATIONS

COC	Operable Unit 1 Waste Pit Concentration								
	1	2	3	4	5	6	Burn	Clearwell	Surf. Soil
Arsenic[a]	11.3	380	21300	5.16	2150	54.9	34.7	54	4.9
Barium[a]	405	1960	8080	4580	30200	95	3050	6140	56.9
Beryllium[a]	8.21	26.8	14.4	50.6	14.8	5.7	7.14	7.78	0.8
Cadmium[a]	16.2	13.5	25.9	24.5	11.6	5.7	15.4	7.2	5.8
Cobalt[a]	33.8	1320	36	129	35.5	26	98.9	23	10.4
Manganese[a]	2030	2660	16700	4750	3050	221	944	13200	574
Nickel[a]	47.1	1580	206	167	150	51	187	167	29.4
Aroclor 1248[c]	3500	321	2730	5920	550	ND	ND	308	ND
Aroclor 1254[c]	9980	323	2080	6800	750	81	7700	643	1400
2378-TCDF[b]	7.64	ND[d]	ND	6.97	ND	ND	ND	ND	ND
HpCDD[b]	1.45	8.1	2.1	3.16	ND	ND	0.98	ND	ND
HpCDF[b]	1.75	5.9	0.687	3.18	ND	ND	ND	ND	ND
HxCDD[b]	3.21	0.32	0.260	1.85	ND	ND	ND	ND	ND
HxCDF[b]	2.26	2.7	0.267	5.39	ND	ND	ND	ND	ND
OCDD[b]	0.54	45.9	12.7	6.52	ND	ND	4.00	ND	ND
OCDF[b]	0.76	4.9	0.745	3.66	ND	ND	0.13	ND	ND
Tetrachloroethene[b]	252	45	ND	30000	ND	31100	260	ND	ND
Benzo(a)anthracene[c]	180	100000	360	4700	ND	ND	6300	890	ND
Benzo(a)pyrene[c]	140	75200	280	4500	ND	ND	3900	670	ND
Benzo(b)fluorathene[c]	307	130000	560	5200	ND	ND	9600	710	ND
Chrysene[c]	451	86000	370	3860	ND	ND	7000	1000	ND

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TABLE D.3-10
(Continued)

COC	Operable Unit 1 Waste Pit Concentration								
	1	2	3	4	5	6	Burn	Clearwell	Surf. Soil
Indeno(123cd)pyrene[c]	ND[d]	46000	130	990	ND	ND	2200	270	ND

[a] Units = mg/kg
[b] Units = ng/g
[c] Units = μg/kg
[d] ND = Not Detected

SOURCE: U.S. Dept. of Energy (DOE), 1994, "Draft Final Remedial Investigation Report for Operable Unit 1," DOE, Fernald Field Office, Fernald, OH (Appendix E and Section E.2).

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TABLE D.3-11

VITRIFIED WASTE RADIONUCLIDE CONCENTRATIONS

Radionuclide	Vitrified Concentration[a], pCi/g								
	1	2	3	4	5	6	Burn	Clearwell	S. Soils
Sr-90	3.36	2.85	3.71	71.00	14.36	3.93	0.36	15.93	1.21
Tc-99	10.71	441.43	372.14	140.71	1478.57	119.29	37.36	373.57	6.21
Cs-137	0.79	2.57	ND	ND	54.29	77.14	ND	290.00	0.71
Ra-226	61.93	607.14	218.57	26.14	80.00	3.14	24.43	84.29	0.71
Th-228	93.57	497.86	395.71	1657.14	30.64	1.07	9.21	39.21	3.93
Th-230	3900.00	13142.86	6121.43	1085.71	4864.29	34.00	2721.43	3400.00	53.50
Th-232	93.57	191.43	282.86	505.71	32.21	0.79	9.43	26.36	3.07
U-234	644.29	8214.29	792.86	2928.57	664.29	3614.29	1114.29	569.29	42.93
U-235	127.86	3942.86	37.00	641.43	38.50	1314.29	72.14	249.29	4.86
U-238	7428.57	8500.00	928.57	31785.71	645.00	14714.29	1285.71	971.43	175.00
Np-237	ND[b]	ND	1.50	0.29	32.86	2.43	0.43	1.57	0.36
Pu-238	ND	0.07	0.71	0.36	2.57	0.93	0.36	0.29	0.29
Pu-239/240	ND	0.43	10.00	0.29	6.93	10.21	0.29	0.29	0.07

[a] Values in this table were derived by increasing the unit volume in Table D.3-9 by 40 percent, which is the increase in volume due to vitrification (Parsons, 1993).
[b] ND = Not Detected.

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TABLE D.3-12

DRIED WASTE RADIONUCLIDE CONCENTRATIONS

Radionuclide	Dried Concentration,[a] pCi/g								
	1	2	3	4	5	6	Burn	Clearwell	S. Soils
Sr-90	4.20	3.56	4.64	88.75	17.95	4.91	0.45	19.91	1.52
Tc-99	13.39	551.79	465.18	175.89	1848.21	149.11	46.70	466.96	7.77
Cs-137	0.98	3.21	ND	ND	67.86	96.43	ND	362.50	0.89
Ra-226	77.41	758.93	273.21	32.68	100.00	3.93	30.54	105.36	0.89
Th-228	116.96	622.32	494.64	2071.43	38.30	1.34	11.52	49.02	4.91
Th-230	4875.00	16428.57	7651.79	1357.14	6080.36	42.50	3401.79	4250.00	66.88
Th-232	116.96	239.29	353.57	632.14	40.27	0.98	11.79	32.95	3.84
U-234	805.36	10267.86	991.07	3660.71	830.36	4517.86	1392.86	711.61	53.66
U-235	159.82	4928.57	46.25	801.79	48.13	1642.86	90.18	311.61	6.07
U-238	9285.71	10625.00	1160.71	39732.14	806.25	18392.86	1607.14	1214.29	218.75
Np-237	ND[b]	ND	1.88	0.36	41.07	3.04	0.54	1.96	0.45
Pu-238	ND	0.09	0.89	0.45	3.21	1.16	0.45	0.36	0.36
Pu-239/240	ND	0.54	12.50	0.36	8.66	12.77	0.36	0.36	0.09

[a] Values in this table were derived by increasing the unit volume in Table D.3-9 by 12 percent, which is the increase in volume due to drying (Parsons, 1993).
[b] ND = Not Detected.

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TABLE D.3-13

CEMENT WASTE RADIONUCLIDE CONCENTRATIONS

Radionuclide	Cement Waste Form Concentration,[a] pCi/g								
	1	2	3	4	5	6	Burn	Clearwell	S. Soils
Sr-90	2.61	2.22	2.89	55.22	11.17	3.06	0.28	12.39	0.94
Tc-99	8.33	343.33	289.44	109.44	1150.00	92.78	29.06	290.56	4.83
Cs-137	0.61	2.00	ND	ND	42.22	60.00	ND	225.56	0.56
Ra-226	48.17	472.22	170.00	20.33	62.22	2.44	19.00	65.56	0.56
Th-228	72.78	387.22	307.78	1288.89	23.83	0.83	7.17	30.50	3.06
Th-230	3033.33	10222.22	4761.11	844.44	3783.33	26.44	2116.67	2644.44	41.61
Th-232	72.78	148.89	220.00	393.33	25.06	0.61	7.33	20.50	2.39
U-234	501.11	6388.89	616.67	2277.78	516.67	2811.11	866.67	442.78	33.39
U-235	99.44	3066.67	28.78	498.89	29.94	1022.22	56.11	193.89	3.78
U-238	5777.78	6611.11	722.22	24722.22	501.67	11444.44	1000.00	755.56	136.11
Np-237	ND[b]	ND	1.17	0.22	25.56	1.89	0.33	1.22	0.28
Pu-238	ND	0.06	0.56	0.28	2.00	0.72	0.28	0.22	0.22
Pu-239/240	ND	0.33	7.78	0.22	5.39	7.94	0.22	0.22	0.06

[a] The values in this table are derived from Table D.3-9 based on bulking factors in DOE, 1993a.
[b] ND = Not Detected.

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TABLE D.3-14

TRANSPORTATION ANALYSIS PARAMETERS

Parameter	Value	Units	Reference
No. of Rail Trips, Repr. Commercial Disposal Facility	374	trips	Calculated
No. of Rail Trips, NTS	444	trips	Calculated
No. of Truck Trips, NTS	48809	trips	Calculated
No. of Rail Cars per Train	22	cars	Calculated
No. of Packages per Rail Car	25	packages	Calculated
No. of Packages per Truck	5	packages	Calculated
Miles to Repr. Commercial Disposal Facility (One Way)	1972	rail miles	Calculated
Miles to Las Vegas (One Way)	2213	rail miles	Calculated
Round Trip Miles: Las Vegas to NTS	111	highway miles	Calculated
Weight of Waste per Package	2450	kg	Calculated
Weight of Waste per Gondola Car	72730	kg	Calculated
Transport Index, Package	0.0074/0.0022[a]	mrem/hr	Calculated
Transport Index, Gondola Car	0.00039	mrem/hr	Calculated
Package Size, Container	2.1/1.2[a]	meters	Calculated
Package Size, Gondola	30.35	meters	Calculated

[a] Train/Truck.

TABLE D.3-15

PARAMETERS USED TO ESTIMATE POTENTIAL LONG-TERM EXPOSURES[a]

Pathway Parameters	Expanded Trespasser Child Age 6-18	Expanded Trespasser Adult 18-50	On-Property Resident Farmer Age 1-70	On-Property Resident Child Age 1-6	Off-Property Resident Farmer Age 1-70	Off-Property Resident Child Age 1-6
Inhalation of Dusts, Volatiles, and Radon						
IR (m^3/hr)	0.83	0.83	0.83	0.5	0.83	0.5
ET Indoors (hr/d)	N/A	N/A	18.3	22	18.3	22
ET Outdoors (hr/d)	2	1	5.7	2	5.7	2
EF (d/yr)	110	40	350	350	350	350
ED (yr)	12	32	70	6	70	6
BW (kg)	43	70	70	15	70	15
AT-Noncancer (d)[f]	4380	11680	25550	2190	25550	2190
AT-Cancer (d)[g]	25550	25550	25550	25550	25550	25550
Ingestion of Drinking Water						
IR (ℓ/d)	N/A	N/A	2	1	2	1
FI (unitless)	N/A	N/A	1	1	1	1
EF (d/yr)	N/A	N/A	350[d]	350[d]	350[d]	350
ED (yr)	N/A	N/A	70	6	70	6
BW (kg)	N/A	N/A	70	15	70	15
AT-Noncancer (d)[f]	N/A	N/A	25550	2190	25550	2190
AT-Cancer (d)[g]	N/A	N/A	25550	25550	25550	25550

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Pathway Parameters	Expanded Trespasser Child Age 6-18	Expanded Trespasser Adult 18-50	On-Property Resident Farmer Age 1-70	On-Property Resident Child Age 1-6	Off-Property Resident Farmer Age 1-70	Off-Property Resident Child Age 1-6
Inhalation of Volatiles Released from Household Water Uses						
IR (m^3/day)	N/A	N/A	15	15	15	15
EF (d/yr)	N/A	N/A	350[d]	350[d]	350[d]	350
ED (yr)	N/A	N/A	70	6	70	6
BW (kg)	N/A	N/A	70	15	70	15
AT-Noncancer (d)[f]	N/A	N/A	25550	2190	25550	2190
AT-Cancer (d)[g]	N/A	N/A	25550	25550	25550	25550
Incidental Ingestion of Soil/Sediment						
IR (mg/day)	100	100	180	200	N/A	N/A
FI (unitless)	0.125	0.125	1	1	N/A	N/A
EF (d/yr)	110	40	350[d]	350[d]	350[d]	N/A
ED (yr)	12	32	70	6	70	N/A
BW (kg)	43	70	70	15	70	N/A
AT-Noncancer (d)[f]	4380	11680	25550	2190	25550	N/A
AT-Cancer (d)[g]	25550	25550	25550	25550	25550	N/A
Dermal Contact While Bathing						
SA (m^2)	N/A	N/A	2.3	0.8	2.3	0.8
PC (cm/hr)	N/A	N/A	csv	csv	csv	csv
ET (hr/d)	N/A	N/A	0.25[h]	0.25	0.25[h]	0.25
EF (d/yr)	N/A	N/A	350[d]	350[d]	350[d]	350

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TABLE D.3-15
(Continued)

Pathway Parameters	Expanded Trespasser Child Age 6-18	Expanded Trespasser Adult 18-50	On-Property Resident Farmer Age 1-70	On-Property Resident Child Age 1-6	Off-Property Resident Farmer Age 1-70	Off-Property Resident Child Age 1-6
ED (yr)	N/A	N/A	70	6	70	6
BW (kg)	N/A	N/A	70	15	70	15
AT-Noncancer (d)[f]	N/A	N/A	25550	2190	25550	2190
AT-Cancer (d)[g]	N/A	N/A	25550	25550	25550	25550
Dermal Contact With Soil/Sediment						
SA (m^2)	0.42	0.575	0.575	0.2	0.575	0.2
DA (cm/m^2)	1	1	1	1	1	1
ABS	cvs	cvs	cvs	cvs	csv	csv
EF (d/yr)	110	40	350[d]	350[d]	350[d]	350
ED (yr)	12	32	70	6	70	6
BW (kg)	43	70	70	15	70	15
AT-Noncancer (d)[f]	4380	11680	25550	2190	25550	2190
AT-Cancer (d)[g]	25550	25550	25550	25550	25550	25550
Inhalation of Dusts, Volatiles, and Radon						
DR (mrem/hr)	csv	csv	csv	csv	N/A	N/A
ET Indoors (hr/d)	N/A	N/A	18.3	22	N/A	N/A
ET Outdoors (hr/d)	2	1	5.7	2	N/A	N/A
EF (d/yr)	110	40	350	350	N/A	N/A
ED (yr)	12	32	70	6	N/A	N/A
BW (kg)	43	70	70	15	N/A	N/A

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TABLE D.3-15
(Continued)

Pathway Parameters	Expanded Trespasser Child Age 6-18	Expanded Trespasser Adult 18-50	On-Property Resident Farmer Age 1-70	On-Property Resident Child Age 1-6	Off-Property Resident Farmer Age 1-70	Off-Property Resident Child Age 1-6
Ingestion of Vegetables and Fruit						
IR (g/d)	N/A	N/A	122	106	122	106
FI (unitless)	N/A	N/A	0.5	0.5	0.5	0.5
EF (d/yr)	N/A	N/A	350[d]	350[d]	350[d]	350
ED (yr)	N/A	N/A	70	6	70	6
BW (kg)	N/A	N/A	70	15	70	15
AT-Noncancer (d)[f]	N/A	N/A	25550	2190	25550	2190
AT-Cancer (d)[g]	N/A	N/A	25550	25550	25550	25550
Ingestion of Meat						
IR (g/d)	N/A	N/A	75	29	75	29
EF (d/yr)	N/A	N/A	350[d]	350[d]	350[d]	350
ED (yr)	N/A	N/A	70	6	70	6
BW (kg)	N/A	N/A	70	15	70	15
AT-Noncancer (d)[f]	N/A	N/A	25550	2190	25550	2190
AT-Cancer (d)[g]	N/A	N/A	25550	25550	25550	25550
Ingestion of Milk						
IR (L/d)	N/A	N/A	0.3	0.68	0.3	0.68
EF (d/yr)	N/A	N/A	350[d]	350[d]	350[d]	350
ED (yr)	N/A	N/A	70	6	70	6
BW (kg)	N/A	N/A	70	15	70	15
AT-Noncancer(d)[f]	N/A	N/A	25550	2190	25550	2190

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TABLE D.3-15
(Continued)

Pathway Parameters	Expanded Trespasser Child Age 6-18	Expanded Trespasser Adult 18-50	On-Property Resident Farmer Age 1-70	On-Property Resident Child Age 1-6	Off-Property Resident Farmer Age 1-70	Off-Property Resident Child Age 1-6
AT-Cancer(d)[a]	N/A	N/A	25550	25550	25550	25550

[a] Parameter values obtained from Final RI Report for Operable Unit 4 (February 1994), Table D.3-12.

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POTENTIAL RECEPTOR	LAND USE SCENARIO: Continued Federal Ownership with No Access Controls	LAND USE SCENARIO: Private Ownership
On-Property Farmer On-Property Child	Not Applicable	Surface Soil - Inhalation - Ingestion - Dermal Contact - Direct Radiation Groundwater - Inhalation - Ingestion - Dermal Contact Farm Produce (crops, dairy, meat) - Ingestion
Off-Property Farmer Off-Property Child	Surface Soil - Inhalation Groundwater - Inhalation - Ingestion - Dermal Contact Farm Produce (crops, dairy, meat) - Ingestion	Surface Soil - Inhalation Groundwater - Inhalation - Ingestion - Dermal Contact Farm Produce (crops, dairy, meat) - Ingestion
Expanded Trespasser	Surface Soil - Inhalation - Ingestion - Dermal Contact - Direct Radiation	Not Applicable

FIGURE D.3-1
OPERABLE UNIT 1
RESIDUAL RISK EXPOSURE PATHWAYS FOR POTENTIAL RECEPTORS
IN THE CONSIDERED LAND USE SCENARIOS

D.4.0 TOXICITY ASSESSMENT

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D.4.1 CANCER AND NONCANCER TOXICITY CRITERIA

The risk of developing radiologically or chemically induced cancer is estimated by computing an ILCR, expressed as a probability. The chemical ILCR is calculated as the product of the reasonable maximum daily intake or dose, expressed as milligram/kilogram (mg/kg) per day, and the cancer slope factor (CSF), which is the risk per unit intake or dose, or the risk per mg/kg-day. This model implies linearity in the dose-response relationship over the entire dose range of concern. The radiological ILCR is calculated as the product of the radionuclide activity intake (pCi/life) and the CSF, which is the risk per unit activity intake, or the risk per pCi. In addition, cancer risks associated with external radiation are estimated for radionuclide COCs.

Cancer risks associated with multiple chemical and radionuclide exposures are assumed to be additive within the two classes of contaminants. However, due to differences in the methods used to derive the toxicity parameter values for the two classes of contaminants, cancer risks due to radionuclide and chemical exposures are not considered to be strictly comparable, and radiological and chemical risks are not summed in the calculations of potential carcinogenic risk.

The risk of developing chemically induced noncancer effects is estimated as a ratio (HQ). The HQ is calculated as the ratio of the exposure dose, or intake, divided by a reference dose (RfD), which is a dose at which adverse effects are not expected to occur. A HQ equal to or greater than 1 indicates that an adverse effect might be expected to occur. In the case of multiple chemical exposures, the potential for adverse noncancer effects is evaluated using HIs, which are defined as the sum of the HQs for the individual contaminant exposures.

The COCs in the soil and groundwater to which the potential receptors could be exposed include contaminants that may induce both carcinogenic and noncancer effects. Potential routes of exposure include inhalation, ingestion, and direct contact, but is assumed that many of the potential routes of exposure can be mitigated through the use of protective equipment and/or access controls. Table D.4-1 presents the toxicity values for the chemical COCs in soil, taken largely from the most recent version of the Health Effects Assessment Summary Tables (HEAST) (EPA 1993b) and Integrated Risk Information System (IRIS). The toxicity values include chronic oral RfD values and CSFs for inhalation, oral, and dermal exposure, when available. The use of chronic RfDs provides a

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conservative evaluation of remedial action risks, as the long-term toxicity criteria are generally more stringent than the subchronic values. They are also applicable in the residual risk scenarios.

The inhalation pathway RfD values were derived from inhalation pathway Reference Concentration (RfC) values by multiplying the RfC values by the standard default daily adult inhalation rate of 20 m^3/day, as recommended by the EPA (1992b). In the assessment of inhalation pathway risks, scenario-specific assumptions about daily inhalation pathway exposures were used. In evaluating the potential for adverse affects associated with cadmium exposure, the RfD derived for drinking water exposure was used for the groundwater pathway. In evaluating risks for all other ingestion pathways, the RfD derived for food exposures was used.

As noted previously, one transport pathway of concern for residual exposure is leaching of contaminants to groundwater. Although the source term differs with different remedial alternatives, the COCs predicted to enter the groundwater through the leachate are presented in Section D.5.0. Toxicity values for these COCs are presented in Table D.4-1. The RfD values in Table D.4-1 reflect chronic exposure, because exposure could potentially be over a lifetime.

Table D.4-2 presents Chemical Specific Factors (CSFs) for exposure to radionuclides during and after the remediation process. Because cancer risk is calculated as a function of cumulative dose, these CSFs pertain to both short- and long-term exposure.

Toxicity profiles for the radionuclides and nonradioactive COCs are presented in Section E.4 of the RI Report for Operable Unit 1.

D.4.2 MISSING TOXICOLOGICAL REFERENCE VALUES

A number of the nonradioactive COCs listed in Table D.4-1 do not have toxicological criterion values for all pathways (e.g., cancer slope factors, oral references doses, or inhalation reference concentrations) which have been verified by EPA. After searching available sources for these values, a request was made to EPA, Region V, to supply the missing values. The EPA was unable to provide all of the needed values for each of the exposure routes evaluated. The potential toxic effects of the compounds which lack toxicological reference values for both cancer and noncancer endpoints for either oral, inhalation, or dermal exposures are addressed qualitatively below.

Of the nonradioactive COCs identified in surface and subsurface soils, only four lack toxicological criterion values for inhalation and dermal exposure routes. Four of these compounds belong to a group of structurally related compounds known as polycyclic aromatic hydrocarbons (PAHs), namely benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene and indeno(g,h,i)perylene. Only a few PAHs have been characterized with respect to their toxicities and available information on PAHs shows a wide range of relative potencies with both cancer and noncancer endpoints. The toxicity of the these four PAHs via the inhalation and dermal routes and the impact of this omission may have on the final outcome of the risk assessment cannot be assessed at this time.

D.4.3 INHALATION REFERENCE CONCENTRATIONS

The toxicity of the remaining COCs was quantitatively assessed for oral and dermal exposures, however, 16 compounds remain for which inhalation reference values were unavailable: metals, semivolatile organic compounds (SVOCs), and the polychlorinated biphenyl (PCB) mixtures.

The toxicological reference value needed to quantitatively assess risks due to inhalation exposures of noncarcinogenic compounds are known as RfCs. The method by which RfCs are derived for inhalation exposures parallels that for oral reference doses (RfDs), except that factors such as the dynamics of the respiratory system, diversity across species, including airway diameter and branching effects, clearance rates, and differences in the physicochemical properties of contaminants must be considered.

Metals

Antimony is used with lead alloys in storage battery grids, alloys, rubber, matches, ceramics, enamels and paints. It is a common pollutant in urban air and has been used medicinally as a parasiticide, an emetic, and an expectorant. These medicinal uses have been largely phased out because of its relatively high toxicity. The toxic effects associated with acute oral exposure to antimony include vomiting, diarrhea, irregular respiration, lowered temperature, and collapse. Locally, antimony compounds irritate the skin and mucous membranes. The American Conference of Governmental and Industrial Hygienists (ACGIH) has established a TLV-TWA of 0.5 mg/m^3 for antimony.

Molybdenum is a nutritionally essential trace element. In plants, it is necessary for the bacterial fixing of atmospheric nitrogen and as such it is quite common in food. The human body contains approximately 9 mg of molybdenum, most of which is contained in the liver, kidney, fat, and blood. Symptoms of molybdenum poisoning include decreased copper levels in the blood, gastrointestinal

irritation, and pain and swelling in the joints. Industrial exposures to high concentrations of molybdenum dust have been associated with "hard-metal lung disease." The TLV-TWA for molybdenum has been set at 5.0 mg/m^3.

