

Table D.5.15 Chemical analyses of ground water, Green River, Utah, tailings site (Continued)

FORMATION OF COMPLETION: SANDSTONE
 HYDRAULIC FLOW RELATIONSHIP: UP GRADIENT

		LOCATION ID -- SAMPLE ID AND LOG DATE									
		587-04 03/13/87		587-04 10/05/87		587-04 01/10/88		588-04 09/11/86		588-04 03/13/87	
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE +/- UNCERTAINTY		PARAMETER VALUE +/- UNCERTAINTY		PARAMETER VALUE +/- UNCERTAINTY		PARAMETER VALUE +/- UNCERTAINTY		PARAMETER VALUE +/- UNCERTAINTY	
ALKALINITY	MG/L CaCO3	546.		419.		593.		565.		614.	
ALUMINUM	MG/L	1.1		< 0.1		0.1		0.3		0.3	
AMMONIUM	MG/L	1.0		0.2		0.1		0.9		0.6	
ANTIMONY	MG/L	-		-		-		< 0.003		-	
ARSENIC	MG/L	-		0.04		0.006		< 0.01		-	
BALANCE	Z	-		-		-		-2.87		-	
BARIUM	MG/L	-		-		-		< 0.1		-	
BORON	MG/L	0.9		0.8		0.78		0.6		0.6	
CADMIUM	MG/L	-		-		-		< 0.004		-	
CALCIUM	MG/L	7.28		3.1		4.78		9.96		5.49	
CHLORIDE	MG/L	79.1		93.		76.		240.		319.	
CHROMIUM	MG/L	0.03		< 0.01		0.03		0.06		0.02	
COBALT	MG/L	-		-		-		< 0.05		-	
CONDUCTANCE	UMHU/CM	3000.		2700.		2820.		2350.		2500.	
COPPER	MG/L	-		-		-		0.03		-	
FLUORIDE	MG/L	5.5		5.1		5.3		3.2		3.4	
GROSS ALPHA	PCI/L	1.	13.	0.9	5.9	21.	12.	-		1.	13.
GROSS BETA	PCI/L	13.	8.	0.0	16.	0.	10.	-		0.0	9.4
IRON	MG/L	< 0.03		< 0.03		0.19		0.14		0.04	
LEAD	MG/L	-		-		-		< 0.01		-	
MAGNESIUM	MG/L	0.03		0.78		1.73		1.78		1.30	
MANGANESE	MG/L	< 0.01		< 0.01		< 0.01		0.02		0.03	
MERCURY	MG/L	-		-		-		< 0.0002		-	
MOLYBDENUM	MG/L	< 0.1		0.03		0.07		0.09		< 0.1	
NICKEL	MG/L	-		-		-		< 0.04		-	
NITRATE	MG/L	0.8		< 1.0		< 0.1		3.		< 0.1	
NITRITE	MG/L	-		-		-		< 0.1		-	
ORG. CARBON	MG/L	-		7.		138.		-		-	
PH	SU	11.64		9.35		9.0		8.65		8.30	
PHOSPHATE	MG/L	-		-		-		< 0.1		-	
POTASSIUM	MG/L	4.09		1.27		1.29		1.54		1.21	
RA-226	PCI/L	0.0	0.2	0.1	0.1	0.1	0.1	-		0.2	0.2
RA-228	PCI/L	-		2.9	1.0	0.	0.8	-		-	
SELENIUM	MG/L	< 0.002		< 0.005		0.043		0.096		< 0.002	
SILICA	MG/L	-		-		-		8.		-	
SILVER	MG/L	-		-		-		< 0.01		-	
SODIUM	MG/L	803.		740.		864.		677.		731.	
STRONTIUM	MG/L	-		-		-		0.4		-	
SULFATE	MG/L	1170.		950.		1193.		645.		635.	
SULFIDE	MG/L	-		-		-		-		-	
TEMPERATURE	C - DEGREE	15.0		16.0		16.1		19.		11.0	
TH-230	PCI/L	0.0	0.4	-		-		-		0.3	0.5
TIN	MG/L	-		-		-		< 0.005		-	
TOTAL SOLIDS	MG/L	2480.		2200.		2430.		2000.		2170.	
URANIUM	MG/L	0.0016		0.003		0.0027		< 0.0003		0.0010	
VANADIUM	MG/L	-		< 0.01		< 0.01		0.22		-	

D-150

Table D.5.15 Chemical analyses of groundwater, Green River, Utah, tailings site (Continued)

