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PROJECT 1-246-02-539-05
TASK 5 - REPORT

ENGINEERING ALTERNATIVES FOR REMEDIATING CERCLA SITES

August 26, 1987

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ENGINEERING ALTERNATIVES FOR REMEDIATING CERCLA SITES

1.0 DEFINING ENGINEERING ALTERNATIVES FOR REMEDIATING CERCLA SITES

1.1 Purpose and Objective

The purpose of this task is to evaluate the available remedial action technologies that have been applied to the cleanup of radioactive and hazardous wastes and to select a number of technologies that are most applicable to the problems associated with the 81 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites at Hanford. This selection will enable a comparison of the technical feasibility and unit costs of these technologies to evaluate their applicability to the sites at Hanford. The objective is to identify at least two remedial action alternatives (one a removal alternative, and one an in-place alternative) for each site that, based on the data available, have a high probability for application to the site problem.

2.0 METHODOLOGY OF THE REMEDIAL ACTION SELECTION PROCESS

The actual selection of a remedial action will be made as a part of The Remedial Investigation/Feasibility Study performed for the site. In this effort, it is necessary to identify reasonable alternatives to allow the estimation of the cost and schedule for remediation of each site.

Selection of appropriate remedial actions for the 81 sites is dependent upon the following information:

- o Physical site conditions
- o Volume and types of wastes disposed
- o Fate and transport mechanisms for the wastes
- o Previous applications (and scale) of the remedial technology
- o Technical feasibility of the technology for the waste type and site conditions in terms of effectiveness, reliability, and state of development
- o Applicable environmental regulations
- o Cost

The basic sequence for selecting the most applicable remedial technologies is illustrated in Figure 2-1. The first two tasks, done simultaneously, are the definition of the area, volume, form, and matrix of contaminated materials at each site and the identification of a list of potential remedial technologies.

2.1 <u>Site Conditions and Waste Disposed</u>

Definition of the problem at each site included summarizing the following information:

- o Type of disposal unit
- o Proximal location
- o Radionuclides disposed and their solubility
- o Other wastes disposed, including salts
- o Depth of wastes
- o Depth to groundwater

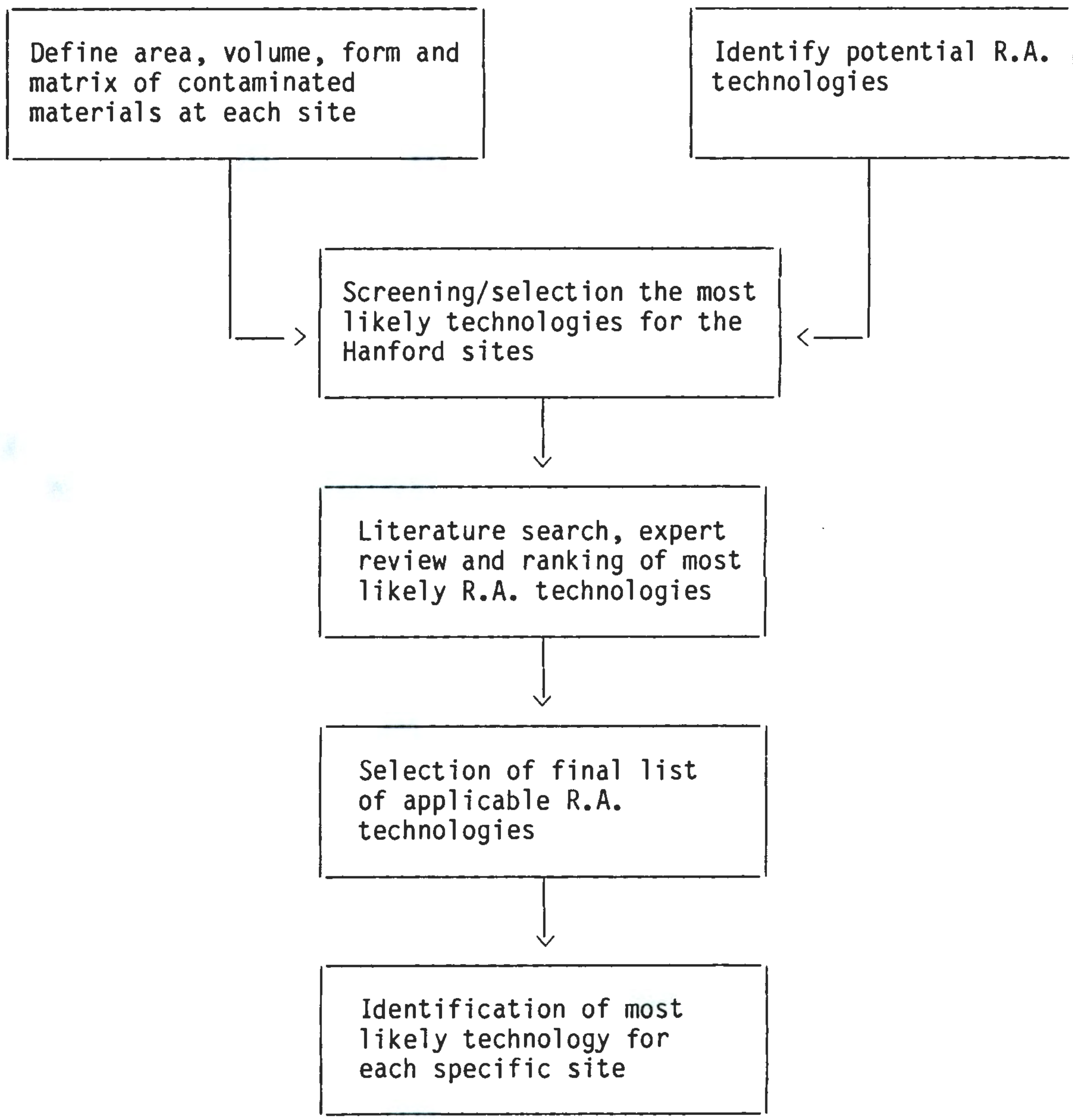

FIGURE 2-1. R.A. TECHNOLOGY SELECTION SEQUENCE

- o Volume of liquid wastes disposed
- o Calculated field capacity for the soil column

This information is presented in Columns 1-15 of Table 2-1.

2.2 Pathways and Fate of Pollutants

Since selection of remedial technologies is primarily dependent on knowing how much contaminated material there is, and where it is, calculations or assumptions on the following pathways or fates were made for each site.

- o Soil attenuation - This is used to determine the probable fate of heavy metals and nonsoluble radionuclides. It is assumed that unless very high rates of water were applied to the site or acid solutions were disposed of at the site, most of these elements would adsorb to soil particles within a 20-foot depth below the point of application.

- o Downward migration - It has been assumed that the more soluble radionuclides such as tritium or cesium and salts such as nitrates or sulfates would have migrated through the soil column to groundwater in the time period since the sites were closed. It should be noted, however, that some active sites releasing these elements to the soil column may be near CERCLA sites.

- o Radionuclide uptake - An analysis was made of the potential for plant root uptake at each site. Maximum root penetration was assumed to be 40 feet.

- o Groundwater release - If the field capacity (FC) of the soil column is exceeded by the volume of waste disposed, groundwater contamination has been assumed. In addition, if the FC/volume ratio was less than ten, or more than ten million liters of water were applied, or the contaminate types were highly migratory, a high potential for discharge to groundwater was assumed. Note that no evaporation losses were considered.

KEY TO TABLE 2-1

POTENTIAL REMEDIAL ACTION ALTERNATIVES - CERCLA SITES

Column No.	Title	Explanation
1	Site number	Site ID number from Phase II report
2	Type	Type of disposal unit
3	Proximal location	0 - site is within 500' of another site 1 - continuous sites
4	HRS score	Not m HRS score
5	Total curies disposed	
6	Total of H, C, Ru, Eu	Total disposed curies of H-3, C-14, Ru-106, Eu-154, Eu-155
7	Total of Cs, Sr	Total disposed curies of cesium and strontium
8	Total of all else	Total disposed curies of all other radionuclides
9	Other waste disposed	See index at bottom of table
10	Depth to waste	Depth to point of application
11	Depth to groundwater	
12	Volume disposed	
13-15	Field capacity	These 3 columns are an estimate of the potential for the liquids disposed at each site to be either still in the soil column (0) or have probably entered the groundwater (X). Three different field capacities (FC = 0.05, 0.1 and 0.25) were used to cover the expected porosity ranges in the Hanford soils.

KEY TO TABLE 2-1 (Continued)

POTENTIAL REMEDIAL ACTION ALTERNATIVES - CERCLA SITES

Column No.	Title	Explanation
16	Soil attenuation	X - highly likely that significant amounts of radionuclides are adsorbed in soil column at less than 20′ depth O - highly likely that other metals (Hg, Cr, etc.) are stored in shallow depth of soil column
17	Downward migration	X - soluble radionuclides in excess of 1.0 curie applied to site O - less than 1.0 curie of soluble radionuclides applied to site
18	Radionuclide uptake	X - more than 1.0 curie of radionuclides stored in top 20′ of soil O - potentially either less than 1.0 curie in top 20′ of soil or more than 1.0 curie in the soil but at depths between 20′ and 40′ deep
19	Groundwater release	X - groundwater contamination highly likely because FC/WV is less than 1.0 O - potential groundwater contamination due to readily soluble contaminants, high volumes (more than 10 million liters) of disposed liquids or FC/WV less than 10
20	Surface erosion	O - waste is less than 10′ below the surface thus potentially subject to erosion
21-26	Potentially feasible remedial action	X - feasible for that site

TABLE 2-1 Potential Remedial Action Alternatives - CERCLA Sites

Hanford Inactive Waste Site Study.

	Site No.	Type	Proximal Location (<500')	HRS Score	Total Curies Disposed (1)	Total of H,C,Ru,Eu	Total of Cs,Sr	Total of All Else	Other Wastes Disposed (2)	Depth to Waste Feet	Depth to GW Feet	Volume Disposed (liters)	Field Capacity (FC=0.05)	Field Capacity (FC=0.1)	Field Capacity (FC=0.25)
1	116-B-1	Trench	o	42.32	1.95	1.45	0.38	0.13	1	20	41	6,000,000	x	x	x
2	116-B-4	Fr. Drain		44.55	4.33	0.00	0.00	4.33	1,2	20	71	300,000	o		
3	116-C-1	Trench	o	42.32	329.58	213.96	7.46	108.17	1	25	41	100,000,000	x	x	x
4	116-C-2	Crib		42.32	1.33	0.33	0.98	0.01	1,2	20	94	3,500,000	x	o	
5	116-D-1B	Trench		42.32	1.48	0.73	0.68	0.08	1,3	15	83	8,000,000	x	x	x
6	116-DR-1	Trench	I	42.32	21.57	6.92	13.51	1.14	1	20	56	40,000,000	x	x	x
7	116-DR-2	Trench		42.32	21.57	6.92	13.51	1.14	1	20	56	40,000,000	x	x	x
8	116-DR-6	Trench	o	42.32	0.00	0.00	0.00	0.00	1	10	83	7,000,000	x	x	x
9	116-DR-7	Crib	o	28.96	0.00	0.00	0.00	0.00	4	10	73	4,000			
10	116-F-1	Trench		44.55	2.17	0.96	0.96	0.25	1,2	10	13	1,000,000,000	x	x	x
11	116-F-2	Trench		42.32	9.77	8.12	0.83	0.82	1	15	35	60,000,000	x	x	x
12	116-F-3	Trench	o	42.32	0.00	0.00	0.00	0.00	1	8	37	4,000,000	x	x	x
13	116-F-6	Trench	o	28.96	3.94	2.87	0.72	0.35	3	10	36	100,000			
14	116-F-9	Trench		42.32	2.84	0.59	2.05	0.19	5	10	50	300,000,000	x	x	x
15	116-F-10	Fr. Drain	o	42.32	0.07	0.05	0.01	0.01	1,2	10	38	400,000	x	x	x
16	116-H-1	Trench		42.32	20.12	14.42	4.56	1.14	1	15	42	90,000,000	x	x	x
17	116-H-2	Trench	o	42.32	1.04	0.28	0.75	0.02	1	6	42	600,000,000	x	x	x
18	116-H-3	Fr. Drain	o	42.32	0.05	0.01	0.03	0.01	1,2	15	42	400,000	x	x	x
19	100 KE*1	Drywell	-	42.32	0.00	0.00	0.00	0.00	6	4	68	0			
20	100 KE*2	Fr. Drain	-	42.32	0.00	0.00	0.00	0.00	6	3	68	0			
21	100 KW*1	Drywell	-	40.09	0.00	0.00	0.00	0.00	6	4	72	0			
22	100 KW*2	Fr. Drain	-	40.09	0.00	0.00	0.00	0.00	6	3	72	0			
23	116-K-1	Crib	o	42.32	30.56	8.79	18.79	2.98	1	30	50	40,000,000	x	x	x
24	116-K-2	Trench	o	51.23	1320.59	961.34	158.75	200.50	1,2,3,7	20	34	300,000,000,000	x	x	x
25	116-KE-2	Crib		35.64	14.65	0.74	2.79	11.12	3	32	68	3,000,000	x	x	x

TABLE 2-1 Potential Remedial Action Alternatives - CERCLA Sites (continued)

Hanford Inactive Waste Site Study.