The major effect of excessive absorption of silver is local or generalized impregnation of various tissues, the result of which is the production of a generalized grayish pigmentation of the skin and mucous membranes, a condition known as Argyrosis. Silver can be absorbed from the lungs and gastrointestinal tract. There are no systemic changes or physical disabilities associated with Argyrosis; however, the pigmentation is permanent. The TLV-TWA for silver is 0.01 mg/m^3.

Thallium is readily absorbed from the gastrointestinal and respiratory tracts and is widely distributed to the tissues of the body. It is used as a catalyst in some alloys and has been used medicinally as a depilatory, but its chief uses have been in rodenticides and insecticides. The major effects of thallium poisoning are on the nervous system, skin, and cardiovascular system. The TLV-TWA for thallium is 0.1 mg/m^3. However, this value bears the notation "skin," meaning that the compound may be taken in through cutaneous absorption, rather than or in addition to, inhalation absorption.

Vanadium is used as a catalyst in the production of several materials, including sulfuric acid. It is used to harden steel, in the manufacturing of pigments, in photography, and in pesticides. Vanadium is ubiquitous and common in many foods, including milk, seafood, cereals, vegetables, and food oils. The average body burden of vanadium has been estimated at 30 mg and a beneficial hematopoietic effect has been postulated but not proven. The toxic action of vanadium dust is largely to the respiratory tract. Following industrial exposures to vanadium dust, workers experience bronchitis, bronchopneumonia, and a discoloration of the tongue. In contrast to its low oral toxicity, the TLV-TWA for vanadium is relatively low, 0.05 mg/m^3, indicating high inhalation toxicity.

Zinc is an essential trace element necessary to enzymatic functions, protein synthesis, and carbohydrate metabolism. It is widely present in the environment, found in water, air, and in all living organisms. The average American daily intake of zinc is approximately 12.6 mg, most of which is consumed through foods. Inhalation of high concentrations of freshly formed zinc fumes in industrial settings has resulted in metal fume fever; however, only freshly formed material is potent, presumably due to flocculation in air which prevents deep penetration into the lungs of "aged" particulates. Workers note that this effect appears most frequently on Mondays or after holidays and

that in even the most severe cases recovery is usually complete in 24 to 48 hours. The TLV-TWA for zinc is 5.0 mg/m^3.

Of the six metals which were not quantitatively assessed with respect to inhalation toxicity, two (molybdenum) and zinc are nutritionally essential trace elements and it has been postulated that vanadium may have beneficial biological effects as well. Of the six metals, silver has the lowest TLV-TWA. However, the critical effect associated with absorption of silver is pigmentation of the skin and mucous membranes which is not accompanied by any serious toxicological effects. The concentrations in air calculated for these metals is, on average, three to four orders of magnitude lower than associated TLV-TWA values. This would indicate that the lack of an inhalation RfC for these metals is likely to have only a slight effect on the overall risk estimate.

PCBs

Compounds with relatively low vapor pressures or strong affinities to bind with organic constituents in soil may present very little risk from an inhalation standpoint because their residence time in air will be low. For example, the PCB Aroclor 1254 does not currently have an inhalation RfC and the TLV-TWA is set at 0.5 mg/m^3 based on dermal absorption through the skin. Aroclor 1254 has both a low vapor pressure and a strong tendency to bind to organics in soil. These physicochemical properties of Aroclor 1254 indicate that inhalation exposures to PCBs in soil are likely to be low and that the lack of an inhalation RfC for Aroclor 1254 is not likely to have a major impact on the final risk assessment for surface and berm soils.

TABLE D.4-1

TOXICITY VALUES FOR NONRADIOACTIVE CONSTITUENTS OF CONCERN IN OPERABLE UNIT 1

	Oral Exposure		Inhalation Exposure		Dermal Exposure	
Chemical	RfD[a] (mg/kg-day)	Cancer Slope Factor[b] (mg/kg-day)	RfD (mg/kg-day)	Cancer Slope Factor (mg/kg-day)	RfD (mg/kg-day)	Cancer Slope Factor (mg/kg-day)
Antimony	0.0004[d]	ND	QUAL[c]	QUAL	0.00006[e]	QUAL
Aroclor-1248	0.00005	7.7	ND		0.00005	10.3
Aroclor-125	0.00005	7.7	ND		0.00005	10.3
Aroclor-1260	0.00005	7.7	ND		0.00005	10.3
Arsenic	0.0003[d]	1.8[g]	QUAL	15	0.000285[m]	3.5
Benzo(a)anthracene	ND	7.3	QUAL	6.1	ND	17
Benzo(a)pyrene	ND	7.3	QUAL	6.1	ND	17
Benzo(b)fluoranthene	ND	7.3	QUAL	6.1	ND	17
Beryllium	0.005[d]	4.3	QUAL	8.4	0.00005[m]	86
Boron	0.09	ND	0.0057	ND	0.0045	ND
Cadmium (water)	0.0005	ND	ND	6.1	0.00005	ND
Cadmium (food)	0.001[i,j]	ND	QUAL	6.3	0.000025[i,j,m]	ND
Chromium(VI)[k]	0.005[d]	ND	QUAL	41	0.0023[e]	ND
Chrysene	ND	7.3	ND	6.1	ND	17
Cobalt	0.06	ND	0.0000007	ND	0.027	ND
Indeno(1,2,3-cd)pyrene	ND	7.3	ND	6.1	ND	17
Molybdenum	0.005[d]	ND	QUAL	ND	0.002[e,f]	ND
Nickel	0.02[d]	ND	QUAL	0.84	0.003[e]	ND
Pentachlorophenol	0.02	0.12	QUAL	ND	0.007	0.13
Silver	0.005[d]	ND	QUAL	ND	ND	ND
Tetrachloroethene	0.01	0.052	QUAL	0.003	0.009	0.058

TABLE D.4-1
(Continued)

Chemical	Oral Exposure		Inhalation Exposure		Dermal Exposure	
	RfD[a] (mg/kg-day)	Cancer Slope Factor[b] (mg/kg-day)	RfD (mg/kg-day)	Cancer Slope Factor (mg/kg-day)	RfD (mg/kg-day)	Cancer Slope Factor (mg/kg-day)
Thallium	0.0006[d,l]	ND	QUAL	ND	0.00006[e]	ND
Uranium	0.003	ND	QUAL	ND	0.00015	ND
Vanadium	0.007[d]	ND	QUAL	ND	0.00045[e,f]	ND
Zinc	0.3[d]	ND	QUAL	ND	0.075[m]	ND
2,3,7,8-TetraCDD	ND	150000	ND	ND	ND	300000
HexaCDD	ND	15000	ND	ND	ND	30000
HeptaCDD	ND	1500	ND	ND	ND	3000
HexaCDF	ND	15000	ND	ND	ND	30000
HeptaCDF	ND	1500	ND	ND	ND	3000

[a] RfD values are for subchronic exposure, unless otherwise noted.
[b] Cancer slope factors are taken from Tables D.4-2 or D.4-4 of the August 12, 1993, Operable Unit 4 Draft Final RI Report noted.
[c] QUAL = not assessed quantitatively; discussed qualitatively in the text (See Section D.3.3).
[d] Source: EPA (1992[b])
[e] Derived by multiplying the oral RfD by the gastrointestinal absorption factor (from Table D.4-4 of the August 1993, draft RI for OU4).
[f] Rounded to one significant figure.
[g] Rounded to two significant figures.
[h] Calculated by multiplying the reference concentration (mg/m^3) by the human inhalation rate of 20 m^3/day and dividing by the human body weight of 70 kg as recommended by the EPA (1992b).
[i] The RfD for cadmium in food was chosen over the RfD for cadmium in drinking water, because cadmium ingested in soil is likely to behave physiologically more like cadmium in food than like cadmium in water.
[j] In the absence of a subchronic RfD, the chronic RfD on IRIS was chosen as being sufficiently protective for subchronic exposure.
[k] As a conservative measure, chromium(VI) was chosen over chromium(III), because the former is the more toxic.
[l] Derived by analogy to thallium sulfate by correcting for differences in molecular weight.
[m] Derived by multiplying the oral RfD by the gastrointestinal absorption factors (from J.S. Dollarhide, U.S. EPA ORO-ECAO, memo to Pat VanLeewen, U.S. EPA (1992b).

TABLE D.4-2
TOXICITY VALUES FOR RADIOLOGICAL CONSTITUENTS OF CONCERN IN OPERABLE UNIT 1, USED TO ESTIMATE RESIDUAL RISK[a]

	Oral Exposure	Inhalation Exposure	Penetrating External Exposure
Radioiostope	Cancer Slope Factor $(pCi)^{-1}$	Cancer Slope Factor $(pCi)^{-1}$	$\frac{g}{(pCi \times yr)}$
Cs-137 + dtr	2.8×10^{-11}	1.9×10^{-11}	2.0×10^{-6}
Np-137 + dtr	2.2×10^{-10}	2.9×10^{-8}	4.3×10^{-7}
Pb-210 + 2 dtr	6.6×10^{-10}	4.0×10^{-9}	1.6×10^{-10}
Pu-238	2.2×10^{-10}	3.9×10^{-8}	2.8×10^{-11}
Pu-239/240	2.3×10^{-10}	3.8×10^{-8}	2.7×10^{-11}
Ra-226 + 5 dtr	1.2×10^{-10}	3.0×10^{-9}	6.0×10^{-6}
Ra-228 + 8 dtr	7.8×10^{-10}	7.0×10^{-9}	6.0×10^{-10}
Rn-222	1.7×10^{-12}	7.7×10^{-12}	5.9×10^{-6}
Sr-90	3.6×10^{-11}	6.2×10^{-11}	ND
Tc-99 + dtr	1.3×10^{-12}	8.3×10^{-12}	6.0×10^{-13}
Th-228 + 7 dtr	5.5×10^{-11}	7.8×10^{-8}	5.6×10^{-6}
Th-230	1.3×10^{-11}	2.9×10^{-8}	5.4×10^{-11}
Th-232	1.2×10^{-11}	2.8×10^{-11}	2.6×10^{-11}
U-234	1.6×10^{-11}	2.6×10^{-8}	3.0×10^{-11}
U-235 + dtr	1.6×10^{-11}	2.5×10^{-8}	2.4×10^{-7}
U-238	2.8×10^{-11}	5.2×10^{-8}	3.6×10^{-8}

[a] Parameter values obtained from Final RI Report for Operable Unit 4 (February 1994), Table D.3-12.

D.5.0 FATE AND TRANSPORT OF CONSTITUENTS OF CONCERN

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D.5.1 AIR TRANSPORT

D.5.1.1 Remedial Action and Transport

A major medium that transports contaminants to a receptor during implementation of remedial alternatives is air. During excavation, contaminated soil can be resuspended in the air. This contaminated air can affect receptors through inhalation or radiation exposure from immersion. During drying, vitrification, and solidification, contaminants are entrained in the off-gas systems for these processes. Some of these contaminants are not contained by the system and are released to the air. The contaminants are then transported to receptor locations.

Mechanical activities, such as excavation, resuspend soil in the air. A correlation can be made between the concentration of contaminants in the soil to the concentration of contaminants in the air through a dust loading factor. This factor is a measure of the mass of soil in a unit volume of air. For the purposes of this remedial action risk assessment, it has been assumed that all receptors are exposed to the same concentration of contaminants, i.e., the concentration of contaminants do not decrease as the plume travels to the nonremediation and off-site individual receptors.

Waste processing (drying, vitrification, and solidification) results in the release of some contaminants through the off-gas system. It is assumed that radon and volatile organic compounds are released without reduction, i.e., the off-gas system does not remove any of the material prior to its release. The plume of contamination moves as a gaussian plume toward the receptor (see Section 3.3.1 on exposure models for details on the gaussian plume model). In this analysis, no credit has been taken for an elevated release, i.e., the release is assumed to take place from ground level.

Section D.5.3.1 presents the exposure point concentrations for the airborne pathways.

D.5.1.2 Residual Risk

Contaminant transport to receptors through air is the primary vector for residual inhalation risks. For the two land use scenarios used to evaluate potential residual risks, the on-property farmer and child, the off-site farmer and child and the expanded trespasser are assumed to be exposed to airborne COCs.

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The on-property farmer and child are exposed to airborne COCs through both groundwater and surface soil transport mechanisms. Groundwater used in the on-property residence may contain Volatile Contaminants that may be inhaled by the farm family during routine household activities such as showering. Particles of surface soil containing residual contamination may be entrained in the air and inhaled during routine activities such as plowing or playing.

The off-site farmer and child are exposed through the same mechanisms as the on-property family. Transport to the off-site exposure point results in exposure concentrations that differ for the off-site and on-property families.

The expanded trespasser receptor is assumed to be at risk of inhaling airborne particulates entrained from surface soil.

For evaluation of residual risks, the soil resuspension factors adopted in the baseline RA are used to calculate volumes of soil to which receptors may be exposed. Concentrations of COCs in entrained soils are assumed to be at the PRGs. Methods used to calculate inhalation exposure to VOCs in groundwater follow EPA guidance. Concentrations of VOCs at the point of exposure are taken from results of groundwater modeling discussed in the following section.

D.5.2 GROUNDWATER

D.5.2.1 Residual Fate and Transport

Fate and transport computer models are used to predict the potential movement of constituents of concern from Operable Unit 1 source terms (including residual soils and materials deposited in a disposal cell) to receptor locations, after remediation is completed. The transport models provide the only means of predicting potential groundwater constituent concentrations at receptor locations in the future under assumed conditions. The four models normally used are:

- The geochemical model used to estimate leachate concentrations
- The hydrogeological evaluation of landfill performance (HELP) model used to estimate exfiltration rates
- The ODAST model to predict contaminant movement through the vadose zone
- The SWIFT III model used to predict contaminant movement through the Great Miami Aquifer

This section presents a brief description of the methodology to quantitatively predict constituent concentrations, which was used conceptually for the modeling effort.

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Conceptual Flow Model

Based on characteristics of the material underlying the on-property disposal facilities and Operable Unit 1, a conceptual model was developed for the pathway between the disposal areas and receptor locations. The elements of the conceptual model are shown in Figure D.5-1. This conceptual model is summarized in the following sections. Since there are two separate disposal locations, the model was developed to account for the variable stratigraphies of the soils. The disposal locations are the Operable Unit 1 footprint for residual contaminated subsurface soils, and the on-property disposal facilities area. Fluids or leachate entering from the disposal areas migrate first through the unsaturated glacial overburden, then through the unsaturated outwash deposits, and finally into the Great Miami Aquifer.

The disposal facilities are designed to minimize the intrusion of water for a period of 1000 years. However, for the purpose of this analysis, it is assumed that the impermeable barriers deteriorate, allowing water to infiltrate and contact the disposed wastes at an increased rate. Leaching of both treated waste in the disposal cell (Alternatives 4A and 4B) and untreated residual soils (Alternatives 4A, 4B, 5A and 5B) was assumed to be at a constant rate for the next 1000 years.

Water flowing through the waste and the vadose zone dissolves materials, forming an aqueous solution (Leachate A). This solution continues to percolate through the soil matrix in the vadose zone as it moves toward the aquifer. Leachate A reacts with the soil matrix through which it flows. These interactions determine what chemical species are present in the percolating water (Leachate B), and how fast they will move in the unsaturated zone. In this analysis, the composition of Leachate B and the speed at which individual constituents migrate are treated individually. In general, the heavy metals will precipitate out at this point through carbonate formation and will not migrate readily.

Contaminant transport in the vadose zone constitutes the bulk of the total migration of water and dissolved materials from waste (source) areas at the FEMP site to the Great Miami Aquifer. This occurs as surface water infiltrates from the surface and percolates through the source of contamination and its surrounding soil into the saturated zone. Downward movement of water, driven by forces of gravitational potential, capillary pressure and other components of total fluid potential, mobilize contaminants for transport through the vadose zone. However, the most important parameters are percolation rate and K_d. Many metals, such as lead and radium, have a large K_d such that the migration rate through the vadose zone is minimal. The effect of K_d and precipitation of metals from

Leachate A is responsible for the fact that many metals are not transported through the vadose zone and into the Great Miami Aquifer.

Fluid flow and contaminant transport process in the vadose zone is conceptualized from the hydrogeology of the site and specific strata. As discussed in the RI Report for Operable Unit 1, the geology of the FEMP site is dominated by glacial sediments. Well sorted sand and gravel glacial outwash forms the regional Great Miami Aquifer. This aquifer is divided by a 0.3- to 6-m-thick (1- to 20-foot-thick) clay interbred at an approximate depth of 36.6 m (120 ft). The transport pathway considered for this analysis is the upper part of the Great Miami Aquifer above the clay interbred. The uppermost 6.1 to 7.6 m (20 to 25 ft) of the outwash deposits is unsaturated and forms model Layer 2 of the vadose zone conceptual flow model. An unweathered gray till interbedded with sand and gravel glaciofluvial stringers overlies the outwash deposits. The thickness of this unit (referred to as glacial overburden) which makes up model Layer 1 ranges between 4.6 and 7.6 m (15 and 25 ft) for disposal areas. However, this layer is not included in vadose zone modeling because of numerous fractures present within this zone. All layer thicknesses were estimated based on geologic boring logs from subsurface investigations conducted across the site.

Using results of vadose zone modeling, the loading rates of each compound were used to calculate the expected maximum concentration which would occur at the point of entry into the Great Miami Aquifer. The modeled maximum concentrations were then compared to risk-based screening concentrations (corresponding to a $1x10^{-7}$ risk or a HQ of 0.1) to determine if detailed modeling would be performed for each compound.

The calibrated groundwater flow model for the FEMP site was used to simulate solute transport of compounds in the Great Miami Aquifer. Based on the amount of material entering the aquifer derived from vadose zone modeling, aquifer loading periods were defined for each compound to reduce the amount of data entry required. In general, loading periods ranged from 10 to 200 years in length depending on the specific compound. Thus, compounds with steady loading rates had long loading periods, whereas compounds with variable loading rates modeled using short loading periods. This allowed the simulation of short loading "spikes" while minimizing data input and run times. The leading period of a compound was simulated for a total of 1000 years in the Great Miami Aquifer. Figure D.5-1 presents the conceptual process of groundwater transport modeling to obtain receptor exposure point concentrations for on-property and off-site receptors. The conceptual model in Figure D.5-1 is tied into the conceptual model for long-term risk assessment (Figure D.2-9).

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Groundwater Modeling Source Terms

Source-terms A (residual soils) and B (disposal cell) were each modeled, including contaminant contributions from both for Alternatives 4A and 4B (on-property waste disposal options), and only residual soil left in place in the Operable Unit 1 Study Area for Alternatives 5A and 5B (off-site waste disposal options).

Table D.5-1 summarizes assumptions needed to define groundwater modeling source-terms for each of these remedial alternatives, including the methods of estimating constituent leachate concentrations from the disposed material. The leachate concentrations from the material for Alternatives 4A and 4B are estimated using Toxicity Characteristic Leaching Procedure (TCLP) sample analytical results of the treated or stabilized material. In contrast, leachate concentrations from residual soils for all alternatives being considered (4A, 4B, 5A, 5B) are estimated using geochemical modeling techniques. In these techniques, 30 percent of the uranium in the soil was assumed to be available for leaching and the leaching coefficient was assumed to be 12 milliliter (mL)/g. A value of 30 percent availability bounds the range of results obtained in leaching experiments conducted on washed and unwashed soils contaminated with uranium. The average percent availability observed for soils with characteristics similar to Operable Unit 1 soils was 20.5 percent (maximum 21.4 percent). The leaching coefficient is based on uranium K_d values provided in the Risk Assessment Work Plan Addendum. This geochemical modeling procedure is a conservative approach which results in leachate concentrations elevated relative to TCLP results.

Groundwater transport modeling estimated water infiltration rates into and through the on-property disposal facilities using the HELP model. Infiltration rates were modeled based on the assumption that the disposal facility deteriorates after 1000 years, allowing water to infiltrate and percolate through disposed material and out of the bottom of the disposal facility (exfiltration), potentially leaching constituents from the material and releasing them from the disposal facility. An exfiltration rate of 1.3 cm/yr was calculated using the HELP model based on disposal facility design and FEMP rainfall data. A rate of 15.2 cm/yr was calculated for the soils left in place based on average rainfall (40.6 in/yr) corrected to account for evapotranspiration. Assumptions of this scenario include:

- The geomembrane water barrier deteriorates and allows infiltration of water
- The quantity of water entering the HELP model system equals the quantity exiting the system

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Groundwater Modeling in the Vadose Zone

The one-dimensional analytical model used to evaluate flow in the vadose zone was ODAST Version 2 (Javandel et al. 1984). The transport equation in ODAST is evaluated as a function of seepage velocity, dispersion coefficient, source decay, retardation factor, depletion time, and source rate. The K_d used for uranium in the ODAST model was 1.8 mL/g which is the value recommended in the FEMP Risk Assessment Work Plan Addendum.

Hydrologic input data for ODAST included the flow rate, COC concentrations, layer thickness, and dispersibility value. The computer code was used for each of the two layers of the vadose zone. Transport through the bottom layer did not begin until the COC reached the bottom of the upper adjacent layer.

Output data from ODAST were in the form of mass loading rates at time increments of 20 years up to 1000 years. The loading rates predicted to reach the Great Miami Aquifer at concentrations greater than the screening levels at the specified time are used as direct input into the SWIFT III model, which estimates the mass concentration in the Great Miami Aquifer. The only constituent which exceeded the screening levels was uranium. The screening levels were derived by calculating the concentration for each COC which was equivalent to a 10^{-7} risk or a HI of 0.2 via the drinking water exposure pathway. It was assumed that a 70 kg (154 pound) man would be drinking 2 L of water for 365 days a year for 70 years. Therefore, if the concentration of COC would not be a cause for concern in the vadose zone, it would not be a cause for concern after further dilution in the aquifer.

Groundwater Modeling in the Aquifer

The SWIFT III model is used to estimate aquifer concentrations of COCs for which the estimated ODAST loading concentrations exceeded the screening level concentrations. Steps in the development of the model for application to the FEMP site have included:

- Construction and calibration of a regional, two-dimensional, steady-state groundwater flow model
- Construction and calibration of a regional, three-dimensional, steady-state groundwater flow model
- Application of a local, two-dimensional, analytical solute transport model to help strategize the numerical solute transport model
- Construction of a local, two-dimensional, transient solute transport model

- Construction and calibration of a local, three-dimensional, transient solute transport model with uranium concentration data from the monitoring wells

The regional model covers an area of 74.3 square kilometers (km^2) [28.7 square miles (mi^2)], including the FEMP site, the Southwest Ohio Water Company (SOWC) collector wells, and a portion of the Great Miami River. The regional model's grid spacing varies between 786 m and 610 m (250 ft and 2000 ft) and has its closest grid spacing in the area of the SOWC collector wells. It was calibrated against field data using steady-state flow assumptions, and calibration results were incorporated into the local area model.

The local model covers a smaller area than the regional model and uses tighter grid spacing, with grid cells 38 m (125 ft) on a side. The smaller grid was established to include the area of existing uranium plume and extends from the northern part of the FEMP site to approximately 460 m (1500 ft) north of the Great Miami River. The grid size was selected based on the need to simulate a uranium dispersivity of 30 m (100 ft) longitudinally, which was the preferred value based on literature review (IT 1990). Using this dispersivity value, the grid size was selected to accommodate dispersivity values as low as 19 m (62.5 ft), or half the distance of the local grid area of 38 m (125 ft). The relationship between the local and regional models was established by imposing the steady-state flow field predicted by the regional model onto the local solute transport model.