FORMATION OF COMPLETION: SANDSTONE
 HYDRAULIC FLOW RELATIONSHIP: UP GRADIENT

PARAMETER	UNIT OF MEASURE	LOCATION ID - SAMPLE ID AND LOG DATE				
		587-01 03/13/87	587-01 10/05/87	587-01 01/10/88	588-01 09/11/86	588-01 03/13/87
		PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
ZINC	MG/L	-	0.005	< 0.005	0.010	-

Table D.5.15 Chemical analyses of groundwater, Green River, Utah, tailings site (Continued)

FORMATION OF COMPLETION: SANDSTONE
 HYDRAULIC FLOW RELATIONSHIP: UP GRADIENT

PARAMETER	UNIT OF MEASURE	LOCATION ID - SAMPLE ID AND LOG DATE									
		588-01 10/02/87		588-01 01/10/88		588-01 07/21/88		817-01 10/22/87		817-02 10/22/87	
		PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	
ALKALINITY	MG/L CaCO3	555.	545.	531.	655.	655.					
ALUMINUM	MG/L	< 0.1	< 0.1	0.02	< 0.1	< 0.1					
AMMONIUM	MG/L	0.2	< 0.1	< 0.1	0.2	0.2					
ANTIMONY	MG/L	-	-	-	-	-					
ARSENIC	MG/L	0.04	0.04	0.042	< 0.04	< 0.04					
BALANCE	%	-	-	-	-	-					
BARIUM	MG/L	-	-	0.02	-	-					
BORON	MG/L	0.7	0.69	0.6	0.6	0.6					
CADMIUM	MG/L	-	-	0.020	-	-					
CALCIUM	MG/L	4.2	4.43	6.90	2.7	2.7					
CHLORIDE	MG/L	220.	240.	660.	320.	310.					
CHROMIUM	MG/L	< 0.01	0.02	0.02	< 0.01	< 0.01					
COBALT	MG/L	-	-	-	-	-					
CONDUCTANCE	UMHO/CM	2390.	2460.	3100.	1950.	1950.					
COPPER	MG/L	-	-	< 0.04	-	-					
FLUORIDE	MG/L	2.6	2.67	3.1	5.6	5.4					
GROSS ALPHA	PCI/L	0.0	22.	0.	20.	30.	22.	0.0	20.		
GROSS BETA	PCI/L	0.0	20.	0.	9.	5.	13.	25.	17.	0.0	
IRON	MG/L	< 0.03	0.4	< 0.04	< 0.03	< 0.03		< 0.03	< 0.03	15.	
LEAD	MG/L	-	-	0.01	-	-		-	-		
MAGNESIUM	MG/L	0.90	0.89	1.48	0.71	0.73					
MANGANESE	MG/L	< 0.04	< 0.04	< 0.04	0.02	0.02					
MERCURY	MG/L	-	-	< 0.0002	-	-					
MOLYBDENUM	MG/L	< 0.04	0.02	< 0.04	0.03	0.04					
NICKEL	MG/L	-	-	-	-	-					
NITRATE	MG/L	< 1.0	< 0.4	< 0.4	< 1.0	< 1.0		< 1.0	< 1.0		
NITRITE	MG/L	-	-	-	-	-		-	-		
ORG. CARBON	MG/L	4.	34.8	127.	< 1.	< 1.		< 1.	< 1.		
PH	SU	8.15	8.25	8.34	8.2	8.2					
PHOSPHATE	MG/L	-	-	-	-	-		-	-		
POTASSIUM	MG/L	0.92	0.97	1.4	1.11	1.11					
RA-226	PCI/L	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	
RA-228	PCI/L	1.1	1.1	0.4	0.4	0.5	0.9	3.8	4.3		
SELENIUM	MG/L	0.007	0.027	0.024	< 0.005	< 0.005		< 0.005	< 0.005		
SILICA	MG/L	-	-	-	-	-		-	-		
SILVER	MG/L	-	-	< 0.04	-	-		-	-		
SODIUM	MG/L	690.	683.	904.	550.	550.					
STRONTIUM	MG/L	-	-	-	-	-		-	-		
SULFATE	MG/L	660.	674.	574.	134.	133.					
SULFIDE	MG/L	-	-	5.6	-	-		-	-		
TEMPERATURE	C - DEGREE	16.0	16.2	16.5	17.0	17.0					
TH-230	PCI/L	-	-	-	-	-		-	-		
TIN	MG/L	-	-	-	-	-		-	-		
TOTAL SOLIDS	MG/L	1880.	1930.	2330.	1500.	1490.					
URANIUM	MG/L	< 0.003	< 0.0003	< 0.0003	< 0.003	< 0.003		< 0.003	< 0.003		
VANADIUM	MG/L	< 0.01	< 0.04	0.04	< 0.04	< 0.04		< 0.04	< 0.04		