		FATE OF CONTAMINANTS					POTENTIALLY FEASIBLE REMEDIAL ACTIONS					
	Site No.	Soil Attenuation	Downward Migration	Vegatation Uptake of Radionuclides	Ground-Water Release	Surface Errosion	Cap/Cover w/ PC Monitoring	Grout-in-Place w/ PC Monitoring	In-Situ Vitrification	Solution Mining & GW Recovery/ Treatment	Excavation & Disposal	No Action
1	116-B-1	o	x	o	x		x			x		
2	116-B-4	x		o	o			x	x		x	
3	116-C-1	x	x	o	x			x	x	x	x	
4	116-C-2	o	x		o		x				x	x
5	116-D-1B	o	o	o	x		x				x	
6	116-DR-1	x	x	o	x			x		x		
7	116-DR-2	x	x	o	x			x		x		
8	116-DR-6	o			x		x				x	x
9	116-DR-7	o					x				x	x
10	116-F-1	o	x	x	x		x	x		x		
11	116-F-2	o	x	x	x				x	x		
12	116-F-3	o			x	o	x					x
13	116-F-6	o	x	x				x	x		x	
14	116-F-9	o	x	o	x			x		x		
15	116-F-10	o	o	o	x		x				x	x
16	116-H-1	x	x	x	x			x	x	x		
17	116-H-2	o	o	o	x	o	x			x		x
18	116-H-3	o	o	o	x		x				x	x
19	100 KE*1	x				o	x				x	
20	100 KE*2	x				o	x				x	
21	100 KW*1	x				o	x				x	
22	100 KW*2	x				o	x				x	
23	116-K-1	x	x	o	x				x	x		
24	116-K-2	x	x	o	x			x		x	x	
25	116-KE-2	x	x	o	x		x	x	x		x	

TABLE 2-1 Potential Remedial Action Alternatives - CERCLA Sites (continued)

Hanford Inactive Waste Site Study.

	Site No.	Type	Proximal Location (<500')	HRS Score	Total Curies Disposed (1)	Total of H,C,Ru,Eu	Total of Cs,Sr	Total of All Else	Other Wastes Disposed (2)	Depth to Waste Feet	Depth to GW Feet	Volume Disposed (liters)	Field Capacity (FC=0.05)	Field Capacity (FC=0.1)	Field Capacity (FC=0.25)
26	216-B-43	Crib		48.67	942.06	170.00	772.00	0.06	2,3,9,10	15	228	2,120,000			
27	216-B-44	Crib		50.42	2097.17	450.00	1646.00	1.17	2,3,9,10	15	222	5,600,000			
28	216-B-45	Crib		52.20	2407.82	390.00	2017.00	0.82	2,3,9,10	15	220	4,920,000			
29	216-B-46	Crib		52.20	1326.50	536.00	788.90	1.60	2,3,9,10	15	219	6,700,000			
30	216-B-48	Crib		52.20	1145.38	327.00	818.00	0.38	2,3,9,10	15	225	4,090,000			
31	216-B-49	Crib		52.20	1975.28	536.00	1438.00	1.28	2,3,9,10	15	223	6,700,000			
32	216-B-50	Crib		43.70	149.57	90.00	59.52	0.05	3	15	223	54,800,000	x	x	o
33	216-B-5	Rec. Well		61.54	369.40	0.00	59.70	309.70	3,8,9,11	302	283	30,600,000	x	x	x
34	216-B-2-2	Ditch		30.67	235.49	0.00	235.49	0.00		8	255	149,000,000,000	x	x	x
35	216-B-6	Rec. Well	o	50.34	0.00	0.00	0.00	0.00	1,3,8	75	296	6,000,000			
36	216-B-7 A&B	Crib		65.44	2764.07	0.00	2451.80	312.27	3,8,9,11	14	241	43,600,000	x	x	o
37	216-B-10A	Crib	o	47.82	3.22	0.00	2.51	0.72	1,3,8	20	300	9,990,000			
38	216-B-16	Crib		52.20	1104.94	450.00	654.00	0.94	3,8,9,10	12	338	5,600,000			
39	216-C-1	Crib	o	39.33	164.53	70.00	93.85	0.68	8	13	282	23,400,000	x	o	
40	216-C-10	Crib	o	33.29	37.92	0.00	37.89	0.02	8	7	286	897,000			
41	216-A-9	Crib	o	42.79	4017.21	4000.00	17.17	0.04	8	12	294	981,000,000	x	x	x
42	216-A-40	Trench	o	32.72	0.00	0.00	0.00	0.00	8	16	284	946,000			
43	216-A-4	Crib	o	47.82	22.68	0.00	12.37	10.31		25	305	6,210,000			
44	216-A-5	Crib	o	50.42	130066.92	130000.00	58.80	8.12		32	313	1,630,000,000	x	x	x
45	216-A-6	Crib		42.14	166.21	0.00	163.40	2.81		19	290	3,400,000,000	x	x	x
46	216-A-7	Crib		42.79	3.07	0.00	2.99	0.08		15	274	326,000			
47	216-A-21	Crib	o	57.89	105.25	0.00	93.84	11.41		19	310	77,800,000	x	x	o
48	216-A-24	Crib		48.67	1712.51	1400.00	312.10	0.41		15	242	820,000,000	x	x	x
49	216-A-27	Crib	o	59.63	69.52	0.00	62.20	7.32		14	308	23,100,000	o		
50	216-A-28	Fr. Drain		32.72	0.21	0.00	0.00	0.21		11	298	30,000			
51	216-A-36A	Crib	o	32.62	2010.56	0.00	2004.00	6.56		22	314	1,070,000			

TABLE 2-1 Potential Remedial Action Alternatives - CERCLA Sites (continued)

Hanford Inactive Waste Site Study.

	Site No.	FATE OF CONTAMINANTS: Soil Attenuation	Downward Migration	Vegatation Uptake of Radionuclides	Ground-Water Release	Surface Errosion	POTENTIALLY FEASIBLE REMEDIAL ACTIONS: Cap/Cover w/ PC Monitoring	Grout-in-Place w/ PC Monitoring	In-Situ Vit-rification	Solution Min-ing & GW Recovery/ Treatment	Excavation & Disposal	No Action
26	216-B-43	o	x	o				x	x	x	x	
27	216-B-44	x	x	x				x	x	x	x	
28	216-B-45	o	x	o				x	x	x	x	
29	216-B-46	x	x	x				x	x	x	x	
30	216-B-48	o	x	o				x	x	x	x	
31	216-B-49	x	x	x				x	x	x	x	
32	216-B-50	o	x	o	o			x	x	x	x	
33	216-B-5	x	x		x			x		x		
34	216-B-2-2	o	x	o	x	o		x		x		
35	216-B-6	o	o		o		x					x
36	216-B-7 A&B	x	x	x	o			x		x	x	
37	216-B-10A	o	x				x	x	x			
38	216-B-16	o	x	o						x	x	
39	216-C-1	o	x	o	o			x	x	x		
40	216-C-10	o	x	o		o	x	x	x		x	
41	216-A-9	x	x	o	x			x		x		
42	216-A-40		o				x					x
43	216-A-4	x	x					x	x		x	
44	216-A-5	x	x	x	x		x	x		x		
45	216-A-6	x	x	x	x			x		x		
46	216-A-7	o	x				x				x	
47	216-A-21	x	x	o	o				x		x	
48	216-A-24	o	x	x	x			x		x		
49	216-A-27	x	x		o				x		x	
50	216-A-28	o					x				x	x
51	216-A-36A	x	x						x		x	

TABLE 2-1 Potential Remedial Action Alternatives - CERCLA Sites (continued)

Hanford Inactive Waste Site Study.

	Site No.	Type	Proximal Location (<500')	HRS Score	Total Curies Disposed (1)	Total of H,C,Ru,Eu	Total of Cs,Sr	Total of All Else	Other Wastes Disposed (2)	Depth to Waste Feet	Depth to GW Feet	Volume Disposed (liters)	Field Capacity (FC=0.05)	Field Capacity (FC=0.1)	Field Capacity (FC=0.25)
52	216-S-5	Crib	o	30.75	130.48	0.16	88.20	42.12	8	15	180	4,100,000,000	x	x	x
53	216-S-6	Crib	o	42.14	384.95	0.50	349.00	35.45	8	15	180	4,470,000,000	x	x	x
54	216-S-16D	Ditch	o	42.14	0.00	0.00	0.00	0.00	8	3	180	400,000,000	x	x	o
55	216-S-16P	Pond	o	32.72	110.57	0.20	82.10	28.27	8	3	180	41,000,000,000	x	x	x
56	216-S-17	Pond	o	38.07	31.62	0.06	31.30	0.26	8	10	180	6,430,000,000	x	x	x
57	216-U-11	Ditch (2)		37.75	0.00	0.00	0.00	0.00	?	7	185	0			
58	216-S-1&2	Crib (2)		57.73	6657.93	4000.00	2570.00	87.93	8	35	197	160,000,000	x	x	x
59	216-S-3	Fr Drain (2)		48.97	3024.41	3000.00	24.35	0.05	1,8	6	190	4,200,000			
60	216-S-4	Fr Drain	o	32.72	0.02	0.02	0.00	0.00	8	20	180	1,000,000			
61	216-S-7	Crib (2)		59.63	2320.40	0.00	2287.00	33.39	8	22	202	390,000,000	x	x	x
62	216-S-9	Crib		39.23	6428.89	6000.00	422.00	6.88	8	30	205	50,300,000	x	x	o
63	216-S-20	Crib		43.70	98.76	0.00	86.30	12.46	8	30	208	135,000,000	x	x	x
64	216-S-21	Crib	o	31.93	117.29	0.00	117.10	0.19	8	21	180	87,100,000	x	x	x
65	216-U-1&2	Crib (2)		48.97	11.50	0.00	0.52	0.01	3,8,9	24	209	15,900,000	x	o	
66	216-U-3	Fr Drain		33.89	0.53	0.00	0.00	0.00	8	12	190	791,000			
67	216-U-4	Rec. Well		32.72	0.00	0.00	0.22	0.00	8	75	227	300,000			
68	216-U-4A	Fr Drain		32.72	0.22	0.00	0.22	0.00	8,9	10	227	545,000			
69	216-U-4B	Fr Drain		30.20	0.22	0.00	0.22	0.00	8	10	230	33,000			
70	216-Z-1&2	Crib		37.75	4672.37	0.00	0.32	4672.04	8,11	21	191	38,900,000	x	x	x
71	216-Z-7	Crib (2)		43.70	591.88	0.00	447.00	144.88	8	5	187	79,900,000	x	x	x
72	216-Z-10	Rec. Well		32.72	3.62	0.00	0.00	3.62	8	150	193	1,000,000	x	x	o

TABLE 2-1 Potential Remedial Action Alternatives - CERCLA Sites (continued)

Hanford Inactive Waste Site Study.

		FATE OF CONTAMINANTS					POTENTIALLY FEASIBLE REMEDIAL ACTIONS					
	Site No.	Soil Attenuation	Downward Migration	Vegatation Uptake of Radionuclides	Ground-Water Release	Surface Errosion	Cap/Cover w/ PC Monitoring	Grout-in-Place w/ PC Monitoring	In-Situ Vitrification	Solution Mining & GW Recovery/ Treatment	Excavation & Disposal	No Action
52	216-S-5	x	x	x	x			x		x	x	
53	216-S-6	x	x	x	x			x		x	x	
54	216-S-16D		o	o	o	o	x					x
55	216-S-16P	x	x	x	x	o	x			x	x	
56	216-S-17	o	x	x	x			x		x	x	
57	216-U-11	o	o	o		o	x				x	
58	216-S-1&2	x	x		x			x	x	x		
59	216-S-3	o	x	o		o		x	x	x	x	
60	216-S-4		o				x					x
61	216-S-7	x	x	o	x			x	x	x		
62	216-S-9	x	x	o	o			x	x	x		
63	216-S-20	x	x	o	x			x	x	x		
64	216-S-21	o	x		x			x	x	x		
65	216-U-1&2	o	o	o	o		x					x
66	216-U-3		o	o			x					x
67	216-U-4		o					x				x
68	216-U-4A		o	o			x	x				x
69	216-U-4B		o	o			x	x				x
70	216-Z-1&2	x	o	o	x			x	x		x	
71	216-Z-7	x	x	x	x	o		x	x		x	
72	216-Z-10		o		o		x					x

TABLE 2-1 Potential Remedial Action Alternatives - CERCLA Sites (continued)

Hanford Inactive Waste Site Study.