The regional and local models each contain five layers. The uppermost two layers represent the upper and lower parts of the upper Great Miami Aquifer that underlies the area. The middle layer represents a clay interbred that is present in the immediate vicinity of the FEMP site, and the lowermost two layers represent the upper and lower parts of the Great Miami Aquifer. In regions where the clay interbred is not present, the middle layer has the same characteristics as the upper two layers. The layers extend laterally into bedrock to the edges of the buried valley that contains the aquifer. The number of aquifer cells in each layer was decreased with depth in the aquifer to simulate the narrowing bedrock valley. This was done using bedrock topography maps of the region and simulating the U-shaped buried valley which contains the Great Miami Aquifer.

Effects of pumping wells in the vicinity of the FEMP site are included in the SWIFT III model runs. A FEMP production well, three industrial wells located to the south of the FEMP site, and two large capacity collector wells owned by the SOWC are used. These wells are assumed to pump for the 1000-year period. The groundwater concentrations were predicted using the SWIFT III model for a

1000-year period with 100-year increments. A K_d of 1.4 mL/g for uranium was used for the SWIFT III model.

Modeling Results

Figure D.5-2 illustrates potential residual risk exposure points used in the groundwater model. Receptor points 1 and 2 represent on-property exposure points and receptor point 3, the off-site exposure points.

D.5.3 EXPOSURE POINT CONCENTRATIONS

D.5.3.1 Remedial Action Risk Exposure Point Concentrations

As discussed in section D.5.1.1 above, airborne contaminants are generated during remedial actions through soil excavation, soil drying, and vitrification and cement solidification. Remediation workers, nonremediation workers, and off-site individuals are exposed to these airborne contaminants, specifically, remediation workers are exposed to resuspended soil from excavation, and nonremediation workers and off-site individuals are exposed to resuspended soil from excavation, and off-gas releases from drying and vitrification/solidification.

Table D.5-2 presents the exposure point concentrations during excavation for the three receptors for radionuclides. It has been assumed that all three receptors see the same concentration. Table D.5-3 presents the exposure point concentrations from excavation for chemicals, Table D.5-4 presents the exposure point concentrations for the off-site individual.

The nonremediation worker exposure point concentration for radon-222 for drying, vitrification for remediation workers, and solidification is 1600 pCi per cubic meter and 730 pCi per cubic meter and 800 pCi per cubic meter, respectively. For the VOC release, the exposure point concentration for drying, vitrification, and solidification of tetrachloroethane is 42 milligrams per cubic meter, 19 milligrams per cubic meter, and 21 milligrams per cubic meter, respectively.

For the off-site individual, the radon-222 concentration for drying, vitrification, and solidification is 430 pCi per cubic meter, 200 pCi per cubic meter, and 210 pCi per cubic meter, respectively. For the VOC release, the tetrachloroethane concentration for drying, vitrification, and solidification is 11 milligrams per cubic meter, 50 milligrams per cubic meter and 5.6 milligrams per cubic meter, respectively.

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D.5.3.2 Residual Risk Exposure Point Concentrations

Groundwater is a medium of concern for contaminant exposure once remediation is complete and contributes to several pathways of exposure, including ingestion of fruit and vegetables irrigated with groundwater, ingestion of meat products, ingestion of drinking water obtained from wells, and dermal contact with groundwater during household activities, and inhalation of VOCs form use of groundwater in the home.

Table D.5-7 presents groundwater fate and transport modeling results.

TABLE D.5-1

SUMMARY OF ON-PROPERTY SOURCE TERMS FOR OPERABLE UNIT 1 GROUNDWATER TRANSPORT MODELING

Remedial Alternative	Source Term	Treatment Description	Waste Leachate Estimation	Water Exfiltration Rate (cm/yr)[a]
4A	Pit Materials	Cement, on-site disposal	Waste Acceptance Criteria	0.84
4B	Pit Materials	Vitrify, on site disposal	Waste Acceptance Criteria	0.84
5A	Pit Materials	Off-site disposal	NA[b]	NA
5B	Pit materials	Off-site disposal	NA	NA
	Residual Pit Soils	Cap	Waste Acceptance Criteria	2.3
	Residual Surface Soils	None	Geochemical Modeling	17.0

[a] An exfiltration rate of 0.84 cm/year is used for all remedial alternatives involving disposal in the on-property vault disposal facility.
[b] NA = Not Applicable.

TABLE D.5-2

RADIONUCLIDE EXPOSURE POINT CONCENTRATIONS - EXCAVATION

Radionuclide	Exposure Point Concentration pCi/m^3
Sr-90	0.0092
Tc-99	0.34
Cs-137	0.010
Rn-220	0.11
Ra-226	0.11
Th-228	0.28
Th-230	3.5
Th-232	0.14
U-234	1.1
U-235	0.27
U-238	4.1
Np-237	0.0049
Pu-238	0.00064
Pu-239/240	0.0040

TABLE D.5-3

EXPOSURE POINT CONCENTRATIONS, NON-REMEDIATION WORKER - EXCAVATION

Chemical	Exposure Point Concentration mg/cu.m.
Arsenic	1.4×10^{-8}
Beryllium	2.2×10^{-9}
Cadmium	1.6×10^{-8}
Nickel	8.2×10^{-8}
Aroclor 1248	0
Aroclor 1254	0
2378-TCDF	0
HpCDD	0
HpCDF	0
HxCDD	0
HxCDF	0
OCDD	0
OCDF	0
Tetrachloroethene	9.2×10^{-9}
Benzo(a)anthracene	0
Benzo(a)pyrene	0
Benzo(b)fluorathene	0
Chrysene	0
Indeno(123cd)pyrene	0
Barium	1.6×10^{-7}
Cobalt	2.9×10^{-8}
Manganese	1.6×10^{-6}

TABLE D.5-4

EXPOSURE POINT CONCENTRATIONS, OFF-SITE INDIVIDUAL, EXCAVATION

Chemical	Exposure Point Concentration mg/cu.m.
Arsenic	1.3×10^{-9}
Beryllium	2.0×10^{-10}
Cadmium	1.4×10^{-9}
Nickel	7.3×10^{-9}
Aroclor 1248	0
Aroclor 1254	0
2378-TCDF	0
HpCDD	0
HpCDF	0
HxCDD	0
HxCDF	0
OCDD	0
OCDF	0
Tetrachloroethene	8.2×10^{-10}
Benzo(a)anthracene	0
Benzo(a)pyrene	0
Benzo(b)fluorathene	0
Chrysene	0
Indeno(123cd)pyrene	0
Barium	1.4×10^{-8}
Cobalt	2.6×10^{-9}
Manganese	1.4×10^{-7}

TABLE D.5-5

SURFACE SOIL CONCENTRATIONS

Contaminant	Residual Soil Concentration
Radionuclides pCi/g	
Cs-137 + 1d	1.8
Np-137 + 1d	0.05
Pu-238	0.05
Pu-239/240	0.05
Sr-90 +1d	0.90
Th-230	902
U-234	17.5
U-235 +1d	9.3
U-238 +2d	56
Chemicals Mg/kg	
Antimony	28
Beryllium	0.63
Cadmium	7.7
Uranium	190
Aroclor-1254	0.09
Benzo(a)anthracene	0.098
Benzo(a)pyrene	0.042
Benzo(a)fluoranthene	0.059
Benzo(k)Fluoranthene	0.046
Chrysene	0.088

TABLE D.5-6

AIR PARTICULATE CONCENTRATIONS

Contaminant	On-Property Farm Air Concentration	Expanded Tresspasser Air Concentration	Off-Property Farmer Air Concentration
Radionuclides pCi/g			
Cs-137 + 1d	$9.8x10^{-5}$	$1.3x10^{-5}$	$9.9x10^{-7}$
Np-137 + 1d	$2.7x10^{-6}$	$3.5x10^{-7}$	$2.8x10^{-8}$
Pu-238	$2.7x10^{-6}$	$3.5x10^{-7}$	$2.8x10^{-8}$
Pu-239/240	$2.7x10^{-6}$	$3.5x10^{-7}$	$2.8x10^{-8}$
Sr-90 +1d	$4.9x10^{-5}$	$6.3x10^{-6}$	$5.0x10^{-7}$
Th-230	$4.9x10^{-2}$	$6.3x10^{-3}$	$5.0x10^{-4}$
U-234	$9.6x10^{-4}$	$1.2x10^{-4}$	$9.6x10^{-6}$
U-235 +1d	$5.1x10^{-4}$	$6.5x10^{-5}$	$5.1x10^{-6}$
U-238 +2d	$3.1x10^{-3}$	$3.9x10^{-4}$	$3.1x10^{-5}$
Chemicals Mg/kg			
Antimony	$1.5x10^{-6}$	$2.0x10^{-7}$	$1.5x10^{-8}$
Beryllium	$3.4x10^{-8}$	$4.4x10^{-9}$	$3.5x10^{-10}$
Cadmium	$4.2x10^{-7}$	$5.4x10^{-8}$	$4.2x10^{-9}$
Uranium	$1.0x10^{-5}$	$1.3x10^{-6}$	$1.0x10^{-7}$
Aroclor-1254	$4.9x10^{-9}$	$4.4x10^{-9}$	$5.0x10^{-11}$
Benzo(a)anthracene	$5.4x10^{-9}$	$6.9x10^{-10}$	$5.4x10^{-11}$
Benzo(a)pyrene	$2.3x10^{-9}$	$2.9x10^{-10}$	$2.3x10^{-11}$
Benzo(a)fluoranthene	$3.2x10^{-9}$	$4.1x10^{-10}$	$3.2x10^{-11}$
Benzo(k)Fluoranthene	$2.5x10^{-9}$	$3.2x10^{-10}$	$2.5x10^{-11}$
Chrysene	$4.8x10^{-9}$	$6.2x10^{-10}$	$4.8x10^{-11}$

TABLE D.5-7

GROUNDWATER FATE AND TRANSPORT MODELING RESULTS

COC	Max. Conc. GMA Beneath Waste Area (Years)	Max. Conc. In GMA Beneath Waste Area (μg/L)	Max. Conc. In GMA Beneath Waste Area (pCi/L)	Max. Conc. GMA at the Fenceline (Years)	Max. Conc. GMA at the Fenceline (μg/L)	Max. Conc. GMA at the Fenceline (pCi/L)	Resident Farmer PRG (μg/L)
Np-237	620	5.9E-04	4.1E-01	1000	2.6E-05	0.01827332	9.9E+04
Sr-90	120	1.6E-08	3.9E-03	380	2.7E-12	6.37289E-07	2.4E-01
U-238	380	7.2E+01	2.4E+01	1000	3.5E+00	1.164695505	1.6E+00
Tc-99	590	1.3E-01	2.2E+03	100	8.2E-04	13.8805	1.3E+05
U-234	380	8.2E-03	5.1E+01	1000	3.9E-05	0.2457936	1.5E-04
U-235	380	5.5E-01	1.2E+00	1000	2.6E-02	0.05658336	4.4E-01
Antimony	1000	2.6E+00	N/A	1000	2.7E-04	N/A	8.0E-01
Boron	960	3.5E+01	N/A	760	1.5E+00	N/A	1.7E+03
Cadmium	820	9.3E-01	N/A	1000	1.5E-02	N/A	5.5E-02
Cyanide	20	3.6E+00	N/A	20	1.0E-03	N/A	1.6E+01
Lead	940	1.6E+00	N/A	960	2.5E-04	N/A	1.5E+01
Mercury	1000	2.8E-01	N/A	1000	1.6E-03	N/A	1.0E-02
Molybdenum	700	2.7E+01	N/A	880	5.0E-01	N/A	8.4E+01
Vinyl Chloride	30	4.8E-01	N/A	70	4.0E-03	N/A	9.1E-03
Aroclor-1254	820	7.0E-03	N/A	1000	3.9E-05	N/A	7.7E-05

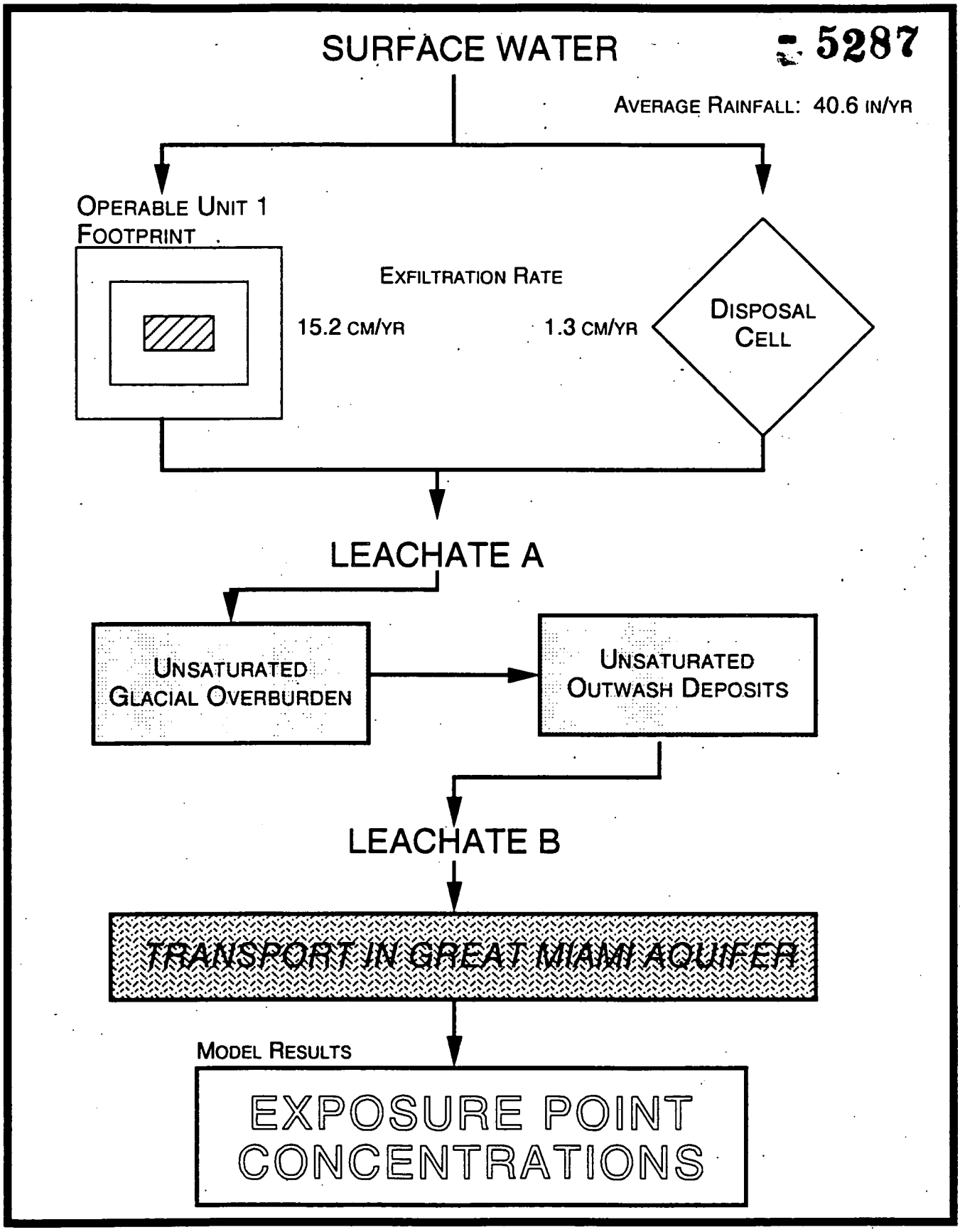

FIGURE D5.1
OPERABLE UNIT 1
CONCEPTUAL MODEL FOR RESIDUAL CONTAMINANT TRANSPORT IN GROUNDWATER

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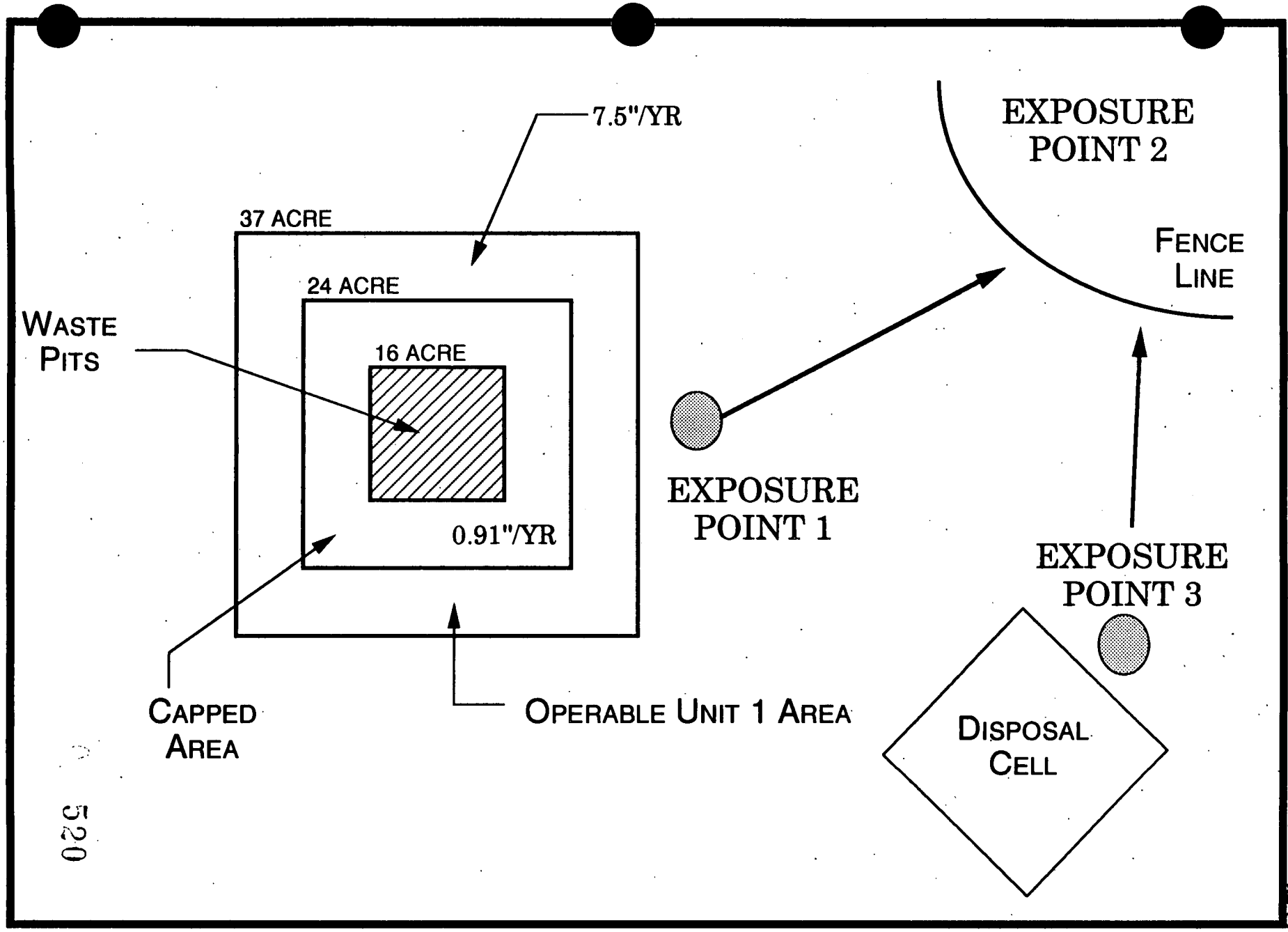

FIGURE D.5-2
OPERABLE UNIT 1
CONCEPTUAL MODEL FOR RESIDUAL GROUNDWATER RISKS
MODEL SOURCE TERMS AND EXPOSURE POINTS

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D.6.0 REMEDIAL ACTION RISK ASSESSMENT

This section presents the results of the risk estimates during remedial action activities. Tables summarize the risks by receptor and hazard classification (cancer risk, noncancerous chemical risk, and mechanical injury) for each alternative. A separate section presents transportation risk assessment results.

D.6.1 CONSTRUCTION RISKS

Construction activities include all activities associated with a remedial alternative except those related to en route transport of waste material. Construction risks include risks related to excavation, waste processing, and waste package handling. Waste package handling includes (for Alternative 5A) handling at the railyard in Las Vegas where packages are transferred from train to truck.

Construction risks are summarized in a series of tables. Each table in this section is set up in a similar manner. The first column presents the exposure mode. Then, the impacts for each alternative for the exposure mode are reported. When an impact is not applicable to a certain alternative, a notation is made in the table. Table D.6-1 presents the cancer risks to a remediation worker for the four alternatives, 4A, 4B, 5A, and 5B. Table D.6-2 presents the risk of injury or fatality to a remediation worker from mechanical hazards. Table D.6-3 presents the cancer risks for the nonremediation worker. Table D.6-4 presents the cancer risks for the off-site individual. Table D.6-5 presents the Hazard Index for each alternative for both the nonremediation worker and the off-site individual.

The dose equivalent delivered to remediation workers for each alternative over the course of the alternative (greater than a year in all cases) is well below US DOE annual limits. Alternatives 4A, 4B, and 5B deliver 32 millirem to a remediation worker. Alternative 5A delivers 61 millirem, with the additional dose equivalent associated with package handling.

The mechanical hazard impacts are dominated by on-property disposal, with the disposal of cementitious waste (Alternative 4B) delivering greater impacts than the disposal of vitrified waste (Alternative 4A). On-property disposal of cementitious waste requires the most person-hours.

The cancer risk to nonremediation workers and off-site individuals is attributable to chemical carcinogenic impacts from soil excavation. The risk, 5.2×10^{-5} for non-remediation workers and

TABLE D.6-1

DOSE EQUIVALENT TO REMEDIATION WORKERS

Exposure Mode	Dose Equivalent, millirem			
	Alternative 4A	Alternative 4B	Alternative 5A	Alternative 5B
Direct Radiation, Drying	20	20	20	20
Direct Radiation, Package Handling	NA[a]	NA[a]	29	NA[a]
Direct Radiation, Excavation	12	12	12	12
Immersion, Excavation	6.74×10^{-7}	6.74×10^{-7}	6.74×10^{-7}	6.74×10^{-7}

[a]NA = Not Applicable

TABLE D.6-2

MECHANICAL HAZARD RISK TO REMEDIATION WORKERS

Exposure Mode	Occurrences of Injury or Fatality							
	Alternative 4A		Alternative 4B		Alternative 5A		Alternative 5B	
	Injury	Fatality	Injury	Fatality	Injury	Fatality	Injury	Fatality
Excavation	10	0.15	10	0.15	10	0.15	10	0.15
Drying	5.7	0.084	5.7	0.084	5.7	0.084	5.7	0.084
Package/Waste Handling	NA[a]	NA	NA	NA	5.8	0.086	3.0	0.044
Onsite Disposal	61	0.89	78.	1.2	NA	NA	NA	NA
Restoration	5.8	0.086	5.8	0.086	5.8	0.086	5.8	0.086
Vitrification	3.5	0.051	NA	NA	NA	NA	NA	NA
Solidification	NA	NA	4.3	0.063	NA	NA	NA	NA

[a] NA = Not Applicable.