D-152

Table D.5.15 Chemical analyses of groundwater, Green River, Utah, tailings site (Continued)

FORMATION OF COMPLETION: SANDSTONE
 HYDRAULIC FLOW RELATIONSHIP: UP GRADIENT

PARAMETER	UNIT OF MEASURE	LOCATION ID - SAMPLE ID AND LOG DATE				
		588-01 10/02/87	588-01 04/10/88	588-01 07/21/88	817-01 10/22/87	817-02 10/22/87
		PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
ZINC	MG/L	< 0.005	0.007	< 0.005	< 0.005	< 0.005

Table D.5.15 Chemical analyses of groundwater, Green River, Utah, tailings site (Continued)

FORMATION OF COMPLETION: SANDSTONE
 HYDRAULIC FLOW RELATIONSHIP: UP GRADIENT

		----- LOCATION ID - SAMPLE ID AND LOG DATE -----									
		B47-03 10/22/87		B47-04 10/22/87		B47-05 10/22/87		B47-04 01/10/88		B47-02 01/10/88	
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE+/-UNCERTAINTY		PARAMETER VALUE+/-UNCERTAINTY		PARAMETER VALUE+/-UNCERTAINTY		PARAMETER VALUE+/-UNCERTAINTY		PARAMETER VALUE+/-UNCERTAINTY	
ZINC	MG/L	<	0.005	<	0.005	<	0.005		0.009		0.011

Table D.5.15 Chemical analyses of groundwater, Green River, Utah, tailings site (Continued)

FORMATION OF COMPLETION: SANDSTONE
 HYDRAULIC FLOW RELATIONSHIP: UP GRADIENT

PARAMETER	UNIT OF MEASURE	LOCATION ID - SAMPLE ID AND LOG DATE									
		817-03 04/10/88		817-04 04/10/88		817-05 01/10/88		817-01 07/18/88		818-01 10/20/87	
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	
ALKALINITY	MG/L CaCO3	688.	688.	688.	688.	662.	541.				
ALUMINUM	MG/L	< 0.1	< 0.1	< 0.1	< 0.1	0.01	< 0.1				
AMMONIUM	MG/L	< 0.1	< 0.1	< 0.1	< 0.1	0.1	0.2				
ANTIMONY	MG/L	-	-	-	-	-	-				
ARSENIC	MG/L	< 0.01	< 0.01	< 0.01	< 0.01	0.002	0.01				
BALANCE	%	-	-	-	-	-	-				
BARIUM	MG/L	-	-	-	-	0.13	-				
BORON	MG/L	0.77	0.79	0.8	0.8	0.8	0.7				
CADMIUM	MG/L	-	-	-	-	0.002	-				
CALCIUM	MG/L	2.54	2.54	2.51	2.51	2.47	6.4				
CHLORIDE	MG/L	330.	320.	330.	330.	360.	450.				
CHROMIUM	MG/L	0.03	0.03	0.03	0.03	< 0.01	< 0.01				
COBALT	MG/L	-	-	-	-	-	-				
CONDUCTANCE	UMHO/CM	1960.	1960.	1960.	1960.	2000.	2900.				
COPPER	MG/L	-	-	-	-	< 0.01	-				
FLUORIDE	MG/L	5.08	5.16	5.22	5.22	6.1	2.6				
GROSS ALPHA	PCI/L	6.	11.	4.6	9.3	3.	10.	0.	16.	0.0	2.1
GROSS BETA	PCI/L	6.	8.6	11.	9.	5.3	9.1	9.	11.	0.2	2.4
IRON	MG/L	0.45	0.45	0.45	0.45	< 0.01	< 0.03				
LEAD	MG/L	-	-	-	-	0.01	-				
MAGNESIUM	MG/L	0.60	0.62	0.64	0.64	0.53	1.39				
MANGANESE	MG/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.03				
MERCURY	MG/L	-	-	-	-	< 0.0002	-				
MOLYBDENUM	MG/L	0.06	0.07	0.07	0.07	0.05	< 0.01				
NICKEL	MG/L	-	-	-	-	-	-				
NITRATE	MG/L	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 1.0				
NITRITE	MG/L	-	-	-	-	-	-				
ORG. CARBON	MG/L	155.	163.	160.	160.	165.	6.				
PH	SU	8.4	8.4	8.4	8.4	8.39	8.3				
PHOSPHATE	MG/L	-	-	-	-	-	-				
POTASSIUM	MG/L	0.85	0.85	0.86	0.86	2.6	1.41				
RA-226	PCI/L	0.	0.1	0.	0.1	0.1	0.3	0.2	0.2	0.1	
RA-228	PCI/L	0.1	0.9	0.	0.8	0.	0.6	0.7	0.7	1.4	
SELENIUM	MG/L	0.008	0.008	0.007	0.007	0.008	0.007				
SILICA	MG/L	-	-	-	-	-	-				
SILVER	MG/L	-	-	-	-	< 0.01	-				
SODIUM	MG/L	564.	560.	558.	558.	589.	810.				
STRONTIUM	MG/L	-	-	-	-	-	-				
SULFATE	MG/L	139.	137.	139.	139.	135.	620.				
SULFIDE	MG/L	-	-	-	-	< 0.1	-				
TEMPERATURE	C - DEGREE	15.5	15.5	15.5	15.5	17.0	18.0				
TH-230	PCI/L	-	-	-	-	-	-				
TIN	MG/L	-	-	-	-	-	-				
TOTAL SOLIDS	MG/L	1490.	1490.	1490.	1490.	1440.	2170.				
URANIUM	MG/L	< 0.0003	< 0.0003	< 0.0003	< 0.0003	< 0.0003	< 0.005				
VANADIUM	MG/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01				