	Site No.	Type	Proximal Location (<500')	HRS Score	Total Curies Disposed (1)	Total of H,C,Ru,Eu	Total of Cs,Sr	Total of All Else	Other Wastes Disposed (2)	Depth to Waste Feet	Depth to GW Feet	Volume Disposed (liters)	Field Capacity (FC=0.05)	Field Capacity (FC=0.1)	Field Capacity (FC=0.25)
73	216-T-2	Rec. Well		50.34	0.00	0.00	0.00	0.00	1,2,8	75	256	6,000,000			
74	216-T-3	Rec. Well		60.40	286.20	0.00	43.60	242.60	2,3,8,9,11	206	249	11,300,000	x	x	x
75	216-T-7	Crib		65.44	58.74	0.00	49.30	9.44	2,3,8,9,11	26	191	110,000,000	x	x	x
76	216-T-8	Crib		47.82	1.21	0.00	0.85	0.36	1,2,8	25	258	500,000			
77	216-T-19	Crib		45.19	0.00	0.00	326.00	5.53	3,8,9	23	189	455,000,000	x	x	x
78	216-T-28	Crib		42.14	331.53	0.00	7.06	4.44	8	15	195	42,300,000	x	x	x
79	316-1	Pond		79.28	0.00	0.00	0.00	0.00	8,12,13,14,15	9	34	10,000,000,000	x	x	x
80	316-2	Pond		79.28	0.00	0.00	0.00	0.00	8,12,13,14,15	10	34	10,000,000,000	x	x	x
81	316-3	Trench		79.28	0.00	0.00	0.00	0.00	12,15	20	43	1,000,000,000	x	x	x

Sub set data file

Isotope (1)	Decay Mode	Other Wastes Disposed (2)		
H-3	Beta	1	Cr(2)O(7)	
C-14	Beta	2	NO(3)S	
Co-60	Gamma	3	SO(4)	
Ni-63	Beta	4	B(4)O(7)	
Sr-90	Beta	5	NH(3)	
Ru-106	Beta	6	Hg	
Cs-134	Beta,Gamma	7	Cu	
Cs-137	Gamma	8	NO(3)	
Eu-152	Beta	9	PO(4)	
Eu-154	Beta	10	CN	
Eu-155	Beta	11	F	
Pu-238	Alpha	12	Metals	(inc. Hg, Pb, Cr, Be, Ag, Ni, etc)
Pu-239	Alpha	13	TCE	Trichlorlethylene
Pu-240	Alpha	14	MIRK	Methyl Isobutyl Ketone
U-235	Alpha	15	U	Uranium
U-238	Alpha			

TABLE 2-1 Potential Remedial Action Alternatives - CERCLA Sites (continued)

Hanford Inactive Waste Site Study.

	Site No.	FATE OF CONTAMINANTS: Soil Attenuation	Downward Migration	Vegatation Uptake of Radionuclides	Ground-Water Release	Surface Errosion	POTENTIALLY FEASIBLE REMEDIAL ACTIONS: Cap/Cover w/ PC Monitoring	Grout-in-Place w/ PC Monitoring	In-Situ Vitrification	Solution Mining & GW Recovery/ Treatment	Excavation & Disposal	No Action
73	216-T-2	o	o				x					x
74	216-T-3	x	x		x			x		x		
75	216-T-7	x	x	o	x			x	x	x		
76	216-T-8	o	o				x					x
77	216-T-19	x	x	o	x			x	x	x	x	
78	216-T-28	x	x	x	x			x	x		x	
79	316-1	x	x	x	x	o	x	x	x	x		
80	316-2	x	x	x	x		x	x	x	x		
81	316-3	x		o	x		x	x	x		x	

- Surface erosion - Those sites with contamination less than ten feet below the ground surface were identified as having a potential for waste dispersion by wind or water erosion.

The summary of the site data and pathways/fate of pollutants for each site is presented in Columns 16-20 of Table 2-1.

2.3 Selection of Technologies

As the first step, published Environmental Protection Agency (EPA) handbooks and conference proceedings that listed numerous potential remedial technologies for hazardous and radioactive wastes were reviewed (see Appendix B for a list of Potential Technologies). The remedial technologies were divided into three groups:

- Waste isolation
- Excavation/removal
- In-situ treatment

Waste isolation addresses those technologies that contain all the contaminated material onsite and involve minimum movement of either wastes or contaminated soils. Excavation/removal addresses those technologies that generally involve removing the contaminated material and transferring it to another location for treatment and disposal. In-situ treatment involves technologies that effectively treat the contaminated material in place. Very little waste or soil is excavated or removed from the site by these technologies, which either extract the hazardous constituents for treatment/recovery or physically, chemically, or biologically detoxify the hazardous constituents.

These groups are listed in the general order of overall demonstrated effectiveness and environmental acceptability from the perspective of meeting applicable standards and providing a permanent solution.

2.4 Screening of Technologies

Specific remedial technologies were identified in each of the three groups discussed above. This technology list is presented in Table 2-2, which shows both primary technologies that are used to treat the contaminated materials and some of the major support technologies that are used to protect the environment during remedial action operations. The next step was to screen these technologies and determine those that would be most applicable to the 81 CERCLA sites at Hanford. This was done by reviewing the site conditions and pollutant pathways and fate and identifying those technologies that were most advantageous based on previous applications to comparable waste types or site conditions.

2.5 Selection of Final Remedial Technologies

Once the primary candidate technologies had been identified, a literature and case study review was conducted to determine the following:

- Operating range/conditions for each technology - effective depth, waste types, soil types, etc.
- State of development of technology - bench, pilot, full scale
- Similarity of wastes and site conditions to those expected at Hanford
- Acceptability - demonstrated ability to meet applicable regulations and standards
- Complexity - simpler is better
- Throughput/capacity - length of time to treat expected waste volumes
- O & M requirements (including decontamination needs)

TABLE 2-2

GENERAL REMEDIATION TECHNOLOGY GROUPS

<u>WASTE ISOLATION</u>

Primary Technologies

- o cap/cover systems
- o slurry walls
- o grout-in-place
- o in-situ vitrification

Support Technologies

- o dust control
- o runoff diversion/collection/treatment
- o equipment decontamination

<u>EXCAVATION/REMOVAL</u>

Primary Technologies

- o excavation/disposal
- o groundwater pump/treat systems
- o solidification/fixation

Support Technologies

- o waste handling/transportation
- o dust control
- o runoff diversion/collection/treatment
- o equipment decontamination

<u>IN SITU TREATMENT</u>

Primary Technologies

- o solution mining
- o soil flushing
- o air/steam stripping
- o biodegradation systems
- o chemical fixation/complexation

Support Technologies

- o extraction/concentration facilities
- o equipment decontamination

This information was then reviewed by the task members, closely compared to the site conditions, and resulted in the selection of 6 technologies for potential application at Hanford:

- o Cap/cover
- o Grout-in-place
- o In-situ vitrification
- o Excavation and disposal
- o Soil flushing
- o Groundwater recovery and treatment

Table 2-3 provides a comparison of the technical feasibility, costs, applicable environmental regulations, and state of development for the technologies evaluated. The process, operations, costs, applications and limitations of the six selected technologies are described in more detail in Appendix A.

In addition, a no-action alternative has been included, since many of the sites received such apparently low volumes of wastes and had either no radionuclide or heavy metal waste or very low (less than two curies) amounts of radioactive materials.

2.6 Selection of the Remedial Technologies by Site

Once the final seven alternatives (six technologies plus no action) were selected, an evaluation was made for each site, and at least two technologies per site were identified as applicable. One further crucial assumption was made: to combine soil flushing and groundwater treatment as one technology since they both involved essentially the same equipment, configuration and operational concerns.

The alternatives were selected for each site based on the following definitions:

Table 2-3
Summary Matrix of Applications of Remedial Action Technologies

	Technical Feasibility						Costs	
Remedial Action Technology	Total Radio-Nuclides	Soluble/ Non-Soluble Radionuclides	Heavy Metals	Organics	Effective Depth (Feet)	Other Limitations	Factor	Unit Cost
Cap/Cover	<10Ci	Non-Soluble	Yes	Yes	No Limit	Susceptible to Subsidence	100 Square Yards	$4,500
Grout-in-Place	No Limit	Non-Soluble	Yes	Yes	No Limit	Extensive Site Character Required Difficult to Verify Effectiveness	100 Cubic Yards	$6,000
Vitrification	No Limit	Non-Soluble Low Volatility	Yes	No	<50	Low Soil Moisture Required High Energy Demand	100 Cubic Yards	$38,900
Excavation/ Disposal	No Limit	Non-Soluble Low Volatility	Yes	Yes	<60	Worker H&S Concerns	100 Cubic Yards	$36,500 - $68,900
Groundwater Pump/ Treatment								
Soil Flushing	No Limit	Soluble	Yes	Poor	No Limit	Need Extensive Characteristics of Soil/Waste Matrix	100 Cubic Yards	$3,500
Water Treatment	No Limit	Soluble	Yes	Yes	No Limit	Required Extensive Aquifer Characterization	100 Cubic Yards	$1,200

Table 2-3 (continued)
Summary Matrix of Applications of RA Technologies

Remedial Action Technology	Applicable Env. Requirements: Air	Surface Water	Ground Water	RCRA	Demonstrated Compliance with Environmental Regulations: CERCLA Sites	RCRA Sites	LLRAD Sites	HLRAD Sites	State of Development: Radionuclides	Heavy Metals	Organics
Source Controls CAP/Systems	Yes	Yes	No	No	Yes	Yes	Yes	Unknown	Full Scale	Full Scale	Full Scale
Grout-in-Place	No	Yes	Yes	No	No	Unknown	No	No	Pilot Scale	Pilot Scale	Unknown
Vitrification	Yes	Yes	No	Yes (Site Prep.)	Unknown	Yes	Yes	Unknown	Pilot Scale At Hanford	Pilot Scale	Unknown
Excavation/ Disposal	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Full Scale	Full Scale	Full Scale
Groundwater Pump/ Treatment											
Soil Flushing	Yes	No	Yes	Yes (Recovered Solution)	Proposed	Yes	Yes	Proposed	Full Scale On Ore Bodies	Full Scale On Ore Bodies Pilot Scale On Wastes	Pilot Scale
Water Treatment	Yes	No	Yes	Yes (Recovered Solution)	Yes	Yes	Yes	Proposed	Full Scale	Full Scale	Full Scale (Stripping)

Cap/Cover: Potentially useful for sites where the total curie count is less than ten, with most wastes having low solubility. Depth of materials is not a relevant item in the decision process, but the volume of wastes applied to the site should be less than 10,000,000 liters so as to be reasonably assured of fairly shallow depths of contamination.

Grout-in-Place: In-situ grouting using bentonites and portland cement to both chemically stabilize the materials (mostly metals) and physically isolate the wastes from water migration. There are no limits on the depth of wastes.

In-Situ Vitrification: Physical isolation of the wastes, with a depth of effectiveness to approximately 50 feet (assumed for this analysis). The actual limitation is the volume rather than the depth.

Excavation and Disposal: Most useful with sites where wastes have low solubility, are near the surface, and have had a low volume of wastewater.

Soil Flushing/Groundwater Recovery and Treatment: Most useful with the soluble pollutants, but generally not effective on wastes where the nonsoluble fraction was greater than 25 percent.

The most likely application for each technology with respect to radionuclide contamination, depth of wastes, and volume of waste and chemical waste discharged is summarized as follows:

Technology	Limiting Site/Waste Conditions				
	Ci Total	Ci Nonsoluble	Chemical Wastes	Depth of Wastes	Volume of Wastes
Cap/Cover	≤10	≤ 1	N.S.	N.S.	< 10,000,000
Grout-in-Place	N.S.	N.S.	N.S.*	N.S.	<100,000,000
In-Situ Vitrification	N.S.	N.S.	N.S.	< 50'**	<100,000,000
Excavation and Disposal	N.S.	≥25% of Ci	N.S.	< 50'+	< 10,000,000
Soil Flushing/ Groundwater Recovery and Treatment	N.S.	≤25% of Ci	N.S.	N.S.	<100,000,000
No Action	< 2	< 1	N.S.	N.S.	N.S.

N.S. = Not significant in decision process (but considered).

* = Any application of grout-in-place must be custom tailored to the geohydrologic conditions and waste characteristics.

+ = Assumed for analysis purposes. Greater depth would require shoring of the work area.

** = This limit is only assumed for applicability of the technology to specific Hanford Sites. The limiting factor is actually the volume that can be vitrified.

Using these criteria, each technology was compared to each site and a decision made on the potential feasibility for application at that site. These decisions are summarized in Columns 21-25 of Table 2-1.

3.0 SUMMARY OF SELECTED REMEDIAL ACTION BY SITE

An evaluation resulted in the selection of two or more remedial actions for each site. The selections were based on technical feasibility and the objective of establishing a reasonable cost range for each site. The remedial action alternatives presented for each site are presented in columns 21-26 of Table 2-1. In total, 19 sites were identified where the no-action alternative might be applicable, 36 sites for possible application of cap/cover, 49 sites for possible grout-in-place applications, 35 sites where in-situ vitrification may be appropriate, 42 sites for possible application of soil flushing and groundwater recovery and treatment, and 42 sites where excavation and disposal are feasible.

In terms of the number of possible remedial action alternatives per site, the 81 sites are distributed as follows:

No. of Possible Remedial Actions	No. of Sites
2	34
3	32
4	15

4.0 REMEDIAL ACTION UNIT COSTS

As discussed in Appendix A, a unit cost has been developed for each proposed remedial action. The costs are in either $/100 cubic yard or $/square yard. The costs include equipment, materials, operation and maintenance (e.g., labor and power) and health and safety. Other costs, such as site preparation (e.g., demolition, road building, etc.), have not been included because they are highly variable for each site. Instead, it is proposed that a contingency factor or allowance for unforeseen costs be included in the site-specific remedial action cost estimate.