TABLE D.6-3

RADIOLOGICAL AND CHEMICAL CANCER RISK TO NONREMEDIATION WORKERS

Exposure Mode	Cancer Risk[a]			
	Alternative 4A	Alternative 4B	Alternative 5A	Alternative 5B
Immersion, Excavation	4.2×10^{-16}	4.2×10^{-16}	4.2×10^{-16}	4.2×10^{-16}
Immersion, Drying	7.0×10^{-8}	7.0×10^{-8}	7.0×10^{-8}	7.0×10^{-8}
Immersion, Vitrification	3.2×10^{-8}	NA	NA	NA
Immersion, Solidification	NA[b]	3.5×10^{-8}	NA	NA
Inhalation, Excavation (Radionuclides)	7.4×10^{-10}	7.4×10^{-10}	7.4×10^{-10}	7.4×10^{-10}
Inhalation, Excavation (Chemicals)	5.2×10^{-5}	5.2×10^{-5}	5.2×10^{-5}	5.2×10^{-5}

[a] The cancer risk is the Incremental Lifetime Cancer Risk for fatal cancers for all exposure modes except "Inhalation, Excavation (Chemicals)" which is the risk for contracting all cancers.
[b] NA = Not Applicable.

TABLE D.6-4

RADIOLOGICAL AND CHEMICAL CANCER RISK TO OFFSITE INDIVIDUALS

Exposure Mode	Cancer Risk[a]			
	Alternative 4A	Alternative 4B	Alternative 5A	Alternative 5B
Immersion, Excavation	1.5×10^{-14}	1.5×10^{-14}	1.5×10^{-14}	1.5×10^{-14}
Immersion, Drying	1.1×10^{-8}	1.1×10^{-8}	1.1×10^{-8}	1.1×10^{-8}
Immersion, Vitrification	5.4×10^{-9}	5.4×10^{-9}	Not Applicable	Not Applicable
Immersion, Solidification	5.9×10^{-9}	5.9×10^{-9}	Not Applicable	Not Applicable
Inhalation, Excavation (Radionuclides)	1.2×10^{-11}	1.2×10^{-11}	1.2×10^{-11}	1.2×10^{-11}
Inhalation, Excavation (Chemicals)	2.9×10^{-6}	2.9×10^{-6}	2.9×10^{-6}	2.9×10^{-6}

[a] The cancer risk is the Incremental Lifetime Cancer Risk for fatal cancers for all exposure modes except "Inhalation, Excavation (Chemicals)," which is the risk for contracting all cancers.

TABLE D.6-5

HAZARD INDEX FOR ALTERNATIVES

Exposure Mode	Hazard Index			
	Alternative 4A	Alternative 4B	Alternative 5A	Alternative 5B
Inhalation, Excavation - Non-Remediation Worker	6.3×10^{-8}	6.3×10^{-8}	6.3×10^{-8}	6.3×10^{-8}
Inhalation, Excavation - Off-Site Individual	3.5×10^{-9}	3.5×10^{-9}	3.5×10^{-9}	3.5×10^{-9}

TABLE D.6-6

RADIOLOGICAL TRANSPORTATION IMPACTS

Exposure Mode	Radiological Transportation Impacts			
	Alternative 5A (to NTS)		Alternative 5B (to RPCDF[a])	
	Dose Equivalent[b]	Cancer Risk[c]	Dose Equivalent[b]	Cancer Risk[c]
Truck Drivers	4.0×10^{-4}	5.0×10^{-8}	NA[d]	NA
Train Crew	4.5×10^{-1}	5.63×10^{-5}	3.3×10^{-2}	NA
Maximum Individual, Public, Routine	1.4×10^{-3}	1.7×10^{-10}	9.5×10^{-4}	1.2×10^{-10}
Population, Routine	4.4×10^{-2}	5.5×10^{-6}	3.6×10^{-2}	4.6×10^{-6}
Population, Train Accident	2.4×10^{-1}	2.7×10^{-5}	3.7×10^{-1}	4.6×10^{-5}
Population, Truck Accident	9.3×10^{-5}	1.2×10^{-8}	NA	NA

[a] RPCDF=Representative Permitted Commercial Disposal Facility.
[b] Units are person-rem, except for maximum individual, where the dose equivalent is in millirem.
[c] The cancer risk is the Incremental Lifetime Cancer Risk for fatal cancers for all exposure modes.
[d] NA = Not Applicable.

TABLE D.6-7

NONRADIOLOGICAL TRANSPORTATION RISKS

Impact	Nonradiological Transportation Risk	
	Alternative 5A (to NTS)	Alternative 5B (to RPCDF[a])
Injury, Train-Crew	45.5	3.4
Injury, Train-Public	0.049	0.030
Injury, Truck-Driver	27.	NA[b]
Injury, Truck-Public	0.47	NA
Fatality, Train-Crew	0.055	0.034
Fatality, Train-Public	0.0025	0.0015
Fatality, Truck-Driver	7.1	NA
Fatality, Truck-Public	0.051	NA

[a] RPCDF = Representative Permitted Commercial Disposal Facility.
[b] NA = Not Applicable.

D.7.0 RESIDUAL RISK ASSESSMENT

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Potential residual risks to human health from exposure to chemicals and radionuclides following implementation of remedial alternatives for Operable Unit 1 have been estimated using the methods described in the Work Plan Addendum (DOE 1992) and the Operable Unit 1 Baseline Risk Assessment. The methods used to characterize residual risks are the same as those used in the Baseline Risk Assessment for the corresponding exposure pathway and receptor combinations.

Exposure pathway and receptor combinations quantitatively evaluated in the residual Risk Assessment are defined in the discussion of the conceptual model in Section D.2.5.2. Pathways evaluated include potential exposure for a on-property resident farmer, on-property resident child, off-property farmer, off-property resident child and expanded trespasser receptors of soil and groundwater contaminants. Exposure of the off-property farmer and child and expanded trespasser receptors addresses the scenario in which federal ownership of the FEMP property is maintained. Exposure of the on-property resident farmer and child receptors addresses the scenario in which federal ownership of the property is not maintained and the land is returned to private farm use. Evaluation of both of these scenarios is specified for residual FS Risk Assessments in Section 10.0 of the Risk Assessment Work Plan Addendum (DOE 1992).

Exposure point concentrations of COCs for the residual risk evaluation are presented in Table D.5-4 for each remedial alternative and receptor location. Groundwater exposure point concentrations for the off-property resident receptor are estimated for each remedial alternative for those COCs which are predicted to reach the Greater Miami Aquifer by the leaching of COCs from disposed materials, through the vadose zone, into the aquifer, and through the aquifer off property. Groundwater exposure point concentrations for the on-property resident receptors are estimated for each remedial alternative by modeling the leaching of constituents from disposed material and through the vadose zone as an estimate of potential Greater Miami Aquifer contamination under FEMP property.

Exposure to air-borne contaminants from on-site soils was evaluated for on- and off-site receptors assuming continued future use of the site as a government facility and future use of the site as a private farm. Dispersion modeling was used to generate soil-to-air transfer factors for calculation of air concentrations for on- and off-site locations assuming current site conditions (corresponding to future use as a government facility) and assuming agricultural use. Soil-to-air transfer factors for each land use/location scenario are as follows:

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private farm/on-site	5.46 x 10-5 g/m3	on-site adult/child residents
private farm/off-site	5.1 x 10-6 g/m3	off-site adult/child residents
government facility/on-site	7.0 x 10-6 g/m3	adult/child trespassers
government facility/off-site	5.5 x 10-7 g/m3	off-site adult/child residents

As discussed in the conceptual model, quantitative risk characterization is performed for the following receptors:

- on-property resident farmer (RME)
- on-property resident child (RME)
- off-property resident farmer (RME)
- off-property resident child (RME)
- on-property expanded trespasser (child and adult) (RME)

Receptor exposures to COCs in groundwater arise from predicted contamination of groundwater assuming leaching from the material followed by migration of leachate into the vadose zone and aquifer. Receptor exposure pathways for radionuclides include:

- Ingestion of groundwater
- Ingestion of vegetables and fruits irrigated with groundwater
- Ingestion of meat and milk from cattle ingesting groundwater and feed irrigated with groundwater

Receptor exposure pathways for chemicals include:

- Ingestion of groundwater
- Dermal exposure through bathing
- Ingestion of vegetables and fruits with groundwater
- Ingestion of meat and milk from cattle ingesting groundwater and feed irrigated with groundwater

Leachate concentrations due to the contaminants in the residual soils beneath the waste pits and the on-site disposal cell were estimated using groundwater model results. The leachate concentrations from the non-pit area surface soils were estimated from geochemical modeling.

Exposure to residual COC concentrations in subsurface soil requires that subsurface soil be brought to the surface by some means, which is unlikely. On-site receptor (on-property farmer and child and expanded trespasser) exposure pathways for radionuclides and chemicals in soil include:

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- Incidental ingestion of soil
- External radiation for radionuclide exposure; dermal contact with soil for chemical exposure
- Ingestion of vegetables and fruits grown in affected soil (residents only)
- Ingestion of meat and milk from cattle feeding on forage grown in affected soil (residents only)

The exposure point concentrations and risk calculations can be found in Attachment I. All receptors (on- and off-site) may be exposed to COCs in soil via inhalation of residual soil particles entrained in the air by wind. On- and off-property residents (excluding the expanded trespasser) may be exposed to soil COCs via deposition of air-borne contaminants with subsequent uptake into vegetables, fruits and forage crops. Dispersion modeling was used to approximate on- and off-site soil-to-air transfer factors for future use of the site for farming and for continued government ownership. Potential exposure pathways for air-borne COCs from soil include:

- Inhalation
- Ingestion of vegetables and fruits affected by deposition (farm residents only)
- Ingestion of meat and milk from cattle feeding on forage affected by deposition (farm residents only).

The exposure point concentrations and risk calculations can be found in Attachment I. The greatest cancer risk for radionuclide and carcinogenic chemical exposure was for, in decreasing order, the on-property resident farmer, followed by the on-property resident child, expanded trespasser, off-property resident farmer and off-property resident child.

For the on-property resident farmer and child receptors, calculated risks due to soil exposure were greater than the calculated risks for groundwater exposure, but the differences were less than one order of magnitude. For the off-property resident farmer and child receptors calculated groundwater risks exceeded calculated soil risks (based on air exposure pathways only) by less than one order of magnitude for radionuclides, over one order of magnitude for carcinogenic chemicals and approximately two orders of magnitude for toxicants.

D.7.1 ALTERNATIVES 4A/4B

Alternatives 4A/4B include the removal of pit wastes and treatment of the removed wastes either by vitrification or cement solidification and placement in an on-site disposal cell. Contaminated non-pit area surface soils are removed to a depth of six inches and replaced with clean fill. Table D.7-1

shows the PRGs calculated for on-site disposal options (see Section 2.0 of the FS) and TCLP results for alternative waste forms (vitrification for Alternative 4A and cementation for Alternative 4B). Because TCLP concentrations were substantially lower the PRG concentrations, on-site disposal alternatives are not considered to pose additional risk beyond those calculated for the residual soils and no additional risk calculations were performed. Potential residual risks for Alternatives 4A and 4B are, therefore, the same as for Alternatives 5A and 5B. These risks are related to residual contaminants in soil and groundwater. These risks are discussed in the following section.

D.7.2 ALTERNATIVES 5A/5B

Alternatives 5A/5B involve excavation, treatment and off-site disposal of pit wastes. As with Alternatives 4A/4B, non-pit area surface soils are removed to a depth of six inches and replaced with clean fill. Future land uses and receptors evaluated were the same for Alternatives 4A/4B and Alternatives 5A/5B. Two future land use scenarios were analyzed: (1) continued government ownership in which the off-property farm family and the expanded trespasser are receptors; and (2) private ownership in which a resident on-property farm family and an off-property farm family are receptors. Table D.7-2 contains a summary of calculated risks assuming continued use of the land as a government facility. Table D.7-3 contains a summary of calculated risks assuming future private farm use. The following paragraphs contain discussion of the calculated risks for the on- and off-property resident farmer and child and expanded trespasser receptors without reference to presumed land use.

For the on-property resident farmer and child, total radiological ILCRs were calculated as 8×10^{-4} and 5×10^{-5}, respectively. Cs-137, Th-230 and U-238 present the highest cancer risks for the adult receptor; Cs-137, Sr-90 and U-238 for the child. Total chemical ILCRs for the on-property farmer and child were 4×10^{-4} and 1×10^{-4}, respectively, primarily due to potential aroclor-1254 and beryllium exposure. The total HI was calculated to be 0.7, with most of the risk contributed by, in order of decreasing risk, uranium and antimony.

Total radiological ILCRs for the off-property farmer and child receptors are 5×10^{-6} and 2×10^{-7}, respectively. The primary contributors to radiological cancer risk are U-238 and Th-230. The total chemical ILCRs for these two receptors are 5×10^{-7} and 9×10^{-8}, respectively, due to aroclor-1254 in groundwater. HIs for the off-property resident farmer and child are 0.05 and 0.1, respectively, primarily due to exposure to uranium in groundwater.

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TABLE D.7-1

OPERABLE UNIT 1: ALTERNATIVES 4A/4B WASTE DISPOSAL CELL PRGS COMPARED WITH RESULTS OF TCLP ANALYSIS OF WASTE FORMS [a]

COC	Waste Leachate PRG	Projected Waste Leachate Concentration	
		Vitrification Stabilization	Cementation Stabilization
Radionuclide pCi/L			
Sr-90	5.1E+06	8.3E+00	1.9E+01
Tc-99	1.9E+03	2.3E+01	6.2E+01
Ra-226	2.3E+07	3.5E+01	4.2E+02
Th-230	4.3E+10	8.1E+01	4.0E+01
U-234	5.9E+06	2.5E+02	5.9E+00
U-235	5.9E+07	2.5E+01	4.0E+00
U-238	3.3E+06	4.0E+02	1.5E+01
Np-237	3.9E+04	6.8E+00	6.0E-01
Pu-238	7.3E+08	9.1E-01	4.7E-01
Metals mg/L			
Arsenic	1.2E+03	9.2E-02	1.6E-02
Barium	9.7E+06	1.7E+00	5.6E+00
Boron	8.1E+03	4.2E-01	5.6E-01
Cyanide			1.0E-02
Lead	3.3E+09	1.9E-02	1.4E-02
Manganese	8.6E+06	1.6E+00	1.5E-02
Molybdenum	3.0E+05	4.5E-01	1.2E+00

[a] TCLP results are from Treatability Study Reports discussed in the main body of the Feasibility Study.

SOURCE: U.S. Dept. of Energy (DOE), 1994a, "Draft Feasibility Study Report for Operable Unit 1," DOE, Fernald Field Office, Fernald, OH (Table 2-11).

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TABLE D.7-2

RESIDUAL RISK SUMMARY
ALTERNATIVES 5A/5B
FUTURE LAND USE, GOVERNMENT FACILITY

Receptor:	Expanded Trespasser			Off-Property Farmer			Off-Property Child		
Source Medium: / COC	Soil	Ground-water	Total	Soil	Ground-water	Total	Soil	Ground-water	Total
ILCR									
Radionuclides									
Cs-137 + 1 d prog	2E-06	--	2E-06	3E-10	--	3E-10	3E-11	--	3E-11
Np-237 + 1 d	1E-08	--	1E-08	1E-10	3E-07	3E-07	2E-12	1E-08	1E-08
Pu-238	4E-10	--	4E-10	1E-10	--	1E-10	3E-12	--	3E-12
Pu-239/240	4E-10	--	4E-10	1E-10	--	1E-10	3E-12	--	3E-12
Sr-90 + 1 d	1E-09	--	1E-09	8E-11	2E-12	8E-11	1E-11	2E-13	1E-11
Th-230	1E-06	--	1E-06	2E-06	--	2E-06	3E-08	--	3E-08
U-234	2E-08	--	2E-08	3E-08	3E-07	3E-07	6E-10	1E-08	1E-08
U-235	1E-06	--	1E-06	2E-08	6E-08	7E-08	3E-10	3E-09	3E-09
U-238 + 2 d	1E-06	--	1E-06	2E-07	2E-06	2E-06	4E-09	1E-07	1E-07
TOTALS:	5E-06	--	5E-06	2E-06	3E-06	5E-06	4E-08	1E-07	2E-07
Carcinogenic Chemicals									
Aroclor-1254	3E-06	--	3E-06	9E-09	5E-07	5E-07	5E-09	8E-08	9E-08
Benzo(a)anthracene	2E-09	--	2E-09	1E-10	--	1E-10	5E-11	--	5E-11
Benzo(a)pyrene	7E-09	--	7E-09	6E-10	--	6E-10	3E-10	--	3E-10
Benzo(b)fluoranthene	1E-09	--	1E-09	3E-10	--	3E-10	2E-10	--	2E-10
Benzo(k)fluoranthene	4E-10	--	4E-10	2E-10	--	2E-10	1E-10	--	1E-10
Beryllium	2E-05	--	2E-05	2E-09	--	2E-09	6E-10	--	6E-10
Cadmium	9E-10	--	9E-10	2E-09	--	2E-09	1E-10	--	1E-10
Chrysene	--	--	--	3E-12	--	3E-12	2E-12	--	2E-12
TOTALS:	2E-05	--	2E-05	1E-08	5E-07	5E-07	6E-09	8E-08	9E-08
HI									
Toxicants									
Antimony	2E-01	--	2E-01	9E-05	3E-05	1E-04	4E-04	1E-04	5E-04
Beryllium	5E-03	--	5E-03	8E-08	--	8E-08	3E-07	--	3E-07
Cadmium	6E-02	--	6E-02	8E-05	3E-03	3E-03	5E-04	2E-02	2E-02
Uranium	5E-01	--	5E-01	3E-05	4E-02	4E-02	2E-04	1E-01	1E-01
TOTALS:	7E-01	--	7E-01	2E-04	5E-02	5E-02	1E-03	1E-01	1E-01

TABLE D.7-3

RESIDUAL RISK SUMMARY
ALTERNATIVES 5A/5B
FUTURE LAND USE, PRIVATE

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Receptor:	On-Property Farmer			On-Property Child			Off-Property Farmer		
Source Medium:	Soil	Groundwater	Total	Soil	Groundwater	Total	Soil	Groundwater	Total
Radionuclides (ILCR)									
Cs-137 + 1 progeny	2E-04	–	2E-04	1E-05	–	1E-05	3E-09	–	3E-09
Np-237 + 1 progeny	1E-06	6E-06	7E-06	8E-08	3E-07	4E-07	9E-10	3E-07	3E-07
Pu-238	6E-08	–	6E-08	5E-09	–	5E-09	1E-09	–	1E-09
Pu-239/240	6E-08	–	6E-08	5E-09	–	5E-09	1E-09	–	1E-09
Sr-90 + 1 progeny	6E-05	1E-08	6E-05	1E-05	9E-10	1E-05	7E-10	2E-12	7E-10
Th-230	2E-04	–	2E-04	8E-06	–	8E-06	2E-05	–	2E-05
U-234	7E-06	5E-05	6E-05	5E-07	3E-06	3E-06	3E-07	3E-07	5E-07
U-235	1E-04	1E-06	1E-04	7E-06	7E-08	7E-06	1E-07	6E-08	2E-07
U-238 + 2 progeny	1E-04	4E-05	2E-04	9E-06	2E-06	1E-05	2E-06	2E-06	4E-06
TOTALS:	7E-04	1E-04	8E-04	5E-05	6E-06	5E-05	2E-05	3E-06	2E-05
Carcinogenic Chemicals (ILCR)									
Aroclor-1254	8E-05	9E-05	2E-04	4E-05	2E-05	5E-05	8E-08	5E-07	6E-07
Benzo(a)anthracene	6E-06	–	6E-06	3E-06	–	3E-06	1E-09	–	1E-09
Benzo(a)pyrene	2E-05	–	2E-05	1E-05	–	1E-05	5E-09	–	5E-09
Benzo(b)fluoranthene	1E-05	–	1E-05	5E-06	–	5E-06	3E-09	–	3E-09
Benzo(k)fluoranthene	5E-06	–	5E-06	3E-06	–	3E-06	2E-09	–	2E-09
Beryllium	2E-04	–	2E-04	3E-05	–	3E-05	2E-08	–	2E-08
Cadmium	2E-07	–	2E-07	1E-08	–	1E-08	2E-08	–	2E-08
Chrysene	2E-07	–	2E-07	8E-08	–	8E-08	3E-11	–	3E-11
TOTALS:	4E-04	9E-05	4E-04	9E-05	2E-05	1E-04	1E-07	5E-07	6E-07
Toxicants (HI)									
Antimony	3E+00	3E-01	3E+00	1E+01	1E+00	1E+01	8E-04	3E-05	8E-04
Cadmium	2E+00	2E-01	2E+00	1E+01	1E+00	1E+01	7E-04	3E-03	4E-03
Uranium	2E+00	9E-01	2E+00	5E+00	3E+00	7E+00	3E-04	4E-02	4E-02
TOTALS:	7E+00	1E+00	8E+00	3E+01	5E+00	3E+01	2E-03	5E-02	5E-02

D.8.0 UNCERTAINTY ANALYSIS

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All risk assessments contain various elements of uncertainty. Sources and characteristics of uncertainties are examined in this section to elucidate the accuracy of risk estimates and the complexity of decisions incorporated into risk estimates, thus aiding in risk management decisions. For the major categories of uncertainty of particular relevance to the Feasibility Study risk evaluation, questions were asked to determine the degree of uncertainty in the risk evaluation:

- COC Selection:
  Are all COCs identified and their concentrations adequately quantified?
- Toxicological Information and Models:
  How accurate is current information concerning toxic properties and dose-response characteristics of the COCs?
- Exposure Pathways:
  Are all potential pathways for transporting contaminants from site environmental media to receptors identified?
- Receptor Characterization and Exposure Assumptions:
  Are future land use scenarios conservative and have all potential receptors identified?
  Are exposure factors reasonable?
- Exposure Point Concentrations:
  Are models for estimating COC transport from site media to the receptor, and for estimating contaminant exposures and intakes reasonable?

Risk evaluation for an FS takes a different approach than a baseline risk assessment at the FEMP site. The FS risk evaluation estimates exposure point concentrations using models and assumptions of site conditions during and following remedial actions. Baseline risk assessments generally use existing data to evaluate current risks. Results of the FS risk evaluation have much more inherent uncertainty with regard to exposure patterns, exposed populations, and exposure concentrations than do the results of the baseline risk assessment. One purpose of this uncertainty analysis is to characterize sources of uncertainty which contribute most to the overall uncertainty in the FS risk evaluation.

D.8.1 CONSTITUENTS OF CONCERN

A major concern of the FS risk evaluation is the reliability of COC identification, both in terms of ensuring that all chemicals or radionuclides have been correctly identified as COCs, and ensuring that their potential concentrations are adequately quantified. The accuracy of COC identification is directly related to the quality of COC characterization data, including information on contaminant

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identification, location, and concentrations. Characterization was controlled by the sampling and analysis plan, which identified sampling locations and analytical protocols.

The source of COC data for the FS risk evaluation was the Operable Unit 1 RI and baseline risk assessment. The RI Report for Operable Unit 1 was prepared according to CERCLA guidelines, and the data were validated. Whenever possible, COC identification was based on risk results in the RI baseline risk assessment from data collected according to a CERCLA sampling plan. However, uncertainty is inherently high in the Waste Pit data due to the heterogeneity of the waste forms. Uncertainty of soil data is inherently higher than groundwater data because soils are heterogeneous.

It is unlikely that major COC contributors to risk for Operable Unit 1 have been overlooked. Any shortcomings in the chemical data that have been gathered at the FEMP site are compensated for by a large database of contaminant type and concentration data. Evaluation of these data have identified a large number of contaminants which are present in Operable Unit 1 wastes and associated materials, and confirm general contamination patterns indicated by past site operations. There is a high degree of certainty that the major contaminants (uranium and other radionuclides, arsenic and other metals, and organics) which could credibly contribute to site risks have been identified.