D-156

Table D.5.15 Chemical analyses of groundwater, Green River, Utah, tailings site (Continued)

FORMATION OF COMPLETION: SANDSTONE
 HYDRAULIC FLOW RELATIONSHIP: UP GRADIENT

LOCATION ID - SAMPLE ID AND LOG DATE	UNIT OF MEASURE	PARAMETER	VALUE+/-UNCERTAINTY	PARAMETER	VALUE+/-UNCERTAINTY	PARAMETER	VALUE+/-UNCERTAINTY
817-03 04/40/88		PARAMETER	0.005	PARAMETER	0.005	PARAMETER	0.005
817-04 04/40/88		PARAMETER	0.005	PARAMETER	0.006	PARAMETER	0.005
847-05 04/40/88		PARAMETER	0.005	PARAMETER	0.005	PARAMETER	0.005
847-04 07/48/88		PARAMETER	0.005	PARAMETER	0.005	PARAMETER	0.005
848-04 10/20/87		PARAMETER	0.005	PARAMETER	0.005	PARAMETER	0.005

FORMATION OF COMPLETION: SANDSTONE
HYDRAULIC FLOW RELATIONSHIP: UP GRADIENT

Table D.5.15 Chemical analyses of groundwater, Green River, Utah, tailings site (Continued)

LOCATION ID - SAMPLE ID AND LOG DATE	UNIT OF MEASURE	PARAMETER	ALKALINITY	ALUMINUM	AMMONIUM	ANTIMONY	ARSENIC	BALANCE	BARIUM	BORON	CADMIUM	CALCIUM	CHLORIDE	CHROMIUM	COBALT	CONDUCTANCE	COPPER	FLUORIDE	GROSS ALPHA	GROSS BETA	IRON	LEAD	MAGNESIUM	MANAGNESE	MERCURY	MOLYBDENUM	NICKEL	NITRATE	NITRITE	ORG. CARBON	PH	PHOSPHATE	POTASSIUM	RA-226	RA-228	SELENIUM	SILICA	SILVER	SODIUM	STRONTIUM	SULFATE	SULFIDE	TEMPERATURE	TH-230	TIN	TOTAL SOLIDS	URANIUM	VANADIUM
818-02 10/20/87	M/L	CACO3	541	0.1	0.2	0.1	0.04	-	-	-	-	6.5	450	0.04	-	2900	-	2.4	0.0	5.6	0.03	-	1.40	0.04	0.04	0.04	0.04	1.0	40	8.3	1.40	0.3	0.1	0.005	-	-	780	590	-	48.0	-	-	2160	0.003	0.01			
818-03 10/20/87	M/L		541	0.1	0.2	0.1	0.04	-	-	-	-	6.4	400	0.04	-	2900	-	2.4	0.0	8.1	0.03	-	1.40	0.04	0.04	0.04	0.04	1.0	4	8.3	1.40	0.3	0.1	0.005	-	-	790	620	-	48.0	-	-	2140	0.003	0.01			
818-04 10/20/87	M/L		541	0.1	0.2	0.1	0.04	-	-	-	-	6.4	400	0.04	-	2900	-	2.7	32	2.0	0.03	-	1.43	0.04	0.04	0.04	0.04	1.0	1	8.3	1.40	0.2	0.1	0.005	-	-	800	580	-	48.0	-	-	2170	0.004	0.01			
818-05 10/20/87	M/L		541	0.1	0.2	0.1	0.04	-	-	-	-	6.4	440	0.04	-	2900	-	2.7	0.0	0.0	0.03	-	1.44	0.04	0.04	0.04	0.04	1.0	4	8.3	1.42	0.4	0.1	0.005	-	-	730	590	-	48.0	-	-	2170	0.005	0.01			
818-01 01/05/88	M/L		546	0.1	0.3	0.1	0.04	-	-	-	-	8.59	600	0.03	-	3460	-	2.9	2	23	0.15	-	1.65	0.02	0.04	0.04	0.04	0.1	146	8.35	2.1	0.1	0.048	-	-	906	599	-	46.2	-	-	2420	0.0014	0.01				