Unit costs for the remedial action alternatives are as follows:

- Cap/cover - $4,500/100 square yards (See Appendix A.1)

- Grout-in-place - $6,000/100 cubic yards (See Appendix A.2)

- In-situ vitrification - $38,900/100 cubic yards (See Appendix A.3)

- Excavation and disposal with incineration - $68,900/100 cubic yards (See Appendix A.5)

  Excavation and disposal without incineration - $36,500/100 cubic yards (See Appendix A.5)

- Soil flushing - $3,500/100 cubic yards (See Appendix A.4)

- Groundwater recovery and treatment - $1,400/100 cubic yards (See Appendix A.4)

For excavation and disposal, the higher number includes waste treatment/preparation for disposal.

5.0 SUMMARY

A review was made of the known site and waste dispersion conditions at the 81 CERCLA sites at Hanford, and an analysis of potential remedial action alternatives led to the selection of six alternatives that could be most feasibly applied to these sites. Each remedial action alternative is described in sufficient detail in Appendix A to enable an order of magnitude cost estimate to be prepared for the cleanup of each of the 81 sites.

TASK 5 - APPENDIX A

A.1 CAP/COVER

A.1.1 General Description

The cap and cover technique provides a horizontal barrier to isolate contaminants within an underlying waste zone and reduce their potential for migration out of this zone. A cap is usually designed as a low permeability barrier to reduce or prevent the movement of surface precipitation down into the contaminated zone. In arid regions, where evapotranspiration regularly exceeds precipitation, a cap can reduce the movement upward to the surface of contaminated water. Other forms of upward contaminant migration that may be reduced by a cap include the withdrawal of contaminated soil moisture by deep rooted plants penetrating into the contaminated zone and the transport of contaminants to the surface by burrowing animals.

The applicability of a cap at Hanford is governed by its prevailing arid climate. Although consideration must be given to an abnormally high precipitation event such as the 100-year storm, the migration of wastes upwards due to the "wicking" of soil moisture and the action of deep rooted plants (Dabrowski, 1973) and burrowing animals (O'Farrell and Gilbert, 1975) are the primary concerns. Because the sites considered for cap/cover deal with low-level radioactive concentrations, the potential for radioactive decay particles penetrating through the 10 to 30 feet of cover soil is expected to be minimal. Site field sampling surveys will determine this later, as described in Section 2, Characterization Plan for CERCLA Sites.

For those sites that contain near the surface a large concentration of radioactive or chemically hazardous materials that cannot be completely or feasibly removed by other technologies, capping can be employed as a barrier above the waste site until the wastes can degrade naturally, in place, with time.

Capping techniques applicable to the Hanford Reservation include:

- Synthetic liners
- Asphalts and asphalt cement
- Reinforced Portland cement
- Low permeability clay bentonite
- Gravel-cobble
- Chemical toxins (herbicides).

An applicable barrier cap may consist of one or a combination of these techniques. For instance, synthetic liners coupled with a soil-bentonite layer are commonly used.

In choosing a technique appropriate to the Hanford Reservation, several concerns must be evaluated. The expected or field-proven life of the cap must be adequate until the wastes within the site are no longer hazardous for contaminant pathways in question. Capital and operation and maintenance costs must also be considered. For sites that are to be capped, consideration must be given to any adjacent active sites that may cause lateral migration of fluids beneath the cap and into the contaminant zone. Subsidence may occur, destroying the cap as the supporting soil beneath it collapses. Many of the waste units considered in this report are cribs, French drains, ditches and trenches. Cribs particularly have a history of subsidence, and if excavation and disposal are used to extract the contaminants concentrated near the surface before a cap is installed, some subsidence is likely.

Long-term monitoring of the cap and site after completion are important. The waste site must be monitored to determine whether contaminants are escaping either to the surface or down towards the ground water. The integrity of the cap must be monitored and periodic maintenance may be needed, such as sealing of asphalt liners that have developed cracks or removal of deep rooted plants and burrowing animals that could disrupt a clay or synthetic liner.

An evaluation of the possible capping technologies indicates that a gravel-cobble barrier or a reinforced concrete cap are the best choices. Synthetic liners and asphalts have too short a life span; it would be necessary to excavate and reinstall a synthetic liner every 20 years. Asphalts, chemical toxins, clays, reinforced concrete, and to some extent gravel-cobble are susceptible to subsidence. Bentonite must be kept moist to be effective. In the arid climate at Hanford, drying and cracking of a bentonite liner is likely. Chemical toxins are still experimental.

Both reinforced concrete and gravel-cobble can be expensive to install. Reinforced concrete is the more expensive of the two, is susceptible to cracking, and requires periodic repairs to maintain cap integrity. The life span of concrete is also expected to be shorter than that of gravel-cobble. Both, however, are effective against burrowing animals. A gravel-cobble liner offers better long-term protection against surface water infiltration if it is covered with a less permeable layer such as the natural soil found at the Hanford Reservation.

A layer of cobbles (1.49 - 2.99 in. diameter) will create a zone of large void spaces lacking nutrients and water. If this zone is deep enough, plant roots will be prevented from penetrating it. The mass of the cobbles prevents burrowing mammals from tunneling beyond the barrier zone. A gravel layer (.118 - .236 in. diameter) above the cobbles prevents finer sediments within the soil column from passing into and filling the cobble voids. The gravel layer is covered with a soil of lower permeability than the gravel to contain any surface water infiltration and to sustain plant life in order to maintain the evapotranspiration levels normal for the area. Should a large storm event saturate the soil layer, capillary action would draw all or most of the water away from the site, due to its lower permeability, without penetrating into the gravel-cobble layer or into the contaminated zone.

A.1.2 Design and Construction

The barrier zone is the cobble layer. It must be of sufficient mass to deter burrowing mammals and of sufficient void space and depth to inhibit plant roots. The area above the site will be excavated to a depth adequate to contain the cobble layer and the supporting layers placed above. The cobble layer will be at most 2.5 feet deep. To protect the cobble layer from filling with smaller particles over time, a gradation of material sizes, decreasing towards the surface, is used to trap these finer particles as they migrate downward. A gravel layer above the cobbles, approximately ten inches deep, will serve this function. Approximately 2.5 feet of sandy soil will be placed above this.

An area above and to some prespecified distance laterally beyond the contaminated zone will be excavated. A layer of cobbles will be placed at the bottom of the excavated pit with its upper surface kept level. The gravel layer will be placed and compacted above the cobbles, and backfill will be placed and compacted in six-inch lifts over the site up to the original grade. The remaining backfill will be placed and compacted over the site with the final surface grade designed to withstand wind erosion and to promote surface water runoff. The depth of excavation of each site may be more or less than the five feet assumed in this Appendix. The controlling criteria will be excavate enough soil so that backfilling of all excavated soil will produce a surface grade adequate to withstand the elements. The compacted soil layer must be able to retain the designed-for storm intensity (like the 100-year storm) and prevent surface water from penetrating into the gravel-cobble layers. After installation, a monitoring plan will be implemented to ensure that the cap is effectively deterring deep rooted plants and burrowing mammals and that the integrity of the cap has not been impacted by subsidence, filling of the cobble voids, or by any unforeseen factors that may be detected during periodic monitoring.

Excavation will require a bulldozer or backhoe, depending on the size of the site. Placement of the cobble, gravel and soil layers will be accomplished by a combination of backhoe and hand or bulldozer. Hand-held vibrating tampers will be used to compact the gravel and soil. The gravel and cobble will be imported by truck and the excess excavated soil will be exported by truck.

In selecting a capping technique, the important factors to be considered include 1) the health and safety of the workers (excavation above a crib could result in sudden collapse of the crib itself; the excavated material may be contaminated and require specific health and safety gear), 2) the environmental impact of excavating (wind may disperse excavated contaminated soil), 3) possible inundation by water (such as flooding of the sites near the Columbia River), 4) design of the site to handle a large storm event (like the 100-year storm), and 5) the expectation that the waste will remain in place and degrade to acceptable radioactive levels or chemical concentrations within a reasonable time. Costs are also of concern; the gravel and cobble must be economically available.

A.1.3 Advantages and Disadvantages

Advantages of the gravel-cobble cap are that it is effective against plant root penetration and burrowing animals, it is not subject to rapid deterioration, and it does not appear to alter water balance relationships when installed correctly (Hakonson et al, 1982). Since it does not deteriorate quickly, operation and maintenance costs should be low over the life of the cap. Disadvantages are that contaminants are still onsite and must be monitored and that subsidence may disrupt the cap.

A.1.4 Remedial Action Schedule

It is assumed that site reconnaissance and surveying have been performed during the earlier characterization phase. It is also assumed that a list of contractors cleared to work at Hanford is available, and that the contractor chosen to implement this remedial action will already be at Hanford and will be able to transfer equipment and personnel from a nearby site.

The remedial action schedules are largely derived from the average daily output values given by construction cost guides (Means, 1985 and Dodge, 1987). Some information has been taken from technical journals when it was more specific than the construction cost guides.

Mobilization of equipment to the generic site and site setup take a day. Excavation to a depth of five feet using two backhoes will take 24 days, installation of the gravel-cobble layers 19 days, and backfilling and compacting the site 53 days. Demobilization and decontamination of equipment will require two days. A total of 19.8 weeks will be required for remedial action implementation. Post remedial action monitoring will continue for 30 years following the remedial action implementation.

A summary of the remedial action schedule for cap/cover is as follows:

o Mobilization/Setup	0.2 weeks
o Prepare and excavate site	4.8 weeks
o Install gravel-cobble layers	3.8 weeks
o Backfill and compact site	10.6 weeks
o Demobilize and decontaminate site	0.4 weeks
Total	19.8 weeks

A.1.5 Resource Requirements

Excavation and backfilling of the site will require two backhoes, both of which will be used to excavate for several days. Four dump trucks will be required to remove excavated materials. So that large portions of the site are not exposed to the elements (wind or precipitation) for an extended period of time, the backhoes will be used to install the gravel-cobble layers and to perform backfilling operations on the fourth day. Ten dump trucks will be required during backfilling operations, along with four vibrating compactors (with operators) and eight laborers. The excavation and the gravel-cobble layer and backfilling operations will continue in tandem until completion of the gravel-cobble layers and the covering soil layer.

The resource requirements are summarized as follows:

Excavation (53-day duration)

Manpower

4 Teamsters (dump truck operators)
2 Operating Engineers-Hoisting (backhoe operators)
2 Oilers (backhoe support)
2 Laborers (backhoe support)

Equipment

2 Backhoes
4 Dump trucks

Laying gravel-cobble and backfilling (72-day duration)

Manpower

10 Teamsters (dump truck operators)
6 Operating Engineers-Hoisting (2 backhoe operators and 4 vibrating compacter operators)
2 Oilers (backhoe support)
8 Laborers (backhoe support and soil compaction)

Equipment

10 Dump trucks
2 Backhoes
4 Vibrating compacters

Materials

7580 yd^3 Cobble
2530 yd^3 Gravel

A.1.6 Costs

The depth of excavation for placement of the cobble layer is five feet. The cap is designed to extend 20 feet in all directions beyond the area of contamination. Side slopes of the excavated site will be 1:1. These criteria have been used to compute the areal extent of contamination for all sites that considered cap/cover as a remedial action. The average of the two median sites gave a cross-sectioned area of 9100 yd^2 to be capped. This generic site was used for costing.

It is assumed that eight hours are worked per day and that holidays are ignored. All costs, except the cost of applying the cobble and gravel layers, have been taken from Dodge, 1987. Table A.1.1 summarizes costs for the cap/cover technology.

TABLE A.1.1 CAP/COVER COSTS

	Hourly Rate ($/hr)	Total Cost ($/yr)
Labor(1):		
1 Site Superintendent	58	$120,640/yr
1 Health & Safety Supervisor	48	99,840/yr
2 Radiation Safety Technicians (40% of time) (Additional labor cost for equipment operators included in equipment costs)	28	46,600/yr
	Subtotal	$267,080/yr
Equipment		
2 Backhoes w/operators and support ($2.49/yd^3)(2)		$ 39,100
10 Dump Trucks w/drivers 1/4 mile round trip ($1.22/yd^3)		19,200
4 Vibrating Compacters w/operators and support ($9.25/yd^3)		145,000
	Subtotal	$203,000
Materials & Safety		
Cobble, 2.5 ft thick ($7.19/yd^2 installed)(3)		$ 65,400
Gravel, 10 in thick ($3.60/yd^2 installed and compacted)(4)		32,800
Health and Safety (5 men including backhoe operator @ $25/day/man during excavation and laying of cobble only = 11 wks)		9,000
	Subtotal	$107,200

Total Cost = Equip + Materials & Safety + Labor for 11 weeks

= $203,000 + 107,200 + (19.8/52) (267,000) = $412,000/unit site

Unit Cost = $412,000/9,100 yd^2
= $45/yd^2

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(1) Kaiser Labor Rates
(2) Means 1987
(3) Hakonson et al. 1982 (adjusted)
(4) Dodge 1987

A.1.7 References

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O'Farrel, T.P. and R.O. Gilbert. 1975. Transport of Radioactive Materials by Jackrabbits on the Hanford Reservation, Health Phys. 29:9-15.