D.8.2 EXPOSURE PATHWAYS AND PARAMETERS

The major source of uncertainty in predicting future exposures associated with Operable Unit 1 is the future disposition of the property itself. Because it is not possible to accurately predict future land use or condition of the site, the reasonable maximum exposure (RME) future conditions were evaluated, as stipulated by the National Oil and Hazardous Substance Pollution Contingency Plan (NCP). The two land uses proposed for this risk assessment span a continuum of land uses with the private farm use being the most conservative and the government reserve without access controls being much less conservative.

D.8.2.1 Uncertainties Associated with Remedial Action Risk Estimates

In general, estimates of remedial action risks in this assessment are conservative, i.e., the estimates tend to overestimate the risks likely to be experienced by potential receptors during remedial activities. Conservative analyses are necessary to compensate for uncertainties inherent in the assessment and to insure that potential risks are not missed. This section presents some of the uncertainties in the assessment, and has been subdivided by exposure mode.

Direct Radiation

Excavation. Direct radiation exposure to a remediation worker during excavation requires an individual standing on contaminated ground during the last phase of excavation. The magnitude of his exposure is directly related to the time he spends standing on the ground. The exposure time is very uncertain. It is likely that a person will spend very little time on contaminated ground, since excavation through the liner will take place without monitoring (and therefore without the presence of monitoring personnel) and contaminated ground should exist only in areas where the liner has been breached.

If a heavy equipment accident should occur, protection from direct radiation afforded the remediation worker inside the cab could be greatly diminished. Exposure parameters for this scenario are difficult to quantify and the results uncertain. Qualitatively, it can be stated that impacts would be small since exposure time would be short and radiation fields would be low.

Drying. Direct radiation exposure to an operator from drying depends on the proximity of the operator to the dryer containing soil material and on the shielding afforded by the dryer. Given the low radiation dose rates associated with the material and the "hands-off" nature of the drying process, it is likely that radiation exposure would be unmeasurable using personnel dosimetry devices. Impacts predicted in the assessment, though small, likely overestimate the dose equivalent that would occur.

Package Handling. Direct radiation exposure impact to a package handler depends on the proximity of the handler to the packages. Most package movements will be done remotely. Handlers will need to perform radiation surveys of each package and to tie-down packages to rail cars. The estimate of the duration of these operations represents the primary uncertainty in this assessment. However, these operations comprise only a small fraction of the total time needed to load a package.

Similar operations will be needed for gondola cars. However, the time required for these activities should be minimal compared to the small time required for individual containers. Although not quantified in this risk assessment, the impact is expected to be negligible.

Immersion and Inhalation

Excavation. As with direct radiation from discrete sources, exposure via ionizing radiation from immersion in and inhalation of airborne contaminants depends on source strength (air concentration)

and exposure duration. For assessment of excavation risks, it is uncertain where the receptors will be with respect to the excavation. This assessment assumes the receptors are located as near as possible to the excavation site. It is likely that nonremediation workers and off-site individuals would be exposed to greatly reduced concentrations, thus reducing their overall exposure.

For remediation workers, inhalation impacts were ignored since the workers would use respirators. However, respirators do not completely eliminate intake of contaminants in the air. Respirators afford a protection factor on the order of a factor of 50 (source: 10 CFR Part 20) to the worker, i.e., the worker wearing a respirator is exposed to a concentration 50 times less than is in the air. Given the low risk from inhalation to nonremediation workers, and the lower exposure time than nonremediation workers (a factor of 5), this risk was not quantified.

If a heavy equipment accident should occur, the protection from inhalation of contaminated soil afforded the remediation worker inside the cab could be greatly diminished. Exposure parameters for this scenario are difficult to quantify and the results uncertain. Qualitatively, it can be stated that impacts would be small since the exposure time would be short and contaminant concentrations low.

This remedial action risk evaluation assumes that pit waste materials and underlying liners are unavailable for transport to receptors due to the high amount of moisture in these materials. Although a reasonable assumption, concentrations of arsenic in pit waste material would result in cancer risk of 10^{-3} if resuspended. Any uncertainty regarding the resuspension of pit material must be eliminated to reduce the resuspension risks, i.e., engineering controls must be in place to ensure that pit materials and liner will not be resuspended during excavation.

Drying, Vitrification, and Cement Solidification

To evaluate releases during waste processing operations, receptors were placed close to the release point (200 meters for nonremediation workers and 400 meters for off-site individuals), thus exposing them to a higher-than-expected concentration of contaminants. Waste processing release is assumed to be from ground level, although any such release will likely be elevated (from a stack vent). Elevated releases result in greater dispersion and lower contaminant exposure point concentrations. Many of the pits contain debris comprised of transit (an asbestos containing building material) and other asbestos wastes. Controls must be in place to eliminate exposure of individuals to asbestos fibers.

Finally, the off-gas system will likely remove a fraction of the contaminants assumed to be released. No credit was taken for off-gas contaminant removal in the assessment.

For nonremediation workers, a breathing rate of 3 cubic meters per hour is used. This assumes the worker is doing heavy labor continually for the 8 hours per day he is working and is exposed. A nominal value of approximately 1 cubic meter, or one third as great, is probably a more reasonable estimate.

Mechanical Hazards

Mechanical hazard risk coefficients are based on general construction activities. Remedial activities considered in this FS generally involve less "hands-on" work. It is likely that actual risk to workers from mechanical hazards will be less than that calculated in this assessment, due to the use of remote operations. Also, the man-hour estimates used in the cost estimate do not have a fine distinction of worker type. Many of the hours could be attributable to non-laborers.

Transportation

Transportation impacts were assessed with the RADTRAN 4 computer code. The exposure scenario was defined based on many of the code default parameter values. These defaults are designed to give upperbound estimates on impacts.

D.8.2.2 Uncertainties Associated with Residual Risk Estimates

Receptors considered in the FS residual risk assessment are Off-property resident farmer, Off-Property resident child, On-property resident farmer, On-property resident farmer, On-property child resident and Expanded Trespasser. Risks were quantified for these receptors, as they are the only ones potentially exposed to contaminated groundwater or surface soil (soil below excavation and fill levels that is, in the future, brought to the surface).

Receptors other than those selected for the FS risk assessment may be exposed to FEMP COCs. However, the conservative exposure scenarios used in this report provides a high degree of assurance that no actual exposed population will receive levels of exposure greater than those estimated in the FS risk assessment.

Potential exposure pathways were evaluated for each exposed receptor. All pathways which could be complete under either of the future land use scenarios (government ownership and private ownership

and agricultural use) were evaluated quantitatively for their potential to be associated with adverse health effects. Each specific receptor population was assumed to be exposed through all pathways which might be complete under minimally plausible conditions. There is a high degree of assurance that total exposures are not underestimated for any actual exposed populations.

Default exposure factor values for characterizing exposures to FEMP receptors were presented in the Risk Assessment Work Plan Addendum (June 1992). For this FS risk assessment, receptor scenarios were selected to represent the highest potential exposures. Exposure factors in the risk assessment are based on surveys of physiological characteristics and behavioral profiles across the United States. Attributes and activities studied in these surveys generally have a broad distribution. To account for most of this distribution, this risk assessment follows the EPA's recommendation to use the 95th percentile values for most exposure factors. In addition, the exposure factors are consistent with EPA guidance and the Risk Assessment Work Plan Addendum.

Exposure Duration

In accordance with EPA guidance for FEMP risk assessments, it was assumed that farm families will occupy the land for a full lifetime (70 years) exposure period. This is a conservative approach. The exposure duration for all individuals (within an age bracket) are realistic, because of the historic stability of communities in the FEMP area.

Exposure Frequency

It was assumed on-property and off-property families would occupy the property for 350 days per year, a conservative but realistic assumption for farm families.

Exposure Time

Farming family members were assumed to spend 24 hours a day on the farm property, whether it is assumed to be on or off the FEMP property. This is a conservative assumption as it does not take into account school time, shopping time, off-farm work, and other activities.

Body Weight

Body weights used in the evaluation of residual risks were derived from standard tables for United States body weight distributions. Values were selected from distribution midpoints because of the certainty regarding those distributions. The actual variation for adults is likely to be less than a factor of two. Although children have a wide range of body weights, the uncertainty is, at most, a factor of

two or three (plus or minus for a given age group). Selection of the midpoint (rather than the 95th percentile) for this variable adds conservatism to the risk estimates because this quantity appears in the denominator of the intake equations (i.e., risk is inversely proportional to body weight).

Ingestion of Soil, Food, and Water

There has been considerable discussion in the scientific literature concerning the appropriate oral ingestion rate of soil and dust for adults and children. Current EPA guidance recommends 100 mg/day for adults and 200 mg/day for children under the age of six. Since the evaluation of residual risk considered farmers who would be exposed to quantities of dust through farming activities, a weighted value of 180 mg/day was used for the on- and off-property farmers. These values are realistic as a multi-year average, but soil ingestion rates could potentially be higher for shorter-term exposures.

The rate and type of food consumption vary greatly from locality to locality and individual to individual. Estimates of food consumption used in the residual risk assessment are national averages and may not be appropriate for some individuals exposed to FEMP COCs. It should be noted that it was assumed that the majority of food consumed will be from local farm products. This is a very conservative assumption. The values presented represent conservative estimates and are not likely to vary by more than a factor of two for the average individual. The greatest uncertainty is in the consumption of specific foods (e.g., vegetables) by children. The direction and magnitude of this uncertainty are unknown.

Consumption of drinking water was set to EPA Region V default values, which are conservative estimates. Over multi-year exposures, these values are not likely to vary widely and may be overestimated by a factor of less than two. Most likely, drinking water consumed will be less than the default values.

Dermal Exposure Factors

Four critical assumptions have been made relating to the assessment of dermal exposure to soils: 1) amount of exposed skin surface area, 2) quantity of soil adhering to the skin, 3) length of time the soil adheres to the skin, and 4) partitioning rate of the COC from soil across the skin barrier. In addition, intake of contaminants associated with dermal contact to water is controlled by dermal permeability to specific waterborne contaminants. These factors vary widely and may contribute substantially to uncertainty in the risk assessment by these pathways. In general, assumptions used to

estimate dermal absorption are consistent with the conservative default values defined in EPA guidance. The average extent of uncertainty in dermal exposure factors is quite large (an order of magnitude or more). In addition, the adjustment of toxicity values for use in the dermal pathway risk assessment, particularly in the case of inorganic contaminants, was performed using conservative assumptions about contaminant intake and likely contributes a further, unknown degree of conservatism to the characterization of dermal pathway risks.

D.8.3 EXPOSURE POINT CONCENTRATIONS

Values used to represent exposure point concentrations were defined to provide conservative estimates of exposure, thus ensuring a conservative evaluation of risks. All residual risk assessment exposure point groundwater concentrations are projected or modeled values. Uncertainties associated with exposure point concentrations estimated by models are additive or multiplicative and include uncertainties associated with each input parameter (diffusion coefficients, groundwater flow rates, etc.), model characteristics, release mechanisms, and source terms. Residual risk evaluation input parameters were based on site information and professional judgment and were designed to be conservative. Input parameters and models were selected and used in a manner consistent with the Risk Assessment Work Plan Addendum.

D.8.4 TOXICOLOGICAL INFORMATION AND MODELS

EPA-supplied RfDs and CSFs were used throughout the residual risk evaluation. Because of this, toxicological evaluations (upon which the residual risk evaluation is based) contribute no more uncertainty than in comparable CERCLA documents. However, the level of uncertainty in the toxicologic data and models is still substantial.

As described in the RI Report for Operable Unit 1 (February, 1994), considerable uncertainty is associated with qualitative (hazard assessment) and quantitative (dose-response) evaluations of Superfund risk assessments. The hazard assessment characterizes the nature and strength of the evidence of causation, or the likelihood that a chemical that induces adverse effects in animals will induce adverse effects in humans. The hazard assessment of carcinogenicity is evaluated as a weight-of-evidence determination, using either the International Agency for Research on Cancer (IARC) (1987) or EPA (1986b) schemes. Positive results in animal cancer tests suggest humans may also manifest a carcinogenic response, but the animal data cannot necessarily be used to predict the target tissue in humans. In the hazard assessment of noncarcinogenic effects, positive animal test results may suggest the nature of the human effects (i.e., the target tissues and type of effects) (EPA 1989g).

There are many sources of uncertainty in dose-response evaluation of carcinogenic (i.e., slope factor or unit risk calculations) and noncarcinogenic effects (i.e., RfD or RfC calculations). The three major sources are:

1. Interspecies extrapolations:

   Animal-to-human extrapolation, commonly used in the absence of quantitative pharmacokinetics, dosimetric, or mechanistic data, is usually based on a consideration of interspecies differences in body weight, surface area, or basal metabolic rate.

2. Intraspecies or individual variation:

   Most toxicity experiments are performed with animals that are similar in age and genotype so that intragroup biological variation is minimal. The human population of concern may reflect a great deal of heterogeneity, however, including unusual sensitivity to specific toxic effects or contaminants.

   Toxicity data from human occupational studies reflect a bias because only those individuals sufficiently healthy to attend work regularly and those not unusually sensitive to the COCs are likely to be occupationally exposed.

3. Key study and database quality:

   The quality of key studies (from which the quantitative data are derived) and the quality of the literature databases add to the uncertainty. For carcinogenic effects, the uncertainty associated with some quality factors (i.e., group size) is incorporated into the 95 percent upper bound estimate of the slope factor. For noncarcinogenic effects, additional uncertainty factors may be applied in the derivation of the RfD or RfC to reflect gaps in the database.

Another source of uncertainty in the quantitative risk estimation for carcinogenicity is the method by which data from high doses in animal studies are extrapolated to the dose range expected for environmentally exposed humans. The linear multi-stage model, which is used in almost all quantitative estimations of human risk from animal data, is based on the nonthreshold assumption of carcinogenesis. A large body of evidence, however, suggests that epigenetic carcinogens (carcinogens, which do not induce mutations), as well as many genotoxic carcinogens may have a threshold dose level below which they are noncarcinogenic (Williams and Weisberger 1991). The linear multi-stage model is therefore regarded as being conservative for many chemicals.

Adding to this is the fact that the EPA-derived slope factors found in IRIS are set at the 95 percent UCL of the linear slope of the multi-stage model. Thus, risks evaluated using the slope factors may be overestimated. This consideration applies to both radiological and chemical estimates of carcinogenic risk. The slope factors derived by EPA for the evaluation of risks due to external

exposure to radiation are of particular concern in this regard. These values were derived using conservative assumptions about exposure conditions and are likely to provide conservative risk estimates.

The methods used to define RfD values for chemical contaminants also incorporate a large degree of conservatism. Sets of multiplicative Uncertainty Factors (UFs) are used to adjust the results of animal and human toxicologic studies to take into account the nature of the endpoint No Observed Adverse Effect Level (NOAEL) to Lowest Observed Adverse Effect Level (LOAEL) seen in the studies, differences in response to different dose schedules, the presence of especially sensitive populations, and the possible differences between human and animal sensitivity to contaminant exposures. Each UF may have a value as high as ten; thus, RfD values typically are set between 100 and 1000 times lower than the lowest dose seen to cause any adverse effects in animal studies. If the human and animal responses to contaminant exposures are not as dissimilar as reflected in the UFs (or if humans are less, rather than more, sensitive to contaminants), it is possible that the use of RfDs overstates the potential for adverse health effects in humans.

The level of uncertainty in the toxicologic data for different chemicals varies because information concerning some constituents and their associated health effects is comparatively scarce, whereas for others much more information is available from health effects studies. Also, different amounts of data may be available concerning the different types of effects for a given COC. For example, uranium (a key COC at Operable Unit 1) has been established as a chemical toxicant (mainly affecting the kidneys) based on human and animal studies. The RfD for uranium was based on the results of animal studies and was calculated by applying an uncertainty factor of 1000 to a LOAEL for nephrotoxicity in rabbits to provide a margin of safety for extrapolation to humans. The uncertainty factor consists of three factors of 10 each for: 1) estimation of a NOAEL from a LOAEL, 2) extrapolation from animals to humans, and 3) the range of sensitivities among exposed humans.

There is even greater uncertainty regarding the carcinogenicity of uranium. As an alpha-particle emitter, uranium is also considered a carcinogen; however, epidemiological evidence of uranium-induced excess cancers is difficult to obtain. This is largely because the human data available on the radiocarcinogenic effects of uranium exposure are for underground miners who were simultaneously exposed to radon and radon progeny, which are known carcinogens. The studies of humans sometimes lack quantitative information concerning uranium exposure, including potential uranium exposure through previous employment, concurrent smoking patterns, or concurrent radon exposure

levels, all of which are needed to definitively determine the risk attributable to uranium exposure. These facts weaken the power of the human studies to detect excess risk, if any, above natural risk. These uncertainties are not well known or easily quantified.

Uncertainties in the interpretation of toxicologic data also affect risk assessment results for inhalation exposures to metals. Hazard Index values associated with particulate inhalation exposures exceed one for several receptors at Operable Unit 1. Almost all of the HI values are contributed by exposures to antimony and chromium.

Chemical speciation is also an issue in evaluating the inhalation pathway risk estimates for chromium exposures. In the risk characterization, it was assumed that all chromium present in soils and groundwater is hexavalent rather than the less toxic trivalent form. Hexavalent chromium is inconsistent with prevailing redox and chemical conditions in environmental media at the FEMP site, and it is likely that only a small portion of the chromium present is actually hexavalent. This failure to adequately consider chromium speciation results in a substantial overestimation of risks associated with chromium exposures, since hexavalent chromium species are much more toxic than trivalent species. In the case of noncarcinogenic health effects, trivalent chromium is estimated to be on the order of 50 times less toxic than hexavalent chromium. In addition, trivalent chromium species are not thought to have any carcinogenic activity in humans, whereas hexavalent chromium compounds are regarded as potent human carcinogens. The assumption that all chromium is hexavalent probably has resulted in a large overestimation of cancer risks and the potential for noncarcinogenic adverse effects associated with chromium exposures.

D.8.5 RISK CHARACTERIZATION

Throughout this risk assessment, potential health effects caused by the simultaneous exposure to multiple on-site COCs were assumed to be additive in nature. Uncertainties associated with summing cancer risks or HIs for multiple substances are of particular concern in the risk characterization step. The assumption of dose additivity ignores possible synergism or antagonism among chemicals and assumes similarity in mechanisms of action. However, data to quantitatively assess chemical interactions are generally lacking. In the absence of adequate information on chemical interactions, EPA guidelines indicate that carcinogenic risks and noncancer HIs should be treated as an additive. These assumptions are made to help prevent an underestimation of cancer risk or potential noncancer health effects at a site (EPA 1986, 1989).

D.9.0 SUMMARY OF RISK ASSESSMENT RESULTS

The following section summarizes the calculated remedial action and residual carcinogenic and noncarcinogenic potential human health risks for each of the feasible remedial alternatives, and concludes by comparing the calculated risks for both the remedial (short-term) and residual (long-term) effects of the alternatives under consideration. The remedial and residual risks are not additive, due to the differing timespan in which they are likely to occur. For example, remedial action is assumed to occur within the next ten to 20 years. In contrast, residual risks are considered to occur over a 1000 year timespan, likely peaking at least a century after remediation is complete. Therefore, these categories of potential risk should be and are considered separately in the FS.

The difficulty in determining groundwater PRGs based on soil contaminants leaching to an aquifer is not uncommon. EPA and state regulatory agencies with which we are familiar have yet to formulate a method by which to develop these numbers. It is a highly complex and site-specific exercise.

However, the relative risks of the different alternatives are unlikely to vary a great deal as the calculations are of a linear nature. In essence, this assessment allows us to rank the alternatives by their relative risks, and allows us to estimate if any of the alternatives are protective of public health over the long term.

D.9.1 ON-SITE DISPOSAL/VITRIFICATION - ALTERNATIVE 4A

Potential health risks from removal, drying, vitrification and on-property disposal of waste material (Alternative 4A) are summarized below.

D.9.1.1 Remedial Action Risk Summary

This alternative is calculated to deliver a dose equivalent to remediation workers of 32 millirem over the course of the alternative. The assessment estimates 86 injuries and the potential for 1.3 fatalities due to mechanical hazards (non-environmental). The radiological and chemical cancer risk to nonremediation workers is 5.2×10^{-5}. The hazard index to nonremediaton workers is 6.3×10^{-8}. The radiological and chemical cancer risk to off-site individuals is 2.9×10^{-6}. The hazard index to an off-site individual is 3.5×10^{-9}. There are no transportation risks associated with this alternative.

D.9.1.2 Residual Risk Summary

Potential receptors in the residual risk scenario are on- and off-property farmers and children and an expanded trespasser exposed to residual contaminants through groundwater and surface soil pathways. The source terms of potential concern include:

- Waste Pits 1-6 residual soils (contribute contaminants to groundwater pathways)
- Burn Pit residual soils (contribute contaminants to groundwater pathways)
- Clearwell residual soils (contribute contaminants to groundwater pathways)
  - Subsurface soils from non-pit areas that are brought to the surface by future activities (contribute contaminants to surface soil pathways)
- On-property disposal cell (contribute contaminants to groundwater pathways)

Future Land Use, Private

The potential radiological ILCR for the on-property farmer from exposure to soils was $7x10^{-4}$ and the potential groundwater radiological ILCR was $1x10^{-4}$. This can be compared to the off-property farmer which had a $2x10^{-5}$ ILCR from soils and a $3x10^{-6}$ risk from groundwater. The chemical ILCR was $4x10^{-4}$ for the on-property farmer soil exposure and $9x10^{-5}$ for groundwater exposure. The off-property farmer chemical ILCR for soil exposure was $1x10^{-7}$ and $5x10^{-7}$ for groundwater exposure. Based on these numbers, this alternative is not protective for the on-property farmer. The total HI for the on-property farmer was 8.0 and 0.05 for the off-property farmer.

Future Land Use, Government

The potential radiological ILCR for the expanded trespasser was $5x10^{-6}$ from soil exposures. The radiological ILCR for the off-property farmer was $2x10^{-6}$ for soil exposure and $3x10^{-6}$ for groundwater exposures. The chemical ILCR for the expanded trespasser was $2x10^{-5}$ from soil exposure. The off-property farmer chemical ILCR from soil exposure was $1x10^{-8}$ and $5x10^{-7}$ from groundwater exposure. The total HI for the expanded trespasser was 0.7 and 0.1 for the off-property farmer. This alternative is protective of the receptors given this land use.

D.9.2 ON-SITE DISPOSAL/CEMENT SOLIDIFICATION - ALTERNATIVE 4B

The potential human health risks resulting from removal, drying, cement solidification and on-property disposal of the wastes and associated material (Alternative 4B) are presented below.

D.9.2.1 Remedial Action Risk Summary

This alternative delivers a dose equivalent to remediation workers of 32 millirem over the course of the remedial action. The assessment estimates 104 injuries and the potential for 1.5 fatalities due to mechanical (non-environmental) hazards. The radiological and chemical cancer risk to nonremediation workers is 5.2×10^{-5}. The hazard to off-site individuals is 2.9×10^{-6}. The hazard index to an off-site individual is 3.5×10^{-9}. There are no transportation risks associated with this alternative.

D.9.2.2 Residual Risk Summary

The leaching properties of the heterogenous wastes in Operable Unit 1 vary. Therefore, no conclusions can be drawn as to the relative stability of the treated waste forms in Alternatives 4A and 4B. The calculated potential carcinogenic and noncarcinogenic health risks would be the same. See Section D.9.1.2 above.