Table D.5.15 Chemical analyses of groundwater, Green River, Utah, tailings site (Continued)

FORMATION OF COMPLETION: SANDSTONE
 HYDRAULIC FLOW RELATIONSHIP: UP GRADIENT

PARAMETER	UNIT OF MEASURE	LOCATION ID - SAMPLE ID AND LOG DATE				
		848-02 10/20/87	848-03 10/20/87	848-04 10/20/87	848-05 10/20/87	848-04 04/05/88
		PARAMETER VALUE +/- UNCERTAINTY	PARAMETER VALUE +/- UNCERTAINTY	PARAMETER VALUE +/- UNCERTAINTY	PARAMETER VALUE +/- UNCERTAINTY	PARAMETER VALUE +/- UNCERTAINTY
ZINC	MG/L	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005

Table D.5.15 Chemical analyses of groundwater, Green River, Utah, tailings site (Continued)

FORMATION OF COMPLETION: SANDSTONE
 HYDRAULIC FLOW RELATIONSHIP: UP GRADIENT

		LOCATION ID - SAMPLE ID AND LOG DATE									
		818-02 01/05/88		818-03 01/05/88		818-04 01/05/88		818-05 01/05/88		818-01 07/16/88	
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
ALKALINITY	MG/L CaCO3	546.	546.	546.	546.	546.	546.	546.	546.	546.	546.
ALUMINUM	MG/L	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.01
AMMONIUM	MG/L	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1
ANTIMONY	MG/L	-	-	-	-	-	-	-	-	-	-
ARSENIC	MG/L	0.04	0.04	0.04	0.04	0.04	0.04	0.007	0.04	0.151	0.151
BALANCE	%	-	-	-	-	-	-	-	-	-	-
BARIUM	MG/L	-	-	-	-	-	-	-	-	-	0.03
BORON	MG/L	0.61	0.59	0.61	0.61	0.61	0.61	0.61	0.61	0.69	0.69
CADMIUM	MG/L	-	-	-	-	-	-	-	-	< 0.001	0.001
CALCIUM	MG/L	8.56	8.47	8.47	8.72	8.54	8.54	8.54	8.54	12.5	12.5
CHLORIDE	MG/L	600.	610.	610.	610.	610.	610.	610.	610.	880.	880.
CHROMIUM	MG/L	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	< 0.01	0.01
COBALT	MG/L	-	-	-	-	-	-	-	-	-	-
CONDUCTANCE	UMHO/CM	3160.	3160.	3160.	3160.	3160.	3160.	3160.	3160.	3800.	3800.
COPPER	MG/L	-	-	-	-	-	-	-	-	< 0.01	0.01
FLUORIDE	MG/L	2.98	2.92	2.92	2.93	2.94	2.94	2.94	2.94	2.9	2.9
GROSS ALPHA	PCI/L	9.	17.	2.	13.	8.	16.	19.	16.	0.	27.
GROSS BETA	PCI/L	7.	18.	0.	18.	15.	18.	8.	16.	0.	18.
IRON	MG/L	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.01	0.01
LEAD	MG/L	-	-	-	-	-	-	-	-	0.17	0.17
MAGNESIUM	MG/L	1.63	1.61	1.61	1.65	1.62	1.62	1.62	1.62	2.31	2.31
MANGANESE	MG/L	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
MERCURY	MG/L	-	-	-	-	-	-	-	-	< 0.0002	0.0002
MOLYBDENUM	MG/L	0.08	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.01	0.01
NICKEL	MG/L	-	-	-	-	-	-	-	-	-	-
NITRATE	MG/L	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	6.3	6.3