U.S. Environmental Protection Agency. 1985. Remedial Action at Waste Disposal Sites.

A.2 GROUT-IN-PLACE

A.2.1 General Description

Grouting is a process whereby one of a variety of suspensions or fluids is injected into an earth formation where it is allowed to set in place. The purpose of this process may be to impart additional strength to the formation, reduce the permeability of the formation, or, in theory, to stabilize and solidify a body of waste or soil in situ. It should be noted that waste stabilization/solidification using grouting techniques is not an established remedial technology and would require further development before it could be used with confidence.

Grout injection may be accomplished by a variety of techniques including curtain grouting, jet grouting, and area grouting. Curtain grouting involves creating an underground barrier wall by injecting columns of grout that overlap vertically and horizontally. Jet grouting employs a high-pressure nozzle to cut a kerf in soil or soft rock where grout is allowed to set. Area or blanket grouting is a low-pressure technique for injecting and stabilizing shallow soils for reduced infiltration or increased strength.

The three general classes of grout utilized today are as follows:

- Suspension grouts
- Chemical grouts
- Bituminous grouts (Tiedemann and Graver, 1982; Bowen, 1981)

Suspension grouts are the most common type of grout and include coarse grouts that contain particles in suspension. Cement, clay, and cement-clay grouts are in this category. These materials are usually the more viscous of the available grouting materials and have the largest particle size. These grouts are restricted to use in the grouting of fractured rock or coarse grained material.

Chemical grouts rely on polymerization reactions to form hardened gels. They have initially low viscosities and thus can be used in finer grained, cohesionless soils as well as a secondary treatment for grouting of coarse soils and rock fissures. Some chemical grouts such as urethane can be suspensions that undergo polymerization to form a gel. This class of grout is comprised of two subclasses: silicates and organic polymer grouts.

Bituminous grouts can be either emulsions of bitumen in water or asphalts. These grouts can be used to seal soils, fill rock cavities, or construct thin cutoff walls.

A.2.2 Design and Construction

The nature of the earth materials at a site will greatly influence the type of grout to be used. If soil materials are to be grouted, the characteristics that must be determined include:

- Permeability
- Porosity
- Particle size distribution

Permeability will influence the selection of grout type (particulate or chemical) to be used, the allowable viscosity, and the required injection pressures (Bowen, 1981). The porosity, or voids ratio, will give an indication of the amount of grout a unit volume of soil will "take," and how rapidly grout may be injected (Herndon and Lenahan, 1976a). The particle size distribution indicates, among other things, the presence of large particles that could interfere with grout injection.

After a detailed site and waste characterization is completed, a grout capable of being injected into the treatment area and immobilizing the wastes must be formulated. For this discussion, it is assumed that a chemical grout is suitable for the alluvial deposits found at Hanford and is also capable of solidifying the waste deposits and immobilizing their hazardous constituents. In actual practice, bench and pilot scale testing would be required on a site-specific level to determine if these assumptions are valid.

Based on background and exploratory data, the location for a pattern of primary injection holes is chosen and injection at one or more zones is identified. Based on field experience in similar soil types, it was estimated that the primary holes would be on 20-foot centers. The first few primary holes are then drilled and slotted grout pipes installed (Millet and Engelhardt, 1982). Background and exploratory data are also used to identify each vertical zone or stage to be grouted. The grout pipe, usually small diameter PVC pipe, is then slotted to allow grout penetration into the formation. Starting at the bottom, successive stages are sealed off using a pneumatic packer and then pressure grouted. Each hole is then pressure tested, often using a nonsetting fluid of the same viscosity as the grout. These tests are used to determine the initial grout mixture and are often conducted using the grout plant and other equipment to be used for the actual grouting (Millet and Engelhardt, 1982 and Karol, 1982a).

Each zone within each primary hole is then injected with the grout mixture until a predetermined amount is pumped (grout take) or a predetermined flow rate at maximum allowable pressure is reached. Maximum allowable pressure is typically around 1 pound per square inch (psi) per foot of overburden (Millet and Engelhardt, 1982). Data from the drilling and injection of the first primary holes is analyzed and, if necessary, the grout mixture or injection pressure modified before completing the remaining primary holes. Following completion of the primary hole grouting, the program is again analyzed, necessary changes made, and a pattern of more closely spaced secondary holes drilled and injected.

The analysis and evaluation of the completed grouting becomes, in essence, another pressure test. Close quality control during drilling and grouting identifies areas that require tertiary hole grouting to complete sealing. Such areas are identified by faster than expected drilling rates and higher than expected grout takes (Millet and Engelhardt, 1982). For a successful grouting program, each hole series (i.e., primary, secondary) will have lower grout takes than the previous one. Many projects will require that proof holes be drilled and injected. A very low grout take on tertiary or proof holes indicates that most voids are grout filled and the grouting program was successful.

A.2.3 Advantages and Disadvantages

The greatest advantage of grout injection, if it can successfully be accomplished, would be the in-situ immobilization of hazardous constituents until they can decay or be recovered for treatment. Other advantages include minimization of human contact with the wastes and the absence of operation and maintenance costs for the completed remedy.

The major disadvantage of this technique lies in its unproven nature. Any application of it has to be custom tailored to both the geohydrologic conditions of the site and to the characteristics of the wastes present. The state-of-the-art of grouting for hazardous material control is such that each proposed waste/grout combination must be thoroughly tested to predict effectiveness of immobilization. Also, because each application of this technique is experimental, long term effectiveness is not known.

A.2.4 Remedial Action Schedule

The following estimated schedule is based on pressure injecting phenolic resin grout into the soils of a site measuring 370 feet square, to a depth of 160 feet. The soils are presumed to be relatively uniform sands with a porosity of 20 percent. Grout injection holes will be located on 20 foot centers, and 400 primary and 361 secondary holes, each 160 feet deep will be required. It is assumed that one rig can drill grout holes at a rate of 3 per week.

Each grout plant will be manifolded to six grout plants and can pump four cubic yards (yd^3) of grout through each pipe. Twelve grout plants will be used. Working a five-day week, total grouting capacity will be 1,440 yd^3/week, or 374,400 yd^3 per year with a soil porosity of 0.20. Based on these estimated quantities, the following represents the estimated remedial action schedule.

- Mobilization and Site Preparation

Drill Rig	0.5 weeks
Grout Plants (12)	6.0 weeks

- Drilling 761 holes, three holes/rig/week, three rigs — 84.5 weeks

- Grouting (162,250 yd^3)

Primary Holes 126,555 yd^3, 1,440 yd^3/week	87.9 weeks
Secondary Holes 35,695 yd^3, 1,440 yd^3/week	24.8 weeks
Total	119.5 weeks = 2.3 years

A.2.5 Resource Requirements

The labor requirements for grout-in-place can be divided into three categories: supervisory personnel, drilling crews, and grouting crews. The supervisory personnel would include one site supervisor overseeing all onsite operations, three labor foremen overseeing drilling and grouting efforts, and one radiation protection technician observing only the drilling effort. Each drill rig would be manned by a lead driller and a driller's helper. Each grout plant would be manned by a crew of four who would mix, test, and inject the grout.

Equipment for grout hold drilling would be limited to a truck and a track or skid-mounted drill rig, outfitted with a minimum of 170 feet of small diameter hollow stem auger. Miscellaneous small tools are standard rig equipment. Each grout plant would consist of a grout mixer, an agitator, a grout pump, a pressure transducer with recorder, a manifold, piping, and a sleeve grout pipe.

The principal materials needed for this effort would be reusable grout pipe of sufficient length to reach the bottom of a grout hold and extend to the grout plant manifold and the grout formulation itself. A typical phenolic resin grout would consist of a polyphenolic polymer power that is soluble in water, a catalyst such as a formaldehyde solution, and an activator, usually a metal salt such as ferric chloride.

A.2.6 Costs

The equipment involved in injecting grouting includes a drill rig for drilling injection holes and a grout plant for mixing and injecting the grout. The drill rig would employ at least two operators and the grout plant at least three. The following costs are based on grouting an area sufficiently large for the crew to work in the same area for a full year. It is assumed that a phenolic resin grout would be used.

Table A.2.1 summarizes the grout injection costs, which are based on Means, 1985, updated using the ENR Construction Cost Index for 1987 (June).

TABLE A.2.1 GROUT INJECTION COSTS

	Hourly Rate ($/hr)	Annual Cost ($/yr)
Labor		
1 Site Supervisor	58[1]	120,640
3 Labor Foremen	44[1]	274,560
48 Laborers (12 4-man Grout Crews)	20[4]	1,996,800
1 Radiation Protection Technician	28[1]	58,240
	Subtotal	$ 2,450,240
Equipment		
Drilling Cost ($100/ft) (3 rigs x 3 wells/wk x 160 ft/well)		7,488,000
12 Grout Plants ($282/day)[3])		1,235,000
	Subtotal	$ 8,723,000
Materials and Safety		
Phenolic Grout ($150/yd^3)[3]		11,232,000
Health and Safety ($25/day/man x 7 men) (Drilling crew only)		45,500
	Subtotal	$11,277,500
	Total Cost	$22,450,000

Volume of Soil Grouted:

$$\frac{4\text{yd}^3\text{/hole/day} \times 6 \text{ holes/plant} \times 12 \text{ plants/site} \times 260 \text{ days}}{20\% \text{ Soil Porosity}} \frac{}{\text{year}} = 374{,}400 \frac{\text{yd}^3}{\text{yr.}}$$

$$\text{Unit Cost} = \frac{\$22{,}450{,}000\text{/yr.}}{374{,}400 \text{ yd/yr.}} = \$60\text{/yd}^3 \text{ of soil}$$

(1) Kaiser Labor Data
(2) SAIC Field Experience
(3) Means (1985 x 1.07)
(4) Dodge

A.2.7 References

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A.3 IN-SITU VITRIFICATION

A.3.1 General Description

Vitrification involves the mixing of waste with molten glass at a temperature greater than 1,300°C. At this temperature all of the combustibles are completely burned away, including the various organic chemicals. Vitrification offers the greatest degree of containment, since the resultant solids formed generally have very low leach rates. The process is being employed on radioactive and highly toxic waste.

In-situ vitrification involves encapsulating previously burned wastes in a glass matrix without first exhuming the waste and is limited in its application to shallow depths and soils with low moisture content. Electrodes embedded in the ground are used to facilitate glassification of the soil. The process is extremely energy intensive; therefore, costs can be very high.

A.3.2 Design and Construction

The vitrification process is most effective at level grades. For those sites that are on slopes, excavation and grading may have to be performed. The excavated soil (a maximum of ten feet) is assumed to be uncontaminated and will provide backfill after the vitrification process.

Upon completion of vitrification activities at a site, the area and equipment are decontaminated. Contaminated equipment with further useful life can be kept in the "hot" area when not in use. Contaminated electrodes with no useful service life would be decontaminated, then disposed of. Other transportable equipment is taken to the decontamination trailer for washing. Standby parts and equipment are decontaminated on a scheduled basis. During the disassembly and repair, direct contact and exposure to personnel should be minimized.

The equipment and materials required to conduct in-situ vitrification include:

1. Electrodes: two-inch diameter, six-foot long molybdenum rods with threaded connection, covered by a one-inch thick graphite sleeve (reusable component; decontamination required). Flaked graphite and glass frit.

2. Off-gas hood: 16-gauge stainless steel panels, bolted and gasketed and supported by trusses and beams. Backfilling around the lower edge (skirt) to minimize leakage; system pressure at six inches of water.

3. Control trailer: power system for vitrification. Pilot design at Hanford Reservation utilized a Scott-Tee transformer connection for conversion of three-phase input into a balanced two-phase output configuration; site management and health physicist offices.

4. Off-gas trailer: scrubber system for inorganic fumes and radioactive particulates entrained in the off-gas from the vitrified mass. Process equipment includes indirect cooling, direct quench, two-stage, high pressure venturi scrubber, and wastewater collection tank.

5. Support trailer: electrical system hardware including glycol cooling unit.

6. Excavation equipment: bulldozer, earth mover, front end loader, and truck.

7. Crane: supports, and diesel generator.

8. Drilling equipment.

9. Decontamination trailer: wash tanks, high-pressure water, detention tanks, pumps, filtration system, and drip pans.

A.3.3 Advantages and Disadvantages

The advantages of using in-situ vitrification at Hanford Reservation are as follows:

1. The technology has been demonstrated at the Hanford site.

2. The remaining chemical and radioactive contaminants are immobilized in a glass matrix with low leachability, thus minimizing future environmental contamination.

3. Safety and health of workers is minimized because the waste is left safely in place, thus reducing dust (radioactive) and landfilling (contact with worker) problems.

The disadvantages of using in-situ vitrification at Hanford Reservation are as follows:

1. In-situ vitrification only immobilizes the contaminants in the upper 50 feet or so of soil and has no effect on contaminants that have already migrated below this elevation.