D.9.3 OFF-SITE DISPOSAL/TREATMENT/NEVADA TEST SITE - ALTERNATIVE 5A

Off-Site Disposal options eliminate the disposal cell related remedial activities and source term from calculated remedial action and residual risks. This analysis shows that decrement in risk, particularly over the long term, to be minor. However, off-site disposal adds train and truck transportation-related risks to the remedial action estimates, and these are considered in the FS.

D.9.3.1 Remedial Action Risk Summary

This alternative delivers a dose equivalent to remediation workers of 61 millirem over the course of the alternative. The assessment estimates 27 injuries and the potential for 0.41 fatalities due to mechanical (non-environmental) hazards. The radiological and chemical cancer risk to nonremediation workers is 5.2×10^{-5}. The hazard index to nonremediation workers is 6.3×10^{-8}. The radiological and chemical cancer risk to off-site individuals is 2.9×10^{-6}. The hazard index to off-site individuals is 3.5×10^{-9}. The collective dose equivalent estimates for truck drivers and train crew are 0.0004 and 0.45, respectively, for the total shipment of material. For the total shipment, the maximum off-site individual's cancer risk from radiation exposure is 1.7×10^{-6}. The cancer risk from a hypothetical train accident is 2.7×10^{-5} to the population. For a hypothetical truck accident, the cancer risk is 1.2×10^{-8} to the population.

D.9.3.2 Residual Risk Summary

Potential receptors in the residual risk scenario include on-property and off-property farmers and children exposed to contaminants in groundwater. The source terms of concern are the same as for the on-property disposal alternatives, excluding the disposal cell. The calculated carcinogenic and non-carcinogenic health risks would be the same.

D.9.4 OFF-SITE DISPOSAL/TREATMENT/PERMITTED COMMERCIAL DISPOSAL FACILITY - ALTERNATIVE 5B

Residual risks for this alternative are the same as for Alternative 5A, as the source terms remain equal. Remedial action risks vary due to the need to containerize waste for shipment to NTS, and due to the bulk shipment mode for this alternative.

D.9.4.1 Remedial Action Risk Summary

This alternative delivers a dose equivalent to remediation workers of 32 millirem over the course of the alternative. The assessment estimates 24 injuries and the potential for 0.36 facilities due to mechanical (non-environmental) hazards. The radiological and chemical cancer risk to nonremediation workers is 5.2×10^{-5}. The hazard index to nonremediation workers is 6.3×10^{-8}. The radiological and chemical cancer risk to off-site individuals is 2.9×10^{-6}. The hazard index to off-site individuals is 3.5×10^{-9}. The collective dose equivalent estimate for the train crew is 0.033 for the total shipment of material. For the total shipment, the maximum off-site individual's cancer risk from radiation exposure is 1.2×10^{-10}. The cancer risk to the entire population along the transport route due to radiation exposure is 4.6×10^{-6}. The cancer risk from a hypothetical train accident is 4.6×10^{-5}.

D.9.4.2 Residual Risk Summary

This residual risk scenario includes the same receptors, exposure scenarios and source terms of concern as Alternative 5A. Therefore, the calculated risks are also the same. See Section D.9.3.2.

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D.9.5 COMPARISON OF RISKS BY REMEDIAL ALTERNATIVE

Remedial action and residual risks are compared, by remedial alternative, in the following paragraph.

D.9.5.1 Remedial Action Risk Comparison

Each remedial alternative delivers comparable radiation dose equivalents to remediation workers. Alternative 5A delivers a higher dose equivalent due to package handling, but the magnitude of the impact is very small. The cancer risk and hazard index to nonremediation workers and off-site individuals are identical for all alternatives since excavation dominates these impacts. Alternatives 5A and 5B include transportation impacts, with the magnitude of the impacts comparable between the two alternatives. Alternatives 4A and 4B produce the most risk from physical injury since on-site disposal dominates this risk.

D.9.5.2 Residual Risk Comparison

It is expected that the residual surface soil concentrations will present the greatest risk to both on and off-property residents in the long term. No distinction can be drawn between Alternatives 4A and 4B based on the inconclusive leaching data from the respective waste forms. On and off-property resident carcinogenic risks vary by about one order of magnitude, and noncarcinogenic effects are greatly reduced for off-property residents (relative to the on-property residents), so protection is provided by maintaining FEMP in government ownership.

However, the incremental risk from the waste material in a disposal cell is calculated to be small. This is a result of assuming the disposal cell is designed to last for 1000 years and operates without failure over that timespan.

It should be noted that residual risk related to off-property disposal at the off-property location are not included in this analysis, and remedial action risks are considered separately. All these factors are to be considered in the FEMP property risk management decisions.

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ATTACHMENT I

RISK CALCULATIONS

PRELIMINARY REMEDIATION GOALS
ON-PROPERTY RESIDENT FARMER, ADULT

5287

Soil-Air Transfer Factor: 5.46E-05 g/m³

	PRGs for Carcinogens at ILCR = 1E-06				PRGs for Toxicants at HQ = 1			
	Exposure Media				Exposure Media			
	Soil	Water	Air	Soil/Air	Soil	Water	Air	Soil/Air
chem =	(mg/Kg)	(mg/L)	(mg/m³)	(mg/Kg)	(mg/Kg)	(mg/L)	(mg/m³)	(mg/Kg)
rad =	(pCi/g)	(pCi/L)	(pCi/m³)	(pCi/g)				
Carcinogens								
beryllium	2.8E-03	5.0E-06	1.8E-07	2.8E-03	–	–	–	–
cadmium	NC	NC	2.5E-06	4.6E+01	–	–	–	–
aroclor-1254	1.1E-03	7.7E-08	5.7E-09	1.1E-03	–	–	–	–
benzo(a)anthracene	1.7E-02	2.2E-05	4.7E-07	1.7E-02	–	–	–	–
benzo(a)pyrene	1.8E-03	2.6E-06	4.0E-08	1.8E-03	–	–	–	–
benzo(b)fluoranthe	6.2E-03	1.1E-05	1.1E-07	6.1E-03	–	–	–	–
benzo(k)fluoranthe	8.9E-03	1.6E-05	1.3E-07	8.9E-03	–	–	–	–
chrysene	5.6E-01	7.1E-04	1.5E-05	5.5E-01	–	–	–	–
Toxicants								
antimony	–	–	–	–	9.0E+00	8.0E-03	1.8E-04	9.0E+00
beryllium	–	–	–	–	6.0E+01	1.1E-01	4.3E-03	6.0E+01
cadmium	–	–	–	–	3.9E+00	5.2E-03	5.5E-05	3.9E+00
uranium	–	–	–	–	1.3E+02	7.9E-02	3.2E-03	1.3E+02
Radionuclides								
Cs-137+1d	1.0E-02	3.0E-01	3.6E-03	1.0E-02	–	–	–	–
Np-237+1d	4.6E-02	7.0E-02	2.7E-04	4.5E-02	–	–	–	–
Pu-238	1.0E+00	7.1E-02	2.1E-04	8.0E-01	–	–	–	–
Pu-239/240	9.7E-01	6.8E-02	2.1E-04	7.8E-01	–	–	–	–
Sr-90+1d	1.6E-02	3.3E-01	6.2E-03	1.6E-02	–	–	–	–
Th-230	1.6E+01	1.2E+00	3.0E-04	4.1E+00	–	–	–	–
U-234	4.5E+00	9.6E-01	3.3E-04	2.6E+00	–	–	–	–
U-235	9.8E-02	9.6E-01	3.4E-04	9.7E-02	–	–	–	–
U-238+2d	5.3E-01	5.5E-01	1.6E-04	4.5E-01	–	–	–	–

NC Not considered carcinogenic via this exposure route.

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PRELIMINARY REMEDIATION GOALS

OFF-PROPERTY RESIDENT FARMER, ADULT

5287

Soil-Air Transfer Factor: 5.5E-07 g/m³

	PRGs for Carcinogens at ILCR = 1E-06				PRGs for Toxicants at HQ = 1			
	Exposure Media				Exposure Media			
	Soil	Water	Air	Soil/Air	Soil	Water	Air	Soil/Air
chem =	(mg/Kg)	(mg/L)	(mg/m³)	(mg/Kg)	(mg/Kg)	(mg/L)	(mg/m³)	(mg/Kg)
rad =	(pCi/g)	(pCi/L)	(pCi/m³)	(pCi/g)				
Carcinogens								
beryllium	N/A	5.0E-06	1.8E-07	3.3E+02	–	–	–	–
cadmium	N/A	NC	2.5E-06	4.6E+03	–	–	–	–
aroclor-1254	N/A	7.7E-08	5.7E-09	1.0E+01	–	–	–	–
benzo(a)anthracene	N/A	2.2E-05	4.7E-07	8.5E+02	–	–	–	–
benzo(a)pyrene	N/A	2.6E-06	4.0E-08	7.2E+01	–	–	–	–
benzo(b)fluoranthene	N/A	1.1E-05	1.1E-07	1.9E+02	–	–	–	–
benzo(k)fluoranthene	N/A	1.6E-05	1.3E-07	2.3E+02	–	–	–	–
chrysene	N/A	7.1E-04	1.5E-05	2.8E+04	–	–	–	–
Toxicants								
antimony	–	–	–	–	N/A	8.0E-03	1.8E-04	3.3E+05
beryllium	–	–	–	–	N/A	1.1E-01	4.3E-03	7.9E+06
cadmium	–	–	–	–	N/A	5.2E-03	5.5E-05	9.9E+04
uranium	–	–	–	–	N/A	7.9E-02	3.2E-03	5.8E+06
Radionuclides								
Cs-137+1d	N/A	3.0E-01	3.6E-03	6.6E+03	–	–	–	–
Np-237+1d	N/A	7.0E-02	2.7E-04	4.9E+02	–	–	–	–
Pu-238	N/A	7.1E-02	2.1E-04	3.8E+02	–	–	–	–
Pu-239/240	N/A	6.8E-02	2.1E-04	3.8E+02	–	–	–	–
Sr-90+1d	N/A	3.3E-01	6.2E-03	1.1E+04	–	–	–	–
Th-230	N/A	1.2E+00	3.0E-04	5.4E+02	–	–	–	–
U-234	N/A	9.6E-01	3.3E-04	6.0E+02	–	–	–	–
U-235	N/A	9.6E-01	3.4E-04	6.2E+02	–	–	–	–
U-238+2d	N/A	5.5E-01	1.6E-04	3.0E+02	–	–	–	–

N/A Not applicable; exposure pathway not relevant for this receptor.
NC Not considered carcinogenic via this exposure route.

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PRELIMINARY REMEDIATION GOALS 5287

EXPANDED TRESPASSER

Soil-Air Transfer Factor: 7.0E-06 g/m³

	PRGs for Carcinogens at ILCR = 1E-06			PRGs for Toxicants at HQ = 1		
	Exposure Media			Exposure Media		
	Soil	Air	Soil/Air	Soil	Air	Soil/Air
chem =	(mg/Kg)	(mg/m³)	(mg/Kg)	(mg/Kg)	(mg/m³)	(mg/Kg)
rad =	(pCi/g)	(pCi/m³)	(pCi/g)			
Radionuclides						
Cs-137+1d	1.1E+00	1.6E+01	1.1E+00	–	–	–
Np-237+1d	5.0E+00	1.1E-02	5.0E+00	–	–	–
Pu-238	1.4E+02	7.9E-03	1.2E+02	–	–	–
Pu-239/240	1.3E+02	8.1E-03	1.2E+02	–	–	–
Sr-90+1d	8.5E+02	5.0E+00	8.5E+02	–	–	–
Th-230	2.2E+03	1.1E-02	9.0E+02	–	–	–
U-234	1.9E+03	1.2E-02	8.9E+02	–	–	–
U-235	9.3E+00	1.2E-02	9.2E+00	–	–	–
U-238+2d	5.9E+01	5.9E-03	5.5E+01	–	–	–
Carcinogenic Chemicals						
beryllium	2.5E-02	4.6E-05	2.5E-02	–	–	–
cadmium	N/A	6.3E-05	9.0E+03	–	–	–
aroclor-1254	3.5E-02	ND	3.5E-02	–	–	–
benzo(a)anthracene	3.9E+01	4.3E-04	3.9E+01	–	–	–
benzo(a)pyrene	5.7E+00	6.3E-05	5.7E+00	–	–	–
benzo(b)fluoranthene	4.7E+01	5.2E-04	4.7E+01	–	–	–
benzo(k)fluoranthene	1.1E+02	1.2E-03	1.1E+02	–	–	–
chrysene	1.3E+03	ND	1.3E+03	–	–	–
Toxicants						
antimony	–	–	–	1.5E+02	ND	1.5E+02
beryllium	–	–	–	1.3E+02	ND	1.3E+02
cadmium	–	–	–	1.3E+02	ND	1.3E+02
uranium	–	–	–	3.8E+02	ND	3.8E+02

N/A - Not applicable. Chemical not a chemical of interest for medium or exposure pathway not applicable.
ND - No data for toxicity assessment for exposure pathway.

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EXPOSURE POINT CONCENTRATIONS

ON-PROPERTY RESIDENT FARMER, ADULT
FUTURE LAND USE, FUTURE SOURCE TERM

- 5287

	5.46E-05 = Soil-to-Air Transfer Factor (g/m³) Exposure Point Concentrations		
Transfer Media:	Air	Soil	Groundwater
Contaminants of Concern	mg/m³	mg/kg	mg/L
Radionuclides	pCi/m³	pCi/g	pCi/L
Cs-137+1d	9.8E-05	1.8E+00	0.0E+00
Np-237+1d	2.7E-06	5.0E-02	4.13E-01
Pu-238	2.7E-06	5.0E-02	0.0E+00
Pu-239/240	2.7E-06	5.0E-02	0.0E+00
Sr-90+1d	4.9E-05	9.0E-01	3.9E-03
Th-230	4.9E-02	9.02E+02	0.0E+00
U-234	9.6E-04	1.75E+01	5.12E+01
U-235	5.1E-04	9.3E+00	1.19E+00
U-238+2d	3.1E-03	5.6E+01	2.43E+01
Carcinogenic Chemicals			
beryllium	3.4E-08	6.3E-01	0.0E+00
cadmium	4.2E-07	7.7E+00	9.34E-04
aroclor-1254	4.9E-09	9.0E-02	6.99E-06
benzo(a)anthracene	5.4E-09	9.8E-02	0.0E+00
benzo(a)pyrene	2.3E-09	4.2E-02	0.0E+00
benzo(b)fluoranthene	3.2E-09	5.9E-02	0.0E+00
benzo(k)fluoranthene	2.5E-09	4.6E-02	0.0E+00
chrysene	4.8E-09	8.8E-02	0.0E+00
Toxicants			
antimony	1.5E-06	2.8E+01	2.55E-03
beryllium	3.4E-08	6.3E-01	0.0E+00
cadmium	4.2E-07	7.7E+00	9.34E-04
uranium	1.0E-05	1.9E+02	7.31E-02

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EXPOSURE POINT CONCENTRATIONS

ON-PROPERTY RESIDENT CHILD

FUTURE LAND USE, FUTURE SOURCE TERM

5287

	5.46E-05 = Soil-to-Air Transfer Factor Exposure Point Concentrations		
Transfer Media:	Air	Soil	Groundwater
Contaminants of Concern	mg/m³	mg/kg	mg/L
Radionuclides	pCi/m³	pCi/g	pCi/L
Cs-137+1d	9.8E-05	1.8E+00	0.0E+00
Np-237+1d	2.7E-06	5.0E-02	4.13E-01
Pu-238	2.7E-06	5.0E-02	0.0E+00
Pu-239/240	2.7E-06	5.0E-02	0.0E+00
Sr-90+1d	4.9E-05	9.0E-01	3.9E-03
Th-230	4.9E-02	9.02E+02	0.0E+00
U-234	9.6E-04	1.75E+01	5.12E+01
U-235	5.1E-04	9.3E+00	1.19E+00
U-238+2d	3.1E-03	5.6E+01	2.43E+01
Carcinogenic Chemicals			
beryllium	3.4E-08	6.3E-01	0.0E+00
cadmium	4.2E-07	7.7E+00	9.34E-04
aroclor-1254	4.9E-09	9.0E-02	6.99E-06
benzo(a)anthracene	5.4E-09	9.8E-02	0.0E+00
benzo(a)pyrene	2.3E-09	4.2E-02	0.0E+00
benzo(b)fluoranthene	3.2E-09	5.9E-02	0.0E+00
benzo(k)fluoranthene	2.5E-09	4.6E-02	0.0E+00
chrysene	4.8E-09	8.8E-02	0.0E+00
Toxicants			
antimony	1.5E-06	2.8E+01	2.55E-03
beryllium	3.4E-08	6.3E-01	0.0E+00
cadmium	4.2E-07	7.7E+00	9.34E-04
uranium	1.0E-05	1.9E+02	7.31E-02

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EXPOSURE POINT CONCENTRATIONS

5287

OFF-PROPERTY RESIDENT FARMER, ADULT
FUTURE LAND USE, FUTURE SOURCE TERM

	5.5E-07 = Soil-to-Air Transfer Factor (g/m³) Exposure Point Concentrations		
Transfer Media:	Air	(No Direct Contact) Soil	Groundwater
Contaminants of Concern	mg/m³	mg/kg	mg/L
Radionuclides	pCi/m³	pCi/g	pCi/L
Cs-137+1d	9.9E-07	1.8E+00	0.0E+00
Np-237+1d	2.8E-08	5.0E-02	1.83E-02
Pu-238	2.8E-08	5.0E-02	0.0E+00
Pu-239/240	2.8E-08	5.0E-02	0.0E+00
Sr-90+1d	5.0E-07	9.0E-01	6.37E-07
Th-230	5.0E-04	9.02E+02	0.0E+00
U-234	9.6E-06	1.75E+01	2.46E-01
U-235	5.1E-06	9.3E+00	5.66E-02
U-238+2d	3.1E-05	5.6E+01	1.16E+00
Carcinogenic Chemicals			
beryllium	3.5E-10	6.3E-01	0.0E+00
cadmium	4.2E-09	7.7E+00	1.53E-05
aroclor-1254	5.0E-11	9.0E-02	3.87E-08
benzo(a)anthracene	5.4E-11	9.8E-02	0.0E+00
benzo(a)pyrene	2.3E-11	4.2E-02	0.0E+00
benzo(b)fluoranthene	3.2E-11	5.9E-02	0.0E+00
benzo(k)fluoranthene	2.5E-11	4.6E-02	0.0E+00
chrysene	4.8E-11	8.8E-02	0.0E+00
Toxicants			
antimony	1.5E-08	2.8E+01	2.72E-07
beryllium	3.5E-10	6.3E-01	0.0E+00
cadmium	4.2E-09	7.7E+00	1.53E-05
uranium	1.0E-07	1.9E+02	3.51E-03

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EXPOSURE POINT CONCENTRATIONS

OFF-PROPERTY RESIDENT CHILD

FUTURE LAND USE, FUTURE SOURCE TERM

5287

	5.5E-07 = Soil-to-Air Transfer Factor (g/m³) Exposure Point Concentrations		
Transfer Media:	Air	(No Direct Contact) Soil	Groundwater
Contaminants of Concern	mg/m³	mg/kg	mg/L
Radionuclides	pCi/m³	pCi/g	pCi/L
Cs-137+1d	9.9E-07	1.8E+00	0.0E+00
Np-237+1d	2.8E-08	5.0E-02	1.83E-02
Pu-238	2.8E-08	5.0E-02	0.0E+00
Pu-239/240	2.8E-08	5.0E-02	0.0E+00
Sr-90+1d	5.0E-07	9.0E-01	6.37E-07
Th-230	5.0E-04	9.02E+02	0.0E+00
U-234	9.6E-06	1.75E+01	2.46E-01
U-235	5.1E-06	9.3E+00	5.66E-02
U-238+2d	3.1E-05	5.6E+01	1.16E+00
Carcinogenic Chemicals			
beryllium	3.5E-10	6.3E-01	0.0E+00
cadmium	4.2E-09	7.7E+00	1.53E-05
aroclor-1254	5.0E-11	9.0E-02	3.87E-08
benzo(a)anthracene	5.4E-11	9.8E-02	0.0E+00
benzo(a)pyrene	2.3E-11	4.2E-02	0.0E+00
benzo(b)fluoranthene	3.2E-11	5.9E-02	0.0E+00
benzo(k)fluoranthene	2.5E-11	4.6E-02	0.0E+00
chrysene	4.8E-11	8.8E-02	0.0E+00
Toxicants			
antimony	1.5E-08	2.8E+01	2.72E-07
beryllium	3.5E-10	6.3E-01	0.0E+00
cadmium	4.2E-09	7.7E+00	1.53E-05
uranium	1.0E-07	1.9E+02	3.51E-03

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EXPOSURE POINT CONCENTRATIONS

5287

TRESPASSER, ADULT

FUTURE LAND USE, FUTURE SOURCE TERM

	7.0E-06 = Soil-to-Air Transfer Factor	
	Exposure Point Concentrations	
Transfer Media:	Air	Soil
Contaminants of Concern	mg/m³	mg/kg
Radionuclides	pCi/m³	pCi/g
Cs-137+1d	1.3E-05	1.8E+00
Np-237+1d	3.5E-07	5.0E-02
Pu-238	3.5E-07	5.0E-02
Pu-239/240	3.5E-07	5.0E-02
Sr-90+1d	6.3E-06	9.0E-01
Th-230	6.3E-03	9.02E+02
U-234	1.2E-04	1.75E+01
U-235	6.5E-05	9.3E+00
U-238+2d	3.9E-04	5.6E+01
Carcinogenic Chemicals		
beryllium	4.4E-09	6.3E-01
cadmium	5.4E-08	7.7E+00
aroclor-1254	6.3E-10	9.0E-02
benzo(a)anthracene	6.9E-10	9.8E-02
benzo(a)pyrene	2.9E-10	4.2E-02
benzo(b)fluoranthene	4.1E-10	5.9E-02
benzo(k)fluoranthene	3.2E-10	4.6E-02
chrysene	6.2E-10	8.8E-02
Toxicants		
antimony	2.0E-07	2.8E+01
beryllium	4.4E-09	6.3E-01
cadmium	5.4E-08	7.7E+00
uranium	1.3E-06	1.9E+02

EXPOSURE POINT CONCENTRATIONS

TRESPASSER, CHILD

FUTURE LAND USE, FUTURE SOURCE TERM

5287

	7.0E-06 = Soil-to-Air Transfer Factor	
	Exposure Point Concentrations	
Transfer Media:	Air	Soil
Contaminants of Concern	mg/m³	mg/kg
Radionuclides	pCi/m³	pCi/g
Cs-137+1d	1.3E-05	1.8E+00
Np-237+1d	3.5E-07	5.0E-02
Pu-238	3.5E-07	5.0E-02
Pu-239/240	3.5E-07	5.0E-02
Sr-90+1d	6.3E-06	9.0E-01
Th-230	6.3E-03	9.02E+02
U-234	1.2E-04	1.75E+01
U-235	6.5E-05	9.3E+00
U-238+2d	3.9E-04	5.6E+01
Carcinogenic Chemicals		
beryllium	4.4E-09	6.3E-01
cadmium	5.4E-08	7.7E+00
aroclor-1254	6.3E-10	9.0E-02
benzo(a)anthracene	6.9E-10	9.8E-02
benzo(a)pyrene	2.9E-10	4.2E-02
benzo(b)fluoranthene	4.1E-10	5.9E-02
benzo(k)fluoranthene	3.2E-10	4.6E-02
chrysene	6.2E-10	8.8E-02
Toxicants		
antimony	2.0E-07	2.8E+01
beryllium	4.4E-09	6.3E-01
cadmium	5.4E-08	7.7E+00
uranium	1.3E-06	1.9E+02

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INCREMENTAL LIFETIME CANCER RISKS
ON-PROPERTY RESIDENT FARMER, ADULT
FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Air				Soil					
Exposure Pathways: / Contaminants of Concern	Inhalation	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Incidental Ingestion	Dermal Contact	External Exposure
Radionuclides										
Cs-137+1d	2.2E-10	5.1E-09	9.1E-09	1.3E-08	1.9E-06	8.3E-06	1.2E-05	2.2E-07	N/A	1.5E-04
Np-237+1d	9.2E-09	9.4E-10	5.3E-12	1.9E-12	1.4E-07	6.1E-09	2.2E-09	4.9E-08	N/A	8.9E-07
Pu-238	1.2E-08	8.8E-10	3.2E-14	2.5E-14	6.3E-10	5.3E-12	4.2E-12	4.9E-08	N/A	5.8E-11
Pu-239/240	1.2E-08	9.2E-10	7.2E-14	5.8E-14	6.6E-10	5.5E-12	4.4E-12	5.1E-08	N/A	5.6E-11
Sr-90+1d	3.5E-10	3.3E-09	2.0E-10	4.0E-09	1.0E-05	2.2E-06	4.5E-05	1.4E-07	N/A	ND
Th-230	1.7E-04	9.5E-07	1.1E-09	3.8E-09	1.3E-06	7.0E-08	2.3E-07	5.2E-05	N/A	2.0E-06
U-234	2.9E-06	2.2E-08	2.5E-10	3.0E-09	1.4E-06	9.5E-08	1.1E-06	1.2E-06	N/A	2.2E-08
U-235	1.5E-06	1.2E-08	1.3E-10	1.6E-09	7.6E-07	5.1E-08	6.1E-07	6.6E-07	N/A	9.3E-05
U-238+2d	1.8E-05	1.3E-07	1.4E-09	1.7E-08	8.0E-06	5.3E-07	6.4E-06	6.9E-06	N/A	8.4E-05
Sum Radionuclides:	2E-04	1E-06	1E-08	4E-08	2E-05	1E-05	6E-05	6E-05	--	3E-04
Carcinogenic Chemicals										
beryllium	1.9E-08	1.4E-07	2.8E-08	1.0E-10	2.9E-06	2.8E-06	1.0E-08	6.7E-06	2.1E-04	N/A
cadmium	1.7E-07	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
aroclor-1254	ND	1.1E-07	3.3E-07	4.2E-07	6.3E-06	2.2E-05	2.7E-05	1.7E-06	2.2E-05	N/A
benzo(a)anthracene	3.1E-10	4.9E-09	2.7E-09	3.5E-09	1.7E-06	1.7E-06	2.2E-06	2.6E-07	ND	N/A
benzo(a)pyrene	9.1E-10	1.4E-08	1.9E-08	2.4E-08	3.0E-06	8.8E-06	1.1E-05	7.6E-07	ND	N/A
benzo(b)fluoranthene	1.6E-10	2.4E-09	1.2E-08	1.5E-08	2.3E-07	4.1E-06	5.2E-06	1.3E-07	ND	N/A
benzo(k)fluoranthene	5.2E-11	8.1E-10	8.4E-09	1.1E-08	5.4E-08	2.2E-06	2.8E-06	4.3E-08	ND	N/A
chrysene	ND	1.4E-10	7.8E-11	9.9E-11	4.5E-08	4.7E-08	5.9E-08	7.0E-09	ND	N/A
Sum Chemicals:	2E-07	3E-07	4E-07	5E-07	1E-05	4E-05	5E-05	1E-05	2E-04	

N/A - Not applicable. Chemical not a chemical of interest for medium or exposure pathway not applicable.
ND - No data for toxicity assessment for exposure pathway.

INCREMENTAL LIFETIME CANCER RISKS
ON-PROPERTY RESIDENT FARMER, ADULT
FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Groundwater						Total Risk
Exposure Pathways: / Contaminants of Concern	Ingestion of Drinking Water	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Inhalation of VOC's	Dermal Contact while Bathing	
Radionuclides							
Cs-137+1d	N/A	N/A	N/A	N/A	N/A	N/A	2E-04
Np-237+1d	4.5E-06	1.4E-06	5.0E-09	1.9E-09	N/A	N/A	7E-06
Pu-238	N/A	N/A	N/A	N/A	N/A	N/A	6E-08
Pu-239/240	N/A	N/A	N/A	N/A	N/A	N/A	6E-08
Sr-90+1d	6.9E-09	2.8E-09	1.0E-10	2.0E-09	N/A	N/A	6E-05
Th-230	N/A	N/A	N/A	N/A	N/A	N/A	2E-04
U-234	4.0E-05	1.2E-05	8.9E-08	1.1E-06	N/A	N/A	6E-05
U-235	9.3E-07	2.8E-07	2.1E-09	2.6E-08	N/A	N/A	1E-04
U-238+2d	3.3E-05	1.0E-05	7.4E-08	9.2E-07	N/A	N/A	2E-04
Sum Radionuclides:	8E-05	2E-05	2E-07	2E-06	–	–	
Carcinogenic Chemicals				TOTAL RADIOLOGICAL ILCR:			8E-04
beryllium	N/A	N/A	N/A	N/A	N/A	N/A	2E-04
cadmium	ND	ND	ND	ND	ND	ND	2E-07
aroclor-1254	1.5E-06	1.9E-06	1.9E-06	2.4E-06	ND	8.3E-05	2E-04
benzo(a)anthracene	N/A	N/A	N/A	N/A	N/A	N/A	6E-06
benzo(a)pyrene	N/A	N/A	N/A	N/A	N/A	N/A	2E-05
benzo(b)fluoranthene	N/A	N/A	N/A	N/A	N/A	N/A	1E-05
benzo(k)fluoranthene	N/A	N/A	N/A	N/A	N/A	N/A	5E-06
chrysene	N/A	N/A	N/A	N/A	N/A	N/A	2E-07
Sum Chemicals:	1E-06	2E-06	2E-06	2E-06	–	8E-05	
				TOTAL CHEMICAL ILCR:			4E-04

N/A - Not applicable. Chemical not a chemical of interest for medium or exposure pathway not applicable.
ND - No data for toxicity assessment for exposure pathway.

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HAZARD QUOTIENTS
ON-PROPERTY RESIDENT FARMER, ADULT
FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Air				Soil					
Exposure Pathways: / Toxicants	Inhalation	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Incidental Ingestion	Dermal Contact	External Exposure
antimony	ND	6.1E-03	1.7E-03	6.7E-04	1.5E+00	7.6E-01	3.0E-01	1.7E-01	3.7E-01	N/A
beryllium	ND	6.7E-06	1.3E-06	4.7E-09	1.4E-04	1.3E-04	4.7E-07	3.1E-04	9.9E-03	N/A
cadmium	ND	3.6E-03	4.9E-04	3.6E-03	8.3E-01	1.2E-01	8.9E-01	1.9E-02	1.2E-01	N/A
uranium	ND	2.8E-03	3.2E-05	3.8E-04	1.8E-01	1.2E-02	1.4E-01	1.6E-01	1.0E+00	N/A
Sums:	--	1E-02	2E-03	5E-03	3E+00	9E-01	1E+00	3E-01	1E+00	--

N/A - Not applicable. Chemical not a chemical of interest for medium or exposure pathway not applicable.
ND - No data for toxicity assessment for exposure pathway.

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HAZARD QUOTIENTS
ON-PROPERTY RESIDENT FARMER, ADULT
FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Groundwater						Total Risk
Exposure Pathways: / Contaminants of Concern	Ingestion of Drinking Water	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Inhalation of VOC's	Dermal Contact while Bathing	
Toxicants							
antimony	1.7E-01	1.2E-01	1.7E-02	6.8E-03	N/A	3.3E-03	3E+00
beryllium	N/A	N/A	N/A	N/A	N/A	N/A	1E-02
cadmium	2.6E-02	9.8E-02	6.7E-03	4.9E-02	N/A	1.5E-03	2E+00
uranium	6.7E-01	2.0E-01	1.5E-03	1.8E-02	N/A	3.8E-02	.2E+00
Sums:	9E-01	4E-01	3E-02	7E-02	--	4E-02	
						TOTAL HI:	8E+00

N/A - Not applicable. Chemical not a chemical of interest for medium or exposure pathway not applicable.
ND - No data for toxicity assessment for exposure pathway.

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INCREMENTAL LIFETIME CANCER RISKS

ON-PROPERTY RESIDENT CHILD

FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Air				Soil					
Exposure Pathways: / Contaminants of Concern	Inhalation	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Incidental Ingestion	Dermal Contact	External Exposure
Radionuclides										
Cs-137+1d	3.9E-12	3.8E-10	3.0E-10	2.5E-09	1.4E-07	2.8E-07	2.3E-06	2.1E-08	N/A	1.1E-05
Np-237+1d	1.7E-10	7.0E-11	1.8E-13	3.8E-13	1.0E-08	2.0E-10	4.3E-10	4.6E-09	N/A	6.7E-08
Pu-238	2.2E-10	6.5E-11	1.1E-15	4.9E-15	4.7E-11	1.7E-13	8.2E-13	4.6E-09	N/A	4.4E-12
Pu-239/240	2.2E-10	6.9E-11	2.4E-15	1.1E-14	4.9E-11	1.8E-13	8.6E-13	4.8E-09	N/A	4.2E-12
Sr-90+1d	6.4E-12	2.5E-10	6.6E-12	7.8E-10	7.7E-07	7.4E-08	8.7E-06	1.4E-08	N/A	ND
Th-230	3.0E-06	7.1E-08	3.8E-11	7.4E-10	9.5E-08	2.3E-09	4.5E-08	4.9E-06	N/A	1.5E-07
U-234	5.2E-08	1.7E-09	8.3E-12	5.8E-10	1.1E-07	3.2E-09	2.2E-07	1.2E-07	N/A	1.6E-09
U-235	2.7E-08	8.9E-10	4.4E-12	3.1E-10	5.7E-08	1.7E-09	1.2E-07	6.2E-08	N/A	7.0E-06
U-238+2d	3.3E-07	9.4E-09	4.6E-11	3.3E-09	6.0E-07	1.8E-08	1.2E-06	6.6E-07	N/A	6.3E-06
Sum Radionuclides:	3E-06	8E-08	4E-10	8E-09	2E-06	4E-07	1E-05	6E-06	--	2E-05
Carcinogenic Chemicals										
beryllium	1.6E-09	5.0E-08	4.3E-09	9.1E-11	1.0E-06	4.3E-07	9.1E-09	3.0E-06	3.0E-05	N/A
cadmium	1.4E-08	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
aroclor-1254	ND	4.0E-08	5.1E-08	3.8E-07	2.2E-06	3.4E-06	2.5E-05	7.6E-07	3.0E-06	N/A
benzo(a)anthracene	2.6E-11	1.7E-09	4.2E-10	3.1E-09	5.8E-07	2.6E-07	2.0E-06	1.1E-07	ND	N/A
benzo(a)pyrene	7.7E-11	4.9E-09	2.9E-09	2.2E-08	1.0E-06	1.4E-06	1.0E-05	3.4E-07	ND	N/A
benzo(b)fluoranthene	1.3E-11	8.3E-10	1.9E-09	1.4E-08	8.1E-08	6.3E-07	4.7E-06	5.8E-08	ND	N/A
benzo(k)fluoranthene	4.4E-12	2.8E-10	1.3E-09	9.6E-09	1.9E-08	3.5E-07	2.6E-06	1.9E-08	ND	N/A
chrysene	ND	4.7E-11	1.2E-11	9.0E-11	1.6E-08	7.2E-09	5.4E-08	3.1E-09	ND	N/A
Sum Chemicals:	2E-08	1E-07	6E-08	4E-07	5E-06	6E-06	4E-05	4E-06	3E-05	--

N/A - Not applicable. Chemical not a chemical of interest for medium or exposure pathway not applicable.

ND - No data for toxicity assessment for exposure pathway.

INCREMENTAL LIFETIME CANCER RISKS
ON-PROPERTY RESIDENT CHILD
FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Groundwater						Total Risk
Exposure Pathways: / Contaminants of Concern	Ingestion of Drinking Water	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Inhalation of VOC's	Dermal Contact while Bathing	
Radionuclides							
Cs-137+1d	N/A	N/A	N/A	N/A	N/A	N/A	1E-05
Np-237+1d	1.9E-07	1.1E-07	1.7E-10	3.6E-10	N/A	N/A	4E-07
Pu-238	N/A	N/A	N/A	N/A	N/A	N/A	5E-09
Pu-239/240	N/A	N/A	N/A	N/A	N/A	N/A	5E-09
Sr-90+1d	2.9E-10	2.1E-10	3.3E-12	3.9E-10	N/A	N/A	1E-05
Th-230	N/A	N/A	N/A	N/A	N/A	N/A	8E-06
U-234	1.7E-06	9.0E-07	2.9E-09	2.1E-07	N/A	N/A	3E-06
U-235	4.0E-08	2.1E-08	6.9E-11	5.0E-09	N/A	N/A	7E-06
U-238+2d	1.4E-06	7.5E-07	2.4E-09	1.8E-07	N/A	N/A	1E-05
Sum Radionuclides:	3E-06	2E-06	6E-09	4E-07	--	--	
				TOTAL RADIOLOGICAL ILCR:			5E-05
Carcinogenic Chemicals							
beryllium	N/A	N/A	N/A	N/A	N/A	N/A	3E-05
cadmium	ND	ND	ND	ND	ND	ND	1E-08
aroclor-1254	2.9E-07	6.7E-07	2.9E-07	2.1E-06	ND	1.2E-05	5E-05
benzo(a)anthracene	N/A	N/A	N/A	N/A	N/A	N/A	3E-06
benzo(a)pyrene	N/A	N/A	N/A	N/A	N/A	N/A	1E-05
benzo(b)fluoranthene	N/A	N/A	N/A	N/A	N/A	N/A	5E-06
benzo(k)fluoranthene	N/A	N/A	N/A	N/A	N/A	N/A	3E-06
chrysene	N/A	N/A	N/A	N/A	N/A	N/A	8E-08
Sum Chemicals:	3E-07	7E-07	3E-07	2E-06	--	1E-05	
				TOTAL CHEMICAL ILCR:			1E-04

N/A - Not applicable. Chemical not a chemical of interest for medium or exposure pathway not applicable.
ND - No data for toxicity assessment for exposure pathway.

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HAZARD QUOTIENTS
ON-PROPERTY RESIDENT CHILD
FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Air				Soil					
Exposure Pathways: / Contaminants of Concern	Inhalation	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Incidental Ingestion	Dermal Contact	External Exposure
Toxicants										
antimony	ND	2.5E-02	3.0E-03	7.1E-03	6.1E+00	1.4E+00	3.2E+00	8.9E-01	6.0E-01	ND
beryllium	ND	2.7E-05	2.3E-06	4.9E-08	5.5E-04	2.3E-04	4.9E-06	1.6E-03	1.6E-02	ND
cadmium	ND	1.5E-02	8.9E-04	3.8E-02	3.3E+00	2.2E-01	9.4E+00	9.8E-02	2.0E-01	ND
uranium	ND	1.2E-02	5.7E-05	4.0E-03	7.3E-01	2.2E-02	1.5E+00	8.1E-01	1.6E+00	ND
Sums:	–	5E-02	4E-03	5E-02	1E+01	2E+00	1E+01	2E+00	2E+00	–

N/A - Not applicable. Chemical not a chemical of interest for medium or exposure pathway not applicable.
ND - No data for toxicity assessment for exposure pathway.

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HAZARD QUOTIENTS
ON-PROPERTY RESIDENT CHILD
FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Groundwater						Total Risk
Exposure Pathways: / Contaminants of Concern	Ingestion of Drinking Water	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Inhalation of VOC's	Dermal Contact while Bathing	
Toxicants							
antimony	4.1E-01	4.7E-01	3.1E-02	7.2E-02	N/A	5.4E-03	1E+01
beryllium	N/A	N/A	N/A	N/A	N/A	N/A	2E-02
cadmium	6.0E-02	4.0E-01	1.2E-02	5.2E-01	N/A	2.4E-03	1E+01
uranium	1.6E+00	8.1E-01	2.7E-03	1.9E-01	N/A	6.2E-02	7E+00
Sums:	2E+00	2E+00	5E-02	8E-01	–	7E-02	
						TOTAL HI:	3E+01

N/A - Not applicable. Chemical not a chemical of interest for medium or exposure pathway not applicable.
ND - No data for toxicity assessment for exposure pathway.

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INCREMENTAL LIFETIME CANCER RISKS

OFF-PROPERTY RESIDENT FARMER, ADULT
FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Air				Groundwater						Total Risk
Exposure Pathways: / Contaminants of Concern	Inhalation	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Ingestion of Drinking Water	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Inhalation of VOC's	Dermal Contact while Bathing	
Radionuclides											
Cs-137+1d	2.2E-12	5.2E-11	9.2E-11	1.3E-10	N/A	N/A	N/A	N/A	N/A	N/A	3E-10
Np-237+1d	9.2E-11	9.5E-12	5.4E-14	1.9E-14	2.0E-07	6.4E-08	2.2E-10	8.2E-11	N/A	N/A	3E-07
Pu-238	1.2E-10	8.9E-12	3.2E-16	2.6E-16	N/A	N/A	N/A	N/A	N/A	N/A	1E-10
Pu-239/240	1.2E-10	9.3E-12	7.3E-16	5.8E-16	N/A	N/A	N/A	N/A	N/A	N/A	1E-10
Sr-90+1d	3.6E-12	3.3E-11	2.0E-12	4.0E-11	1.1E-12	4.5E-13	1.6E-14	3.3E-13	N/A	N/A	8E-11
Th-230	1.7E-06	9.6E-09	1.1E-11	3.8E-11	N/A	N/A	N/A	N/A	N/A	N/A	2E-06
U-234	2.9E-08	2.3E-10	2.5E-12	3.0E-11	1.9E-07	5.8E-08	4.3E-10	5.3E-09	N/A	N/A	3E-07
U-235	1.5E-08	1.2E-10	1.3E-12	1.6E-11	4.4E-08	1.3E-08	9.8E-11	1.2E-09	N/A	N/A	7E-08
U-238+2d	1.9E-07	1.3E-09	1.4E-11	1.7E-10	1.6E-06	4.8E-07	3.5E-09	4.4E-08	N/A	N/A	2E-06
Sum Radionuclides:	2E-06	1E-08	1E-10	4E-10	2E-06	6E-07	4E-09	5E-08	–	–	
								TOTAL RADIOLOGICAL ILCR:			5E-06
Carcinogenic Chemicals											
beryllium	1.9E-10	1.4E-09	2.8E-10	1.0E-12	N/A	N/A	N/A	N/A	N/A	N/A	2E-09
cadmium	1.7E-09	ND	ND	ND	ND	ND	ND	ND	ND	ND	2E-09
aroclor-1254	ND	1.1E-09	3.3E-09	4.2E-09	8.2E-09	1.1E-08	1.0E-08	1.3E-08	ND	4.6E-07	5E-07
benzo(a)anthracene	3.1E-12	4.9E-11	2.8E-11	3.5E-11	N/A	N/A	N/A	N/A	N/A	N/A	1E-10
benzo(a)pyrene	9.1E-12	1.4E-10	1.9E-10	2.4E-10	N/A	N/A	N/A	N/A	N/A	N/A	6E-10
benzo(b)fluoranthene	1.6E-12	2.4E-11	1.2E-10	1.6E-10	N/A	N/A	N/A	N/A	N/A	N/A	3E-10
benzo(k)fluoranthene	5.2E-13	8.1E-12	8.4E-11	1.1E-10	N/A	N/A	N/A	N/A	N/A	N/A	2E-10
chrysene	ND	1.4E-12	7.8E-13	9.9E-13	N/A	N/A	N/A	N/A	N/A	N/A	3E-12
Sum Chemicals:	2E-09	3E-09	4E-09	5E-09	8E-09	1E-08	1E-08	1E-08	–	5E-07	
								TOTAL CHEMICAL ILCR:			5E-07

N/A - Not applicable. Chemical not a chemical of interest for medium or exposure pathway not applicable..
ND - No data for toxicity assessment for exposure pathway.

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HAZARD QUOTIENTS

OFF-PROPERTY RESIDENT FARMER, ADULT
FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Air				Groundwater						Total Risk
Exposure Pathways: / Contaminants of Concern / Toxicants	Inhalation	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Ingestion of Drinking Water	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Inhalation of VOC's	Dermal Contact while Bathing	
antimony	ND	6.2E-05	1.7E-05	6.8E-06	1.9E-05	1.2E-05	1.8E-06	7.3E-07	N/A	3.6E-07	1E-04
beryllium	ND	6.7E-08	1.3E-08	4.7E-11	N/A	N/A	N/A	N/A	N/A	N/A	8E-08
cadmium	ND	3.6E-05	5.0E-06	3.6E-05	4.2E-04	1.6E-03	1.1E-04	8.0E-04	N/A	2.4E-05	3E-03
uranium	ND	2.9E-05	3.2E-07	3.8E-06	3.2E-02	9.6E-03	7.1E-05	8.8E-04	N/A	1.8E-03	4E-02
Sum:	–	1E-04	2E-05	5E-05	3E-02	1E-02	2E-04	2E-03	–	2E-03	
										TOTAL HI:	5E-02

N/A - Not applicable. Chemical not a chemical of interest for medium or exposure pathway not applicable..
ND - No data for toxicity assessment for exposure pathway.

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INCREMENTAL LIFETIME CANCER RISKS

OFF-PROPERTY RESIDENT CHILD

FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Air				Groundwater						Total Risk
Exposure Pathways: / Contaminants of Concern	Inhalation	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Ingestion of Drinking Water	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Inhalation of VOC's	Dermal Contact while Bathing	
Radionuclides											
Cs-137+1d	4.0E-14	3.9E-12	3.0E-12	2.5E-11	N/A	N/A	N/A	N/A	N/A	N/A	3E-11
Np-237+1d	1.7E-12	7.1E-13	1.8E-15	3.8E-15	8.5E-09	4.8E-09	7.3E-12	1.6E-11	N/A	N/A	1E-08
Pu-238	2.3E-12	6.6E-13	1.1E-17	5.0E-17	N/A	N/A	N/A	N/A	N/A	N/A	3E-12
Pu-239/240	2.2E-12	6.9E-13	2.4E-17	1.1E-16	N/A	N/A	N/A	N/A	N/A	N/A	3E-12
Sr-90+1d	6.4E-14	2.5E-12	6.7E-14	7.9E-12	4.8E-14	3.4E-14	5.4E-16	6.4E-14	N/A	N/A	1E-11
Th-230	3.0E-08	7.1E-10	3.8E-13	7.4E-12	N/A	N/A	N/A	N/A	N/A	N/A	3E-08
U-234	5.3E-10	1.7E-11	8.4E-14	5.9E-12	8.3E-09	4.3E-09	1.4E-11	1.0E-09	N/A	N/A	1E-08
U-235	2.7E-10	9.0E-12	4.4E-14	3.1E-12	1.9E-09	9.9E-10	3.3E-12	2.4E-10	N/A	N/A	3E-09
U-238+2d	3.4E-09	9.5E-11	4.7E-13	3.3E-11	6.8E-08	3.6E-08	1.2E-10	8.5E-09	N/A	N/A	1E-07
Sum Radionuclides:	3E-08	8E-10	4E-12	8E-11	9E-08	5E-08	1E-10	1E-08	–	–	
								TOTAL RADIOLOGICAL ILCR:			2E-07
Chemicals											
beryllium	1.6E-11	5.0E-10	4.3E-11	9.1E-13	N/A	N/A	N/A	N/A	N/A	N/A	6E-10
cadmium	1.4E-10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1E-10
aroclor-1254	ND	4.0E-10	5.2E-10	3.8E-09	1.6E-09	3.7E-09	1.6E-09	1.2E-08	N/A	6.4E-08	9E-08
benzo(a)anthracene	2.6E-13	1.7E-11	4.3E-12	3.2E-11	N/A	N/A	N/A	N/A	N/A	N/A	5E-11
benzo(a)pyrene	7.7E-13	4.9E-11	2.9E-11	2.2E-10	N/A	N/A	N/A	N/A	N/A	N/A	3E-10
benzo(b)fluoranthene	1.3E-13	8.3E-12	1.9E-11	1.4E-10	N/A	N/A	N/A	N/A	N/A	N/A	2E-10
benzo(k)fluoranthene	4.4E-14	2.8E-12	1.3E-11	9.7E-11	N/A	N/A	N/A	N/A	N/A	N/A	1E-10
chrysene	ND	4.8E-13	1.2E-13	9.0E-13	N/A	N/A	N/A	N/A	N/A	N/A	1E-12
Sum Chemicals:	2E-10	1E-09	6E-10	4E-09	2E-09	4E-09	2E-09	1E-08	–	6E-08	
								TOTAL CHEMICAL ILCR:			9E-08

N/A - Not applicable. Chemical not a chemical of interest for medium or exposure pathway not applicable.
ND - No data for toxicity assessment for exposure pathway.