2. Cost can become very high because of the large energy consumption.

A.3.4 Remedial Action Schedule

Mobilization of equipment, setup of equipment, site preparation for the first run, drilling of the electrode holes, and placement of the electrodes will take approximately two to three weeks. Preparation of the next area can be performed concurrent with other activities and does not impact the schedule. Changeover of the hood between runs takes 20 hours with a 300 hour run time, 320 hours per 1,360yd^3, or 24 hours per hundred cubic yards.

For a 100 feet by 100 feet site, the total time that work is being performed onsite will be two weeks for mobilization and setup and 21 weeks for vitrification. Backfilling is based on spreading and compaction at a rate of 315 yd^3/day. This will require four six yd^3 dump trucks (six yd^3capacity) each moving 85 yd^3 of soil per day, two miles to the site. At these rates the backfilling will take three weeks.

A.3.5 Resource Requirements

Typical large earth-moving equipment including front end loaders, dump trucks, and graders will be required for excavation and backfilling. During vitrification, a front end loader, a truck, drilling equipment, and a crane capable of moving 25 tons will be required. All items will be leased; however, the crane will be rented and two operators will be employed as needed.

The site work and vitrification support costs include equipment, labor, and supervision (a site manager and site engineer). The vitrification support crew would be staffed in three shifts, seven days a week, requiring four two-man crews. See A.3.2 for a list of equipment and materials.

A.3.6 Costs

The costs are based on a large scale in-situ vitrification study conducted at Hanford. The capital costs have been estimated in 1987 dollars. The vitrification costs are based on a process time of 320 hours (vitrification - 300 hours; demobilization, including decontamination - 20 hours). The vitrification is conducted on a trench 35 feet by 35 feet by 30 feet deep (1,360 yd^3). Soil initially excavated from the vitrification area is stockpiled and later used to backfill the excavated contaminated areas. (Contaminated soil excavated during site preparation would be landfilled and replaced with clean soil.)

The basic cost associated with in-situ vitrification is given as \$386/yd^3 (Batley, 1987), but does not include heath and safety costs associated with working on radiological sites on the cost of backfilling the depression. This depression consists of the ten feet of excavated soil plus an additional 20 percent compaction of the vitrified zone, for a total of 18 feet. Table A.3.1 summarizes the costs for in-situ vitrification.

TABLE A.3.1 IN-SITU VITRIFICATION COSTS

	$\$/yd^3$
Labor (for mobilization, vitrification and backfilling)	\$ 54
Equipment (includes O & M, electricity cost)	\$ 155
Materials and Safety Iincludes supplies and electrodes)	\$ 180
Total	\$ 389

A.3.7 References

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A.4 GROUNDWATER RECOVERY/TREATMENT

A.4.1 Soil Flushing

A.4.1.1 General Description

Soil flushing historically has been a technique used for uranium extraction and production at mining operations. Soil flushing involves selective leaching of radioactive material from contaminated soil by use of chemical solutions injected into the soil column.

Soil flushing of radioactively contaminated soil columns has the advantage of reducing quantities of strontium-90 and cesium-137 typically contained within the Hanford Reservation vadose zone. The applicable geological environment for soil flushing is determined by a site-specific assessment of the amount of radioactive material in the soil column.

A.4.1.2 Design and Construction

There are two major components associated with a soil flushing operation: a surface plant to process injected solutions and treat contaminated fluids, and a well system comprised of injection and production wells equipped with pumps to inject and produce fluids. In addition, chemicals are used to enhance the extraction of contaminants from the groundwater and soil.

During site preparation, the design and performance of soil flushing activities are affected by many factors. Among these are well spacing, soil and groundwater contaminant types and levels, degree of water saturation and fluid conductivity of the soil, chemical activity of the soil with respect to the groundwater and its constituents, and areal extent and depth of contamination.

A surface plant is required for recovery and treatment of contaminated liquid pumped from the soil column. This facility will be a mobile wastewater treatment unit capable of precipitating heavy metals and radionuclides out of solution. The precipitate will be encapsulated and disposed at a landfill. The surface plant will treat groundwater pumped from each site prior to reinjection of groundwater and/or solvents into the soil column. This circulation pattern will be repeated for a number of cycles.

A.4.1.3 Advantages and Disadvantages

The greatest advantage of soil flushing is that it does not involve excavation and transport of large volumes of contaminated soil. The major disadvantage of soil flushing is that the technique is unproved for decontamination of radioactive and chemically contaminated soil columns. Application would require site-specific analysis of the geology. Furthermore, this technology may not result in the desired level of site decontamination.

A.4.1.4 Remedial Action Schedule

The construction schedule for the well system involves the following activities:

1. Site preparation and drilling of wells.

2. Mobilization of contractors and equipment and setup of equipment.

3. Circulation of treatment fluids through the contaminated soil column.

4. Decontamination and demobilization of equipment.

Based on a treatment volume of 25 feet by 25 feet by 250 feet, circulation of 80 gpm, and two wells for this treatment volume, the respective time periods for the above activities are as follows:

- Mobilization/setup (Assumes delivery of modular and portable treatment facility) — 2 weeks

o	Site preparation/drilling	2 weeks
o	Treatment of soil (Assumes 10 pore volume flushes of soil pores at 20% porosity)	12 weeks
o	Decontamination/Demobilization	1 week
	Total	17 weeks

A.4.1.5 Resource Requirements

Manpower requirements for installation and operation of a soil flushing operation consist of the following:

1. Overall project management and supervision of wells and surface processing facilities. Experience in geotechnical well drilling and chemical process engineering. A total staff of three to six, depending on the size and technology used.

2. Operation and maintenance of the well and surface facilities. This requires operator experience with mechanical and chemical process equipment, and equipment used for radioactive decontamination. A total staff of four to eight, depending on the size and technology used.

3. Support of health and safety engineer.

Equipment required for soil flushing includes: drilling rigs; well tubing and casing; down hole well pumps; injection pumps; pumps for circulation fluids through chemical processing equipment; chemical processing equipment for decontamination of radioactive solutions, ion-exchange columns, mixer/settlers, filtration slurries, and storage tanks; and safety equipment for hazardous and radioactive materials.

Materials required for soil flushing include: acids and bases; lime; solvents; ion-exchange resins; and filter media.

A.4.1.6 Costs

The cost for soil flushing does not include a surface recovery concentration facility. The groundwater pump and treatment technology, which operates in tandem with soil flushing, has projected costs for a surface treatment facility and the associated solid waste disposal cost. Table A.4.1 summarizes the costs associated with solution mining techniques.

The following assumptions are used to develop a unitized cost for site remediation at the Hanford Reservation using soil flushing:

- Two wells are required to treat an area 25 feet by 25 feet by 250 feet

- Well costs of $200 per foot of depth

- The wells would treat 156,250 ft^3 of nominal soil volume, with 20 percent porosity (2900 yd^3 of soil per well)

- Soil treatment cost are $1.60/ton at 100 ppm solution

- Pumping rate of 80 gpm (40 gpm per well).

TABLE A.4.1 SOIL FLUSHING COSTS

	Hourly Rate ($/hr)	Annual Cost ($/yr)
Labor		
1 Foreman	44	21,120
7 Laborers	25	84,000
	Subtotal	$105,120
Equipment		
Drilling $100/ft (250 ft, 2 wells)		50,000
Pumping (pumps, pipes, mix tanks) 80 gpm plant, assembled onsite		18,500
	Subtotal	$68,500
Materials and Safety		
Chemicals $160/ton ($19.5 \times 10^6$ gal of water at 10,000 gpm)		15,600
Health and Safety (8 men @ $25/day/man, 15 weeks)		15,000
	Subtotal	$30,600
	Total	$204,220

Volume of Soil Flushed, 5,800 yd^3

$$\text{Unit Cost} = \frac{\$204,000}{5,800\ yd^3} = \$35/yd^3$$

Capital Cost $80,000, 1/yr recovery.

A.4.2 Groundwater Treatment

A.4.2.1 General Description

Treatment of the water removed by the groundwater pumping system will be performed in two stages. The first stage involves the removal of contaminants by chemical addition and sedimentation in a clarifier and filtration through a dual media sand filter and an activated carbon bed. The second stage involves selective ion-exchange for the removal of strontium and cesium, followed by a mixed bed polishing demineralizer unit. Process flow rates up to 100 gallons per minute can be realized for systems of these types in mobile units that could be moved from site to site.

A.4.2.2 Design and Construction

Although the CERCLA sites are not identical, the general approach to treatment of groundwater pumped from the sites will be similar. Differences will obviously exist between sites that contain NH_3 wastes vs. CN wastes, but these differences do not weigh heavily in the overall site cleanup costs and are not addressed in detail here. These details must be identified when the individual site characterizations are performed.

The wastewater treatment trailer will consist of a chemical feed system for pH control and precipitation of the heavy metals such as chromium and lead in the clarifier along with uranium and plutonium. Fine particulate matter will then be removed in the dual media sand filter. The water then passes through an activated carbon bed for removal of volatile organic carbon (VOC). While the available data on these 81 CERCLA sites mentions disposal of organic wastes for some but not all of the sites, the activated carbon bed is considered part of the system for radionuclide removal, particularly cobalt-60.

Second stage treatment involves the use of ion-exchange resins specifically selected for removal of cesium and strontium. These units are also trailer mounted and can include additional mixed bed units should they be required for additional chemical or radionuclide removal.

The clean water will be acceptable for unrestricted release, although it is expected that it will be reused as part of the groundwater flushing process. Finally, it is assumed that the generated solids (i.e., sludges), consisting of spent carbon and depleted resins, will be solidified prior to disposal.

A.4.2.3 Advantages and Disadvantages

The advantages of this technique are that it is highly flexible in operation and design, suitable for treatment of a wide range of organics and heavy metals, tolerant of some fluctuations in concentration and flow, and relatively inexpensive. The disadvantages are that it is intolerant of high suspended solid levels; unsuitable for removal of low molecular weight organics and highly soluble, highly ionized organics; limited in practice to wastes with less than 10,000 ppm organics; and requires pretreatment for oil and grease removal where concentrations are greater than ten ppm. Spent resin has the potential for containing high concentrations of contaminants and therefore requires costly pretreatment prior to disposal.

A.4.2.4 Remedial Action Schedule

The remedial action schedule, which consists of setting up and operating a groundwater pumping and treatment system, is the same as that for soil flushing. Thus, 18 days will be required for every two million gallons of groundwater treated, based on an estimated treatment throughput of 80 gallons per minute (gpm), 24 hours per day.

A.4.2.5 Resource Requirements

It is estimated that four crews to two persons each, including a crew supervisor and seven skilled laborers, are required to operate the two mobile wastewater treatment units. The skilled laborers include health and safety technicians.

Equipment includes one chemical treatment trailer and another trailer for radionudide treatment. Materials include chemicals, activated carbon, and sand filter for the chemical wastewater treatment unit and resins for the radionuclide treatment unit. Additionally, safety equipment is required for all workers assigned to the unit.

A.4.2.6 Costs

Waste Water System

The capital costs of the first stage trailer is $500,000 and has been assumed to be spread over five years. Chemical costs are estimated at $120/day. Safety equipment costs $25/day/man for protective clothing such as gloves and may run higher during hot weather, as high as $100/day/man if respirators are needed. The 28,000 pound carbon bed is replaced twice each year at a current cost of $0.90/pound.

It is expected that the equipment will be operated around the clock using four crews of two men each for a total of eight men. One of these will be a supervisor. It is expected that this crew would also operate the radionuclide removal system.

Radionuclide Removal System

The capital cost of this equipment, trailer mounted, is estimated at $100,000, also with a five year design life. The only other costs associated with this operation are for the resins and the processing of these resins into a form suitable for disposal. For the purpose of this analysis it is assumed that these waste products will be solidified.

The resins will be nuclear grade cation resins specifically designed for selectively removing only cesium and strontium at a cost of approximately $1,000/ft^3. Current commercial solidification systems for mobile processing cost between $50 and $70/ft^3. This analysis uses a value of $50/ft^3.

The analysis of resin usage is based on the removal of 21,000 curies of strontium and cesium from a column of water roughly equal to the quantity of liquid disposed of in these sites. It is further assumed that the maxium cesium loading on the resin will be 0.5 uCi/cc which will result in a maximum contact dose rate onthe demineralizer of 200 mR/hour.

Cost Summary

As shown in Table A.4.2, the combined cost of the chemical treatment system and the radionuclide removal system, results in a total cost of $29/1,000 gallons or $12/cubic yard of soil flushed.

TABLE A.4.2 WASTEWATER TREATMENT COSTS

	Hourly Rate ($/hr)	Annual Cost ($/yr)
Labor		
1 Supervisor	44	91,520
7 Skilled Laborers	25	364,000
	Subtotal	$ 455,520
Equipment		
1 Chemical Treatment Trailer, $500,000		100,000
1 Radionuclide Treatment Trailer, $100,000		20,000
	Subtotal	$ 120,000
Materials and Safety		
Chemicals (for Chemical Treatment Trailer) ($120/day)		44,000
Carbon replacement ($28,000 lb @ $.90/lb, twice/yr)		50,000
Sand replacement ($1,000/bed, once/yr)		1,000
Resin (150 ft^3/yr x $1,000/$ft^3$)		150,000
Polishing Resins (600 ft^3/yr x $100/$ft^3$)		60,000
Health and Safety ($25/day/man, 8 men)		73,000
	Subtotal	$ 378,000
Other Support Activities		
Waste Treatment & Disposal		
Sludge from clarifer (3,650 ft^3/yr)		
Sand (100 ft^3/yr)		
Carbon (400 ft^3/yr)		
Resins 750 ft^3/yr		
Processing Cost (4,900 ft^3/yr @ $50/$ft^3$)		245,000
Disposal (4,900 ft^3/yr @ $8/$ft^3$)		39,200
	Subtotal	$ 284,200
	Total Cost	$1,238,000

System Throughput @ 80 gpm = 4.2×10^7 gal/yr
Unit Cost = $29/1000 gal, or $12/$yd^3$

A.4.3 References

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A.5 EXCAVATION, TREATMENT, AND DISPOSAL OF CONTAMINATED SOIL

A.5.1 General Description

One of the recommended remediation techniques for hazardous waste sites is excavation of waste materials, which includes removal of the contaminated soil, waste containers, and waste; treatment to immobilize the hazardous components of the waste, and disposal of the treated waste in an approved disposal site. Excavation, removal, and hauling of the waste to the disposal site is usually accomplished with conventional heavy construction equipment.

A.5.2 Design and Construction

This section describes conventional equipment and methods for the excavation, removal, treatment, and disposal of contaminated soil, sludge, and other solid waste material.

Because of the nature of this action, in which contaminated soil is to be exposed to the elements, it has been determined that an enclosure will be required for the excavation area. The scenario developed for this remediation technology is based on a prefabricated steel building on a concrete foundation. The building is equipped with an "airlock" type entrance large enough for construction equipment to enter. The building is not necessarily airtight, but will be under negative pressure at all times to prevent leakage of contamination. This negative pressure is maintained by an air ventilation system that exhausts through a filter system, typically a particulate filter and activated carbon filter. The air would be continuously monitored for radioactivity. A seperate "clean-room" or other small structure would be located inside the cover structure to provide for office space, a change area, lunch room, and rest room facilities.

There is a wide range of heavy construction equipment that can be used for digging and loading. This includes a trencher, dragline, belt loader, wheel bucket excavator, backhoe, dozer and loader, and crane. However, not all of this equipment is applicable for excavation at a hazardous waste site (USEPA, 1985). While conventional equipment may not be appropriate in these cases, conventional equipment costs and capacities were used in this analysis. The error introduced in the unit cost is minimal since equipment costs are a small fraction of the total cost.

Excavation was assumed to be performed by a backhoe with a boom or dipper stick, with a hoe dipper attached to the outer end. The unit is usually a crawler-mounted, hydraulically operated vehicle. The maximun reach of the boom ranges from 35 to 70 feet. Theoritical production rate for a backhoe is from 360 cubic yard (yd^3)/day for a 1 yd^3 bucket to 1200 yd^3/day for a 3.5 yd^3 bucket (Godfrey, 1984).

Dozers and loaders are usually fitted with a hydraulic controlled blade and bucket lift, and can be either crawler-mounted or equipped with rubber tires. Crawler dozers equipped with blades have tremendous earth-moving power and are excellent graders. The dozers are usually used in combination with other excavators such as backhoes. Front-end loaders are tractors equipped with buckets for digging, lifting, hauling, and dumping materials. They can carry materials as far as 300 feet from the digging area (USEPA, 1985). Depending on the type of bucket capacity, crawler loaders can theoritically produce from about 500 to more than 1200 yd^3/day (Godfrey, 1984).

Due to the inherently hazardous nature of the material, manual handling is not desirable. For this reason is has been assumed that excavated waste material will be loaded into a hopper arrangement and meter-fed into standard 55 gallon drums. These drums will be capped, checked for external contamination, and transferred by roller conveyor to the truck loading station located outside the cover structure. Excavated and drummed waste materials must be transported either to an onsite treatment facility or directly to the approved disposal site.

In either case the filled drums will be loaded onto flatbed tractor trailers using standard forklifts equipped with four-drum grapples. Each truck will be capable of carrying approximately 60 drums weighing approximately 25 tons. Payloads greater than this would require an extensive road construction program which is not considered warranted.

Contaminated soil excavated from the site can be disposed of directly at an engineered and permitted disposal site if the contamination level is within the disposal limitation currently promulgated under RCRA regulation. However, if the waste concentration does not meet the RCRA requirement, the excavated contaminated soil should be treated prior to final disposal. Treatment techniques for contaminated soil include thermal destruction, solidification, and chemical treatment. Among these treatment techniques, thermal destruction is probably the most costly process for removing contaminants from the soil.

Thermal destruction is a treatment technique that uses high temperature oxidation under controlled conditions to break down the waste into basic constituents such as CO_2, H_2O vapor, SO_2, NO_x, HCl, gases, and ash. Waste products such as noxious gases generated by this technology should be controlled using air pollution equipment to prevent the release of undesirable chemicals into the environment (Kaiser Engineers, 1987). At present, there are more than 20 different thermal destruction technologies that appear suitable for hazardous waste treatment. However, only rotary kilns and hearth incenerators are proven technologies that have been commercially and industrially used to treat hazardous and toxic wastes (SAIC, 1987).

Solidification of contaminated soil can be achieved by direct mixing of the soil with a solidification agent such as cement, silicates, or thermoplastics to form a monolithic block of waste with high structural integrity. The contaminants may not interact chemically with the solidifier but are mechanically locked within the solidified matrix. The effectiveness of this method is rather short-term, since the waste could be leached out of the matrix over a long period of time due to the porous nature of cement and grout.

Vitrification is also considered as a solidification technology. In this case, the waste is combined with molten glass at a temperature of 1,350°C or higher. With this technique, the waste is either stable or totally destroyed during the processing. An in-situ vitrification technique is discussed in Appendix A.3.

Chemical treatment of contaminated soil consists of applying chemicals to the soil to mobilize the contaminants for extraction. Soil flushing with surfactants, dilute acids and bases, and water are used to mobilize the contaminants for extraction. This technique is discussed in Section A.4.

Excavated contaminated soil meeting the disposal limitation under RCRA regulation, and treated soil are assumed to be disposed of onsite, since it is envisioned that the amount of excavated waste materials would be too enormous to be disposed of offsite. Therefore, it is assumed that an onsite RCRA-permitted, engineered disposal site will be established to handle the disposal of the excavated soil.

A.5.3 Advantages and Disadvantages

Excavation, packaging, removal, treatment and disposal of contaminated soil are functions performed extensively in hazardous waste site remediation. There are no definite limitations on the types of waste that can be remediated by this technique. However, worker health and safety needs to be considered during the selection of this technique for removing explosive, reactive, highly toxic and radioactive waste materials.

Excavation is applicable for all types of waste sites and conditions, although it may become cost-prohibitive at great depths or in complex geologic formations. Also, due to the potentially great health and safety risks faced by workers, this technique may not be applicable for highly reactive waste sites such as underground tank farms that may still contain highly radioactive residues. In this case, other alternatives such as in-situ treatment technologies should be considered for remediation.

A.5.4 Remedial Action Schedule

Site activities begin with site clearing and laying of the cover building foundation footings. The length of time required for these activities is dependent on the size of the site, but is assumed to require 30 days, with an additional 30 days of curing before erection of the building can start. The erection of the building is also based on building size and is estimated to take one working day per 1000 ft^2 area. For most of the sites, this will require from several weeks to a few months.

During this period, all of the drum handling equipment and other support services can be installed. Once the building is erected, the excavation will proceed at a rate of 630 yd^3/day. Once excavation of the site is completed, backfilling, using uncontaminated native soils, will begin. Initially, approximately five feet of soil will be backfilled over the base of the excavation pit to cover any contaminated soils that were not excavated. Once this is done, the cover structure will be decontaminated and disassembled. Backfilling will continue until the site has been filled to the original grade.

A.5.5 Resource Requirements

Erection of the cover structure will require conventional excavation equipment, but not to depths which could result in exhumation of the disposed waste, i.e., two to three feet for foundation footers. With the building finished, a single backhoe (or front end loader) will be used to dig soil and transfer it to the drum loading equipment. Powered drum conveyors transport the filled, clean drums outside to a loading dock where as many as seven forklifts move the drums onto flatbed trailers. Seven forklifts are needed based on a production rate of 630 cubic yards of soil per day. Each drum can hold seven cubic feet. Therefore, 2430 drums are needed daily, or approximately five drums per minute must be loaded onto a trailer. Each forklift can be equipped to pick up four drums at a time. If each forklift takes five to six minutes to pick up, move, and set down four drums and return to the pickup point, approximately six to seven forklifts are needed.

At the drum loading rates identified above, it will take approximately 30 minutes to load a truck and 30 minutes to unload it. If the travel time to the disposal site is also 30 minutes, a complete round trip will take two hours. In this event, each truck can transport 240 drums per day, for a total of ten trucks required per site. Backfilling of the excavated pit will proceed at 630 yd^3/day.

A.5.6 Costs

The costs associated with the excavation of a site have been broken down into five categories: labor, equipment (leased or rented), materials and safety, capital equipment, and disposal. A sixth cost associated with the thermal destruction via rotary kiln incinerator is also listed.

Labor costs include a site superintendent; one labor foreman; six laborers associated with the drum filling, loading and decontamination; and a clerk to keep records on the progress of work, time sheets, and drum marking. A radiation site manager is also required, as are three radiation safety technicians, one working at the excavation area providing continuous monitoring, and two working on the drum decontamination and marking/labeling efforts. Hourly labor rates are shown in Table A.5.1.

Rental rates for a backhoe, seven forklifts, and ten tractor trailers (including operators), in addition to a detailed breakdown of the various equipment that must be purchased to perform the excavation work are provided in Table A.5.1. The total cost of the building, utilities, and ancillary equipment is only four percent of the total cost. Therefore, while some costs are based on field experience with similar equipment, the error associated with any single cost element is small.

The only regularly consumed material will be drums at a cost of \$21/drum. Health and safety, including such items as gloves, and protective clothing, respirators for workers exposed to dust, will cost \$100 per day per man.

Disposal costs are based on a drum capacity of seven cubic feet, but a burial cost based on 7.5 ft^3 of volume. The cost of thermal destruction is based on currently available information. For rotary kiln incinerators this cost is approximately \$200/ton. Using a soil density of 120 #/ft^3, this cost becomes \$324/yd^3.

TABLE A.5.1 EXCAVATION & DISPOSAL COSTS

	Hourly Rate ($/hr)	Annual Cost ($/yr)
Labor(1)		
1 Site Superintendent	58	$ 121,000
1 Shift Foreman	44	91,520
6 Laborers (drum loading, filling)(2)	20	249,600
3 Radiation Safety Technicians	28	174,720
1 Clerical/Records Manager	26	54,080
1 Radiation Site Manager (labor associated with equipment operation is included with equipment costs)	48	99,840
	Subtotal	$ 790,760
Equipment		
1 Backhoe w/operator ($249/yd^3)(2) 630 yd^3/day x 260 days/yr.		407,862
10 Tractor Trailers-Flatbed w/driver ($350/day)(3) 60 drums/trip, 4 trips/day		1,277,500
7 Forklifts w/operators ($185/day/each)(4)		472,675
8 Dump trucks w/operators ($490/yd^3)		803,000
2 Dozers w/operators and compacters ($2.75/yd^3)		450,500
	Subtotal	$ 3,412,000
Capital Equipment		
Cover Structure (400 x 400)(4) (+ 20% for utilities)		1,872,000
Cover Structure Foundation		19,200
Soil Dumping & Drum Filling Equipment(3)		100,000
Drum Conveyors(3)		50,000
Positive Ventilation System with Filters and Monitoring System 4 required @ 3000 cfm		180,000
Local Air Sampling System		5,000
Structure Air Lock (Personnel & Equipment) not airtight		20,000
Clean Room (lunch/charge/HP)(2)		77,000
Cover Structure Decontamination and Disassembly		1,800,000
	Subtotal	4,123,000

	Hourly Rate ($/hr)	Annual Cost ($/yr)
Materials and Safety		
Drums - 632,000/yr (Steel 55 gal DOT 7-H)(3)		13,267,800
Health & Safety (12 people x $100/day x 260 d/yr) (forklift operator and truck driver not included)		312,000
	Subtotal	$13,580,000
Other Support Activities		
Disposal		
632,000 drums/yr x 7.5 ft^3/drum x $8/$ft^3$		37,920,000
Treatment		

$$\$200/\text{ton} \times \frac{1 \text{ ton}}{2000 \text{ lb}} \times \frac{120 \text{ lb}}{\text{ft}^3} \times \frac{27 \text{ ft}^3}{\text{yd}^3} = \$324/\text{cy}^3$$

(by incineration)

	Total Cost	$56,772,000

Summary

630 yd^3/day x 260 day/yr = 163,800 yd^3/yr

	$/yr	$/$yd^3$	w/o Treatment	w/ Treatment
Labor	1,111,000	7	2%	1%
Equipment	3,412,000	13	4%	2%
Materials & Safety	13,580,000	83	24%	12%
Capital Equipment	4,123,000	12	3%	2%
Disposal	37,920,000	231	67%	35%
Treatment (if required)		324	—	48%
Total w/o Treatment		365	100%	
Total w/Treatment		689		100%

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(1) Kaiser Labor Rates (except as noted)
(2) Dodge 1987
(3) Field Experience
(4) Means 1985

A.5.7 References

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A.6 IN-PLACE DECONTAMINATION

A.6.1 General Description

This technique refers to the decontamination of structures containing waste material such as above-ground tanks, vaults, and waste containers. In-place decontamination consists of removing residues from the structure, rinsing it with an appropriate solution, and, if necessary, filling it with inert material such as sand, clean soil, or cement.