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HAZARD QUOTIENTS

OFF-PROPERTY RESIDENT CHILD

FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Air				Groundwater						Total Risk
Exposure Pathways: / Contaminants of Concern / Toxicants	Inhalation	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Ingestion of Drinking Water	Ingestion of Vegetables and Fruits	Ingestion of Meat	Ingestion of Milk	Inhalation of VOC's	Dermal Contact while Bathing	
antimony	ND	2.5E-04	3.1E-05	7.2E-05	4.3E-05	5.0E-05	3.3E-06	7.7E-06	N/A	5.8E-07	5E-04
beryllium	ND	2.7E-07	2.4E-08	5.0E-10	N/A	N/A	N/A	N/A	N/A	N/A	3E-07
cadmium	ND	1.5E-04	9.0E-06	3.8E-04	9.8E-04	6.5E-03	2.0E-04	8.5E-03	N/A	3.9E-05	2E-02
uranium	ND	1.2E-04	5.8E-07	4.0E-05	7.5E-02	3.9E-02	1.3E-04	9.3E-03	N/A	3.0E-03	1E-01
Sum:	--	5E-04	4E-05	5E-04	8E-02	5E-02	3E-04	2E-02	--	3E-03	
										TOTAL HI:	1E-01

N/A - Not applicable. Chemical not a chemical of interest for medium or exposure pathway not applicable.
ND - No data for toxicity assessment for exposure pathway.

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INCREMENTAL LIFETIME CANCER RISKS

TRESPASSER, ADULT

FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Air	Soil			Total Risks
Exposure Pathways: / Contaminants of Concern	Inhalation	Incidental Ingestion	Dermal Contact	External Exposure	
Radionuclides					
Cs-137+1d	2.5E-13	8.1E-10	N/A	5.3E-07	5E-07
Np-237+1d	1.1E-11	1.8E-10	N/A	3.1E-09	3E-09
Pu-238	1.5E-11	1.8E-10	N/A	2.0E-13	2E-10
Pu-239/240	1.4E-11	1.8E-10	N/A	2.0E-13	2E-10
Sr-90+1d	4.1E-13	5.2E-10	N/A	ND	5E-10
Th-230	1.9E-07	1.9E-07	N/A	7.1E-09	4E-07
U-234	3.4E-09	4.5E-09	N/A	7.7E-11	8E-09
U-235	1.7E-09	2.4E-09	N/A	3.3E-07	3E-07
U-238+2d	2.2E-08	2.5E-08	N/A	2.9E-07	3E-07
Sum Radionuclides:	2E-07	2E-07	–	1E-06	
Carcinogenic Chemicals		TOTAL RADIOLOGICAL ILCR:			2E-06
beryllium	2.2E-11	2.4E-08	1.1E-05	N/A	1E-05
cadmium	2.0E-10	N/A	N/A	N/A	2E-10
aroclor-1254	ND	6.2E-09	1.1E-06	N/A	1E-06
benzo(a)anthracene	3.6E-13	9.3E-10	ND	N/A	9E-10
benzo(a)pyrene	1.1E-12	2.7E-09	ND	N/A	3E-09
benzo(b)fluoranthene	1.8E-13	4.7E-10	ND	N/A	5E-10
benzo(k)fluoranthene	6.1E-14	1.6E-10	ND	N/A	2E-10
chrysene	ND	2.5E-11	ND	N/A	3E-11
Sum Chemicals:	2E-10	3E-08	1E-05	–	
		TOTAL CHEMICAL ILCR:			1E-05

N/A - Not applicable. Chemical not a chemical of interest for medium or exposure pathway not applicable.
ND - No data for toxicity assessment for exposure pathway.

HAZARD QUOTIENTS

TRESPASSER, ADULT

FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Air	Soil			Total Risks
Exposure Pathways: Contaminants of Concern	Inhalation	Incidental Ingestion	Dermal Contact	External Exposure	
Toxicants					
antimony	ND	1.4E-03	4.2E-02	N/A	4E-02
beryllium	ND	2.5E-06	1.1E-03	N/A	1E-03
cadmium	ND	1.5E-04	1.4E-02	N/A	1E-02
uranium	ND	1.2E-03	1.1E-01	N/A	1E-01
Sum:	–	3E-03	2E-01	–	
				TOTAL HI:	2E-01

N/A - Not applicable. Chemical not a chemical of interest for medium or exposure pathway not applicable.
ND - No data for toxicity assessment for exposure pathway.

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INCREMENTAL LIFETIME CANCER RISKS - 5287

TRESPASSER, CHILD
FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Air	Soil			Total Risks
Exposure Pathways:		Incidental	Dermal	External	
Contaminants of Concern	Inhalation	Ingestion	Contact	Exposure	
Radionuclides					
Cs-137+1d	5.2E-13	8.3E-10	N/A	1.1E-06	1E-06
Np-237+1d	2.2E-11	1.8E-10	N/A	6.5E-09	7E-09
Pu-238	3.0E-11	1.8E-10	N/A	4.2E-13	2E-10
Pu-239/240	2.9E-11	1.9E-10	N/A	4.1E-13	2E-10
Sr-90+1d	8.6E-13	5.3E-10	N/A	ND	5E-10
Th-230	4.0E-07	1.9E-07	N/A	1.5E-08	6E-07
U-234	7.0E-09	4.6E-09	N/A	1.6E-10	1E-08
U-235	3.6E-09	2.5E-09	N/A	6.7E-07	7E-07
U-238+2d	4.5E-08	2.6E-08	N/A	6.1E-07	7E-07
Sum Radionuclides:	5E-07	2E-07	–	2E-06	
Carcinogenic Chemicals		TOTAL RADIOLOGICAL ILCR:			3E-06
beryllium	7.4E-11	4.1E-08	1.4E-05	N/A	1E-05
cadmium	6.6E-10	N/A	N/A	N/A	7E-10
aroclor-1254	ND	1.0E-08	1.4E-06	N/A	1E-06
benzo(a)anthracene	1.2E-12	1.6E-09	ND	N/A	2E-09
benzo(a)pyrene	3.6E-12	4.6E-09	ND	N/A	5E-09
benzo(b)fluoranthene	6.2E-13	7.9E-10	ND	N/A	8E-10
benzo(k)fluoranthene	2.1E-13	2.6E-10	ND	N/A	3E-10
chrysene	ND	4.2E-11	ND	N/A	4E-11
Sum Chemicals:	7E-10	6E-08	2E-05	–	
		TOTAL CHEMICAL ILCR:			2E-05

N/A - Not applicable. Chemical not a chemical of interest for medium or exposure pathway not applicable.

ND - No data for toxicity assessment for exposure pathway.

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RESIDUAL RISK SUMMARY

ALTERNATIVES 5A/5B

Future Land Use, Government Facility

Receptor:	Expanded Trespasser			Off-Property Farmer			Off-Property Child		
Source Medium: COC	Soil	Ground-water	Total	Soil	Ground-water	Total	Soil	Ground-water	Total
ILCR									
Radionuclides									
Cs-137 + 1 progeny	2E-06	–	2E-06	3E-10	–	3E-10	3E-11	–	3E-11
Np-237 + 1 progeny	1E-08	–	1E-08	1E-10	3E-07	3E-07	2E-12	1E-08	1E-08
Pu-238	4E-10	–	4E-10	1E-10	–	1E-10	3E-12	–	3E-12
Pu-239/240	4E-10	–	4E-10	1E-10	–	1E-10	3E-12	–	3E-12
Sr-90 + 1 progeny	1E-09	–	1E-09	8E-11	2E-12	8E-11	1E-11	2E-13	1E-11
Th-230	1E-06	–	1E-06	2E-06	–	2E-06	3E-08	–	3E-08
U-234	2E-08	–	2E-08	3E-08	3E-07	3E-07	6E-10	1E-08	1E-08
U-235	1E-06	–	1E-06	2E-08	6E-08	7E-08	3E-10	3E-09	3E-09
U-238 + 2 progeny	1E-06	–	1E-06	2E-07	2E-06	2E-06	4E-09	1E-07	1E-07
TOTALS:	5E-06	–	5E-06	2E-06	3E-06	5E-06	4E-08	1E-07	2E-07
Carcinogenic Chemicals									
Aroclor-1254	3E-06	–	3E-06	9E-09	5E-07	5E-07	5E-09	8E-08	9E-08
Benzo(a)anthracene	2E-09	–	2E-09	1E-10	–	1E-10	5E-11	–	5E-11
Benzo(a)pyrene	7E-09	–	7E-09	6E-10	–	6E-10	3E-10	–	3E-10
Benzo(b)fluoranthene	1E-09	–	1E-09	3E-10	–	3E-10	2E-10	–	2E-10
Benzo(k)fluoranthene	4E-10	–	4E-10	2E-10	–	2E-10	1E-10	–	1E-10
Beryllium	2E-05	–	2E-05	2E-09	–	2E-09	6E-10	–	6E-10
Cadmium	9E-10	–	9E-10	2E-09	–	2E-09	1E-10	–	1E-10
Chrysene	–	–	–	3E-12	–	3E-12	2E-12	–	2E-12
TOTALS:	2E-05	–	2E-05	1E-08	5E-07	5E-07	6E-09	8E-08	9E-08
HI									
Toxicants									
Antimony	2E-01	–	2E-01	9E-05	3E-05	1E-04	4E-04	1E-04	5E-04
Beryllium	5E-03	–	5E-03	8E-08	–	8E-08	3E-07	–	3E-07
Cadmium	6E-02	–	6E-02	8E-05	3E-03	3E-03	5E-04	2E-02	2E-02
Uranium	5E-01	–	5E-01	3E-05	4E-02	4E-02	2E-04	1E-01	1E-01
TOTALS:	7E-01	–	7E-01	2E-04	5E-02	5E-02	1E-03	1E-01	1E-01

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HAZARD QUOTIENTS

TRESPASSER, CHILD

FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Air	Soil			Total Risks
Exposure Pathways: / Contaminants of Concern	Inhalation	Incidental Ingestion	Dermal Contact	External Exposure	
Toxicants					
antimony	ND	6.1E-03	1.4E-01	N/A	1E-01
beryllium	ND	1.1E-05	3.7E-03	N/A	4E-03
cadmium	ND	6.7E-04	4.5E-02	N/A	5E-02
uranium	ND	5.5E-03	3.7E-01	N/A	4E-01
Sum:	–	1E-02	6E-01	–	
				TOTAL HI:	6E-01

N/A - Not applicable. Chemical not a chemical of interest for medium or exposure pathway not applicable.
ND - No data for toxicity assessment for exposure pathway.

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RESIDUAL RISK SUMMARY

ALTERNATIVES 5A/5B

Future Land Use, Private

Receptor:	On-Property Farmer			On-Property Child			Off-Property Farmer & Child		
Source Medium: / COC	Soil	Ground-water	Total	Soil	Ground-water	Total	Soil	Ground-water	Total
ILCR									
Radionuclides									
Cs-137 + 1 progeny	2E-04	–	2E-04	1E-05	–	1E-05	*	*	*
Np-237 + 1 progeny	1E-06	6E-06	7E-06	8E-08	3E-07	4E-07	*	*	*
Pu-238	6E-08	–	6E-08	5E-09	–	5E-09	*	*	*
Pu-239/240	6E-08	–	6E-08	5E-09	–	5E-09	*	*	*
Sr-90 + 1 progeny	6E-05	1E-08	6E-05	1E-05	9E-10	1E-05	*	*	*
Th-230	2E-04	–	2E-04	8E-06	–	8E-06	*	*	*
U-234	7E-06	5E-05	6E-05	5E-07	3E-06	3E-06	*	*	*
U-235	1E-04	1E-06	1E-04	7E-06	7E-08	7E-06	*	*	*
U-238 + 2 progeny	1E-04	4E-05	2E-04	9E-06	2E-06	1E-05	*	*	*
TOTALS:	7E-04	1E-04	8E-04	5E-05	6E-06	5E-05	*	*	*
Carcinogenic Chemicals									
Aroclor-1254	8E-05	9E-05	2E-04	4E-05	2E-05	5E-05	*	*	*
Benzo(a)anthracene	6E-06	–	6E-06	3E-06	–	3E-06	*	*	*
Benzo(a)pyrene	2E-05	–	2E-05	1E-05	–	1E-05	*	*	*
Benzo(b)fluoranthene	1E-05	–	1E-05	5E-06	–	5E-06	*	*	*
Benzo(k)fluoranthene	5E-06	–	5E-06	3E-06	–	3E-06	*	*	*
Beryllium	2E-04	–	2E-04	3E-05	–	3E-05	*	*	*
Cadmium	2E-07	–	2E-07	1E-08	–	1E-08	*	*	*
Chrysene	2E-07	–	2E-07	8E-08	–	8E-08	*	*	*
TOTALS:	4E-04	9E-05	4E-04	9E-05	2E-05	1E-04	*	*	*
HI									
Toxicants									
Antimony	3E+00	3E-01	3E+00	1E+01	1E+00	1E+01	*	*	*
Beryllium	1E-02	–	1E-02	2E-02	–	2E-02	*	*	*
Cadmium	2E+00	2E-01	2E+00	1E+01	1E+00	1E+01	*	*	*
Uranium	2E+00	9E-01	2E+00	5E+00	3E+00	7E+00	*	*	*
TOTALS:	7E+00	1E+00	8E+00	3E+01	5E+00	3E+01	*	*	*

* Off-property farmer and child risks are equal to those for future land use as a government facility.

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ILCR AND HI

TRESPASSER, CHILD

FUTURE LAND USE, FUTURE SOURCE TERM

ILCR AND HI

TRESPASSER, ADULT

FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Air	Soil			Air	Soil			Child + Adult Total Risks		
Exposure Pathways: / Contaminants of Concern	Inhalation	Incidental Ingestion	Dermal Contact	External Exposure	Inhalation	Incidental Ingestion	Dermal Contact	External Exposure	Air	Soil	Total
Radionuclides - ILCRs										ILCR	
Cs-137 + 1d	5.2E-13	8.3E-10	N/A	1.1E-06	2.5E-13	8.1E-10	N/A	5.3E-07	7.8E-13	1.6E-06	2E-06
Np-237 + 1d	2.2E-11	1.8E-10	N/A	6.5E-09	1.1E-11	1.8E-10	N/A	3.1E-09	3.3E-11	1.0E-08	1E-08
Pu-238	3.0E-11	1.8E-10	N/A	4.2E-13	1.5E-11	1.8E-10	N/A	2.0E-13	4.4E-11	3.6E-10	4E-10
Pu-239/240	2.9E-11	1.9E-10	N/A	4.1E-13	1.4E-11	1.8E-10	N/A	2.0E-13	4.3E-11	3.7E-10	4E-10
Sr-90 + 1d	8.6E-13	5.3E-10	N/A	ND	4.1E-13	5.2E-10	N/A	ND	1.3E-12	1.1E-09	1E-09
Th-230	4.0E-07	1.9E-07	N/A	1.5E-08	1.9E-07	1.9E-07	N/A	7.1E-09	6.0E-07	4.0E-07	1E-06
U-234	7.0E-09	4.6E-09	N/A	1.6E-10	3.4E-09	4.5E-09	N/A	7.7E-11	1.0E-08	9.3E-09	2E-08
U-235	3.6E-09	2.5E-09	N/A	6.7E-07	1.7E-09	2.4E-09	N/A	3.3E-07	5.3E-09	1.0E-06	1E-06
U-238 + 2d	4.5E-08	2.6E-08	N/A	6.1E-07	2.2E-08	2.5E-08	N/A	2.9E-07	6.6E-08	9.5E-07	1E-06
Carcinogenic Chemicals - ILCRs										ILCR	
beryllium	7.4E-11	4.1E-08	1.4E-05	N/A	2.2E-11	2.4E-08	1.1E-05	N/A	9.6E-11	2.5E-05	2E-05
cadmium	6.6E-10	N/A	N/A	N/A	2.0E-10	N/A	N/A	N/A	8.5E-10	0.0E+00	9E-10
aroclor-1254	ND	1.0E-08	1.4E-06	N/A	ND	6.2E-09	1.1E-06	N/A	0.0E+00	2.6E-06	3E-06
benzo(a)anthracene	1.2E-12	1.6E-09	ND	N/A	3.6E-13	9.3E-10	ND	N/A	1.6E-12	2.5E-09	2E-09
benzo(a)pyrene	3.6E-12	4.6E-09	ND	N/A	1.1E-12	2.7E-09	ND	N/A	4.6E-12	7.3E-09	7E-09
benzo(b)fluoranthene	6.2E-13	7.9E-10	ND	N/A	1.8E-13	4.7E-10	ND	N/A	8.0E-13	1.3E-09	1E-09
benzo(k)fluoranthene	2.1E-13	2.6E-10	ND	N/A	6.1E-14	1.6E-10	ND	N/A	2.7E-13	4.2E-10	4E-10
chrysene	ND	4.2E-11	ND	N/A	ND	2.5E-11	ND	N/A	0.0E+00	6.8E-11	7E-11
Toxicants - HQs										HQ	
antimony	ND	6.1E-03	1.4E-01	N/A	ND	1.4E-03	4.2E-02	N/A	0.0E+00	1.9E-01	2E-01
beryllium	ND	1.1E-05	3.7E-03	N/A	ND	2.5E-06	1.1E-03	N/A	0.0E+00	4.9E-03	5E-03
cadmium	ND	6.7E-04	4.5E-02	N/A	ND	1.5E-04	1.4E-02	N/A	0.0E+00	6.0E-02	6E-02
uranium	ND	5.5E-03	3.7E-01	N/A	ND	1.2E-03	1.1E-01	N/A	0.0E+00	4.9E-01	5E-01

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ILCR AND HI

TRESPASSER, CHILD

FUTURE LAND USE, FUTURE SOURCE TERM

ILCR AND HI

TRESPASSER, ADULT

FUTURE LAND USE, FUTURE SOURCE TERM

Transfer Media:	Air	Soil			Air	Soil			Child + Adult Total Risks		
Exposure Pathways: / Contaminants of Concern	Inhalation	Incidental Ingestion	Dermal Contact	External Exposure	Inhalation	Incidental Ingestion	Dermal Contact	External Exposure	Air	Soil	Total
Radionuclides - ILCRs									ILCR		
Cs-137 + 1d	5.2E-13	8.3E-10	N/A	1.1E-06	2.5E-13	8.1E-10	N/A	5.3E-07	7.8E-13	1.6E-06	2E-06
Np-237 + 1d	2.2E-11	1.8E-10	N/A	6.5E-09	1.1E-11	1.8E-10	N/A	3.1E-09	3.3E-11	1.0E-08	1E-08
Pu-238	3.0E-11	1.8E-10	N/A	4.2E-13	1.5E-11	1.8E-10	N/A	2.0E-13	4.4E-11	3.6E-10	4E-10
Pu-239/240	2.9E-11	1.9E-10	N/A	4.1E-13	1.4E-11	1.8E-10	N/A	2.0E-13	4.3E-11	3.7E-10	4E-10
Sr-90 + 1d	8.6E-13	5.3E-10	N/A	ND	4.1E-13	5.2E-10	N/A	ND	1.3E-12	1.1E-09	1E-09
Th-230	4.0E-07	1.9E-07	N/A	1.5E-08	1.9E-07	1.9E-07	N/A	7.1E-09	6.0E-07	4.0E-07	1E-06
U-234	7.0E-09	4.6E-09	N/A	1.6E-10	3.4E-09	4.5E-09	N/A	7.7E-11	1.0E-08	9.3E-09	2E-08
U-235	3.6E-09	2.5E-09	N/A	6.7E-07	1.7E-09	2.4E-09	N/A	3.3E-07	5.3E-09	1.0E-06	1E-06
U-238 + 2d	4.5E-08	2.6E-08	N/A	6.1E-07	2.2E-08	2.5E-08	N/A	2.9E-07	6.6E-08	9.5E-07	1E-06
Carcinogenic Chemicals - ILCRs									ILCR		
beryllium	7.4E-11	4.1E-08	1.4E-05	N/A	2.2E-11	2.4E-08	1.1E-05	N/A	9.6E-11	2.5E-05	2E-05
cadmium	6.6E-10	N/A	N/A	N/A	2.0E-10	N/A	N/A	N/A	8.5E-10	0.0E+00	9E-10
aroclor-1254	ND	1.0E-08	1.4E-06	N/A	ND	6.2E-09	1.1E-06	N/A	0.0E+00	2.6E-06	3E-06
benzo(a)anthracene	1.2E-12	1.6E-09	ND	N/A	3.6E-13	9.3E-10	ND	N/A	1.6E-12	2.5E-09	2E-09
benzo(a)pyrene	3.6E-12	4.6E-09	ND	N/A	1.1E-12	2.7E-09	ND	N/A	4.6E-12	7.3E-09	7E-09
benzo(b)fluoranthene	6.2E-13	7.9E-10	ND	N/A	1.8E-13	4.7E-10	ND	N/A	8.0E-13	1.3E-09	1E-09
benzo(k)fluoranthene	2.1E-13	2.6E-10	ND	N/A	6.1E-14	1.6E-10	ND	N/A	2.7E-13	4.2E-10	4E-10
chrysene	ND	4.2E-11	ND	N/A	ND	2.5E-11	ND	N/A	0.0E+00	6.8E-11	7E-11
Toxicants - HQs									HQ		
antimony	ND	6.1E-03	1.4E-01	N/A	ND	1.4E-03	4.2E-02	N/A	0.0E+00	1.9E-01	2E-01
beryllium	ND	1.1E-05	3.7E-03	N/A	ND	2.5E-06	1.1E-03	N/A	0.0E+00	4.9E-03	5E-03
cadmium	ND	6.7E-04	4.5E-02	N/A	ND	1.5E-04	1.4E-02	N/A	0.0E+00	6.0E-02	6E-02
uranium	ND	5.5E-03	3.7E-01	N/A	ND	1.2E-03	1.1E-01	N/A	0.0E+00	4.9E-01	5E-01

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