A.6.2 Design and Construction

This technique does not require complex or state-of-the-art equipment; the requirement is to remove residual contamination and rinse the structure with an appropriate cleaning solution so as to remove all hazardous constituents.

Typically, the residue remaining in the structure will be in the form of a sludge or layer of crystallized salts. In either case, it will be necessary to liquefy the residues prior to removing them, as a liquid is easier to remove than a solid. The removal process consists of pumping the liquefied material out of the container; if it is equipped with a bottom outlet, gravity discharge can be used instead.

After the residue has been removed, a rinsing solution is injected into the unit for cleanup purposes. According to RCRA regulations, it is recommended that three rinsings be used for this type of decontamination technique. Selection of the rinsing solution depends on the chemical characteristics of the waste residues. For example, if the tank is known to contain oil heel, it is suggested that a petroleum-based solvent first be used to liquefy the sludge, followed by a detergent solution for rinsing.

Once the liquefied residue is removed from the unit, proper treatment and disposal of the waste is required. In most cases, the waste will either be chemically neutralized or stabilized in some sort of waste-solidifier matrix. The cost for these treatment techniques is presented in USEPA, 1985. The rinsing solution also requires treatment and proper disposal. In addition, it will be necessary to sample the third (final) rinsing solution to ensure that no hazardous contaminants remain.

Following cleanup of the structure, it can either be left as is, refilled with inert material such as sand or cement, or used for another purpose. Since it is assumed that this technique ensures decontamination, no further action is required.

A.6.3 Advantages and Disadvantages

The advantages of this technique are that it is easy to perform and relatively inexpensive, does not require special equipment and material, and the decontaminated structure can be reused for other purposes.

Disadvantages include requirements for treatment and disposal of the residual waste and rinsing solution. Also, it is not applicable for structures that have leaks or residues that cannot be readily dissolved and removed from the unit. Additionally, if the waste is highly reactive and/or radioactive, a potential occupational health hazard could be a limiting factor. In these cases, other remediation techniques such as in-situ vitrification are more appropriate.

A.6.4 Remedial Action Schedule

For the purpose of estimating the manpower requirements and work schedule for this technique, it is assumed that a 50,000 gallon tank, 15 feet high by 24 feet in diameter, containing about 500 gallons of diesel oil heel is recommended for cleanup. It is also assumed that the tank is equipped with a six-inch diameter bottom outlet capable of discharging approximately 250 gallons per minute.

First, it is assumed that 1,000 gallons of solvent will be mixed with the oil heel in order to liquefy it. The liquefaction phase requires about two days for a complete reaction. During this time, the detergent solution is also prepared for the rinsing phase. When it is determined that the contents of the unit are ready for removal, the bottom outlet is hooked up to a waste storage unit. It is estimated that the discharge of 1,500 gallons of waste will take about six minutes. With a pump capable of delivering 250 gallons per minute, each rinsing will require approximately 200 minutes. It is assumed that the solution will remain in the tank for one hour prior to discharge. The full tank discharge will require an average of about 200 minutes. Thus, for each rinsing, it is estimated that a total of 460 minutes, or approximately eight hours, is required. Assuming that other activities such as refilling tank trucks and setting up equipment will take an additional two hours per rinsing, a sum total of ten hours is estimated for each rinsing of the tank. Thus, an estimated six days will be required to complete the cleanup of the tank.

Second, it is assumed that the tank is left as is after it has been cleaned up, and that treatment of the waste residue and rinsing solution takes place afterward. Using a mobile wastewater treatment facility with a throughput of 80 gallons per minute (gpm), the wastewater treatment requires about 31 hours. Treatment of waste residue is estimated at three hours, or ten percent of the time required for wastewater treatment. Therefore, the total amount of time required for treatment of waste residue and rinsing water is estimated at about four days.

At the third rinsing of the waste unit, three samples of discharge will be collected and analyzed for cleanup confirmation. The sampling and analysis will take about six weeks, with one additional day for an evaluation of the results. Thus, the total amount of time required to clean up the above tank is estimated at eight weeks.

A.6.5 Resource Requirements

The manpower requirement is estimated for different phases of the cleanup operation. For the waste liquefaction phase, it is estimated that about four hours will be required to perform the operation requiring a tank truck operator, a health safety officer, and a field engineer. During the rinsing phase, it is estimated that the operation will take approximately four days, with a crew of two tank truck operators, a health safety officer, and a field engineer. For the waste residue and wastewater treatment phase, it is estimated that a crew of two operators and one health safety technician will be able to perform the operation in four days. For the confirmation sampling phase, it is estimated that one engineer will require one day to evaluate the sampling analysis results. Table A.6.1 shows a summary of the manpower requirement estimated for this remediation technique. Based on the total waste unit volume of 50,000 gallons or 250 cubic yards (yd^3), the estimated unit manpower is calculated at 4.9 man-hours/1,000 gallons or about 1.0 man-hours/yd^3.

A.6.6 Costs

A summary of the costs to clean up the above unit is described in Table A.6.1. The unit cost is approximately $1.10/gallon or $210/$yd^3$ of waste unit volume.

TABLE A.6.1 IN-PLACE DECONTAMINATION COSTS

	Hourly Rate ($/hr)	Annual Cost ($/yr)
<u>Labor</u>		
<u>Waste Liquefaction Phase</u>		
1 Tank Truck Operator	25[(1)]	100
1 Health Safety Officer	48[(2)]	192
1 Field Engineer	44[(2)]	176
<u>Waste Unit Rinsing Phase</u>		
2 Tank Truck Operators	25[(1)]	1,600
1 Health Safety Officer	48[(2)]	1,536
1 Field Engineer	44[(2)]	1,408
<u>Waste Treatment Phase</u>		
2 Operators*		
1 Health Safety Technician*		
<u>Confirmation Sampling Phase</u>		
1 Engineer	58[(2)]	464
	Subtotal	$5,476
<u>Equipment</u>		
<u>Waste Liquefaction Phase</u>		
1 Tank Truck ($360/day)[(1)]		360
<u>Waste Unit Rinsing Phase</u>		
2 Tank Trucks ($360/day)[(1)]		2,880
	Subtotal	$3,240
<u>Materials and Safety</u>		
<u>Waste Liquefaction Phase</u>		
Solvent (1,000 gal, $1/gal)		1,000
<u>Waste Unit Rinsing Phase</u>		
Mixed Detergent Solution (150,000 gal, $0.05/gal)		7,500
	Subtotal	$8,500

TABLE A.6.1 IN-PLACE DECONTAMINATION COSTS (continued)

	Hourly Rate ($/hr)	Annual Cost ($/yr)
<u>Other Support Activities</u>		
<u>Waste Treatment</u>**		
Wastewater Treatment (150,000 gal, $29/1,000 gal)		4,350
Waste Residue Treatment (Drum and Disposal) (1,500 gal or 7.5 yd^3, $1,350/$yd^3$)		10,125
<u>Configuration Sampling Phase</u>		
Sampling Cost (3 samples, $7,000/sample)		21,000
	Subtotal	$35,475
	Total	$52,700

Estimated Volume of Waste Unit	50,000 gal. or ≃ 250 yd^3
Unit Cost	$1.10/gal. or $210/$yd^3$
Estimated Unit Manpower	4.9 man-hours/1,000 gal. or 1.0 man-hours/yd^3

(1) Godfrey, updated using ENR Market Trends
(2) Kaiser
* Labor cost included in unit cost for Waste Treatment/Other
** Unit cost includes labor, equipment, and material

A.7.7 References

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APPENDIX B

REMEDIAL ACTION TECHNOLOGIES

REMEDIAL TECHNOLOGIES

A. Air Pollution Controls

- Capping
  - synthetic membranes
  - clay
  - asphalt
  - multimedia cap
  - concrete
  - chemical sealants/stabilizers

- Dust Control Measures
  - polymers
  - water

Surface Water Controls

- Capping (See A.)

- Grading
  - scarification
  - tracking
  - contour furrowing

- Revegetation
  - grasses
  - legumes
  - shrubs
  - trees, conifers
  - trees, hardwoods

- Diversion and Collection Systems
  - dikes and berms
  - ditches, trenches, diversions
  - terraces and benches
  - chutes and downpipes
  - seepage basins
  - sedimentation basins/ponds
  - levees
  - floodwalls

C. <u>Leachate and Groundwater Controls</u>

- Capping (See A.)

- Containment Barriers

  Function Options (Vertical Barriers)

  - upgradient placement
  - downgradient placement
  - circumferential placement

  Materials/Construction Options (Vertical Barriers)

  - soil-bentonite slurry wall
  - cement-bentonite slurry wall
  - vibrating beam/asphalt wall
  - grout curtains
  - steel sheet piling
  - Envirowall cut-off

  Horizontal Barrier (Bottom Sealing)

  - block displacement
  - grout injection

- Groundwater Pumping

  Function Options

  - extraction alone
  - extraction/injection
  - injection wells

  Equipment/Material Options

  - well points
  - deep wells
  - suction wells
  - ejector wells

- Subsurface Collection Drains

  - French drains
  - tile drain
  - pipe drain (dual media drain)

D. Gas Migration Controls

- Capping (gas barriers) (See A.)
- Gas Collection and/or Recovery

  - passive pipe vents
  - passive trench vents
  - active gas collection systems

E. Waste and Soil Excavation and Removal

- Excavation/Removal

  - backhoe
  - cranes and attachments
  - front end loaders
  - scrapers
  - pumps
  - industrial vacuums
  - drum grapplers
  - forklifts and attachments

- Grading (See B.)
- Capping (See A.)
- Revegetation (See B.)

F. Contaminated Sediments Removal and Containment

- Sediment Removal

  Mechanical Dredging

  - clamshell
  - dragline
  - backhoe

  Hydraulic Dredging

  - plain suction
  - cutterhead
  - dustpan

  Pneumatic Dredging

  - airlift
  - pneuma
  - oozer

- Sediment Turbidity Controls and Containment

  - curtain barriers
  - cofferdams
  - pneumatic barriers
  - capping

G. <u>In-Situ Treatment Methods</u>

  - hydrolysis
  - oxidation
  - reduction
  - soil aeration
  - solvent flushing
  - neutralization
  - polymerization
  - sulfide precipitation
  - bioreclamation
  - permeable treatment beds
  - chemical dechlorination

H. <u>Direct Waste Treatment</u>

- Incineration

  - rotary kiln
  - fluidized bed
  - multiple hearth
  - liquid injection
  - molten salt
  - high temperature fluid wall
  - plasma arc pyrolysis
  - cement kiln
  - pyrolysis/starved combustion
  - wet air oxidation

- Gaseous Waste Treatment

  - activated carbon
  - flares
  - afterburners

- Treatment of Aqueous and Liquid Waste Streams

  Biological Treatment Techniques

  - activated sludge
  - trickling filters
  - aerated lagoons
  - waste stabilization ponds
  - rotating biological discs
  - fluidized bed bioreactors

TABLE 3-1 REMEDIAL TECHNOLOGIES (Continued)

Chemical Treatment Techniques

- neutralization
- precipitation
- oxidation
- hydrolysis
- reduction
- chemical dechlorination
- UV/ozonation

Physical Treatment Techniques

- flow equalization
- flocculation
- sedimentation
- activated carbon
- Kleensorb
- ion exchange
- reverse osmosis
- liquid/liquid extraction
- oil water separator
- steam distillation
- air stripping
- steam stripping
- filtration
- dissolved air flotation

Discharge to POTW

- Solids Handling and Treatment

Dewatering

- screens, hydraulic classifiers, scalpers
- centrifuges
- gravity thickening
- flocculation, sedimentation
- belt filter press
- filter press
- drying or dewatering beds
- vacuum assisted drying beds

Treatment

- neutralization
- solvent
- oxidation
- reduction
- composting

- Solidification/Stabilization/Fixation

  - cement based
  - lime based
  - thermoplastic
  - organic polymer
  - self-cementing techniques
  - surface encapsulation
  - glassification
  - solidification materials (i.e., flyash, polymers, sawdust)

I. Land Disposal Storage

  - landfills
  - surface impoundments
  - land application
  - waste piles
  - deep well injection
  - temporary storage

J. Contaminated Water Supplies and Sewer Lines

- In-Situ Cleaning

- Removal and Replacement

- Alternate Drinking Water Supply

  - bottled water
  - cisterns/tanks
  - deeper or upgradient wells
  - municipal water system
  - relocation of intake

- Individual Treatment Units