NITRITE	MG/L	-	-	-	-	-	-	-	-	-	-
ORG. CARBON	MG/L	146.	144.	144.	135.	147.	147.	147.	147.	120.	120.
PH	SU	8.35	8.35	8.35	8.35	8.35	8.35	8.35	8.35	8.45	8.45
PHOSPHATE	MG/L	-	-	-	-	-	-	-	-	-	-
POTASSIUM	MG/L	1.47	1.35	1.35	1.56	2.01	2.01	2.01	2.01	2.4	2.4
RA-226	PCI/L	0.2	0.2	0.2	0.4	0.5	0.5	0.5	0.5	0.2	0.2
RA-228	PCI/L	0.6	1.0	0.	0.9	0.5	0.9	0.4	0.8	0.5	0.8
SELENIUM	MG/L	0.018	0.016	0.016	0.017	0.016	0.016	0.016	0.016	< 0.001	0.001
SILICA	MG/L	-	-	-	-	-	-	-	-	-	-
SILVER	MG/L	-	-	-	-	-	-	-	-	< 0.01	0.01
SODIUM	MG/L	904.	900.	900.	904.	902.	902.	902.	902.	1040.	1040.
STRONTIUM	MG/L	-	-	-	-	-	-	-	-	-	-
SULFATE	MG/L	589.	594.	594.	604.	600.	600.	600.	600.	535.	535.
SULFIDE	MG/L	-	-	-	-	-	-	-	-	11.	11.
TEMPERATURE	C - DEGREE	16.2	16.2	16.2	16.2	16.2	16.2	16.2	16.2	18.0	18.0
TH-230	PCI/L	-	-	-	-	-	-	-	-	-	-
TIN	MG/L	-	-	-	-	-	-	-	-	-	-
TOTAL SOLIDS	MG/L	2420.	2420.	2420.	2410.	2410.	2410.	2410.	2410.	2800.	2800.
URANIUM	MG/L	0.0012	0.0013	0.0013	0.0012	0.0013	0.0013	0.0013	0.0013	0.0003	0.0003
VANADIUM	MG/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

D-160

Table D.5.15 Chemical analyses of groundwater, Green River, Utah, tailings site (Continued)

FORMATION OF COMPLETION: SANDSTONE
 HYDRAULIC FLOW RELATIONSHIP: UP GRADIENT

		----- LOCATION ID - SAMPLE ID AND LOG DATE -----				
		01B-02 01/05/88	01B-03 01/05/88	01B-04 01/05/88	01B-05 01/05/88	01B-04 07/16/88
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
ZINC	MG/L	0.009	0.007	< 0.005	0.005	< 0.005

MAPPER DATA FILE NAME: GRN04*UOP6W0402493

Table D.5.15 Chemical analyses of groundwater, Green River, Utah, tailings site (Continued)

FORMATION OF COMPLETION: SANDSTONE
 HYDRAULIC FLOW RELATIONSHIP: DOWN GRADIENT

D-162

		LOCATION ID - SAMPLE ID AND LOG DATE									
		582-01 09/12/86		582-01 03/13/87		582-01 10/02/87		582-01 01/10/88		582-01 07/18/88	
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
ALKALINITY	MG/L CaCO3	530.	560.	524.	524.	529.					
ALUMINUM	MG/L	0.3	0.2	< 0.1	< 0.1	< 0.01					
AMMONIUM	MG/L	0.7	0.3	0.3	< 0.1	< 0.1					
ANTIMONY	MG/L	< 0.003	-	-	-	-					
ARSENIC	MG/L	< 0.01	-	< 0.01	< 0.01	-					
BALANCE	%	-0.98	-	-	< 0.04	< 0.04				0.022	
BARIUM	MG/L	0.2	-	-	-	-					
BORON	MG/L	0.8	0.5	0.7	0.7	0.7				< 0.01	
CADMIUM	MG/L	< 0.001	-	-	-	-				0.7	
CALCIUM	MG/L	7.32	4.83	4.4	4.54	5.96				0.001	
CHLORIDE	MG/L	640.	307.	300.	300.	560.					
CHROMIUM	MG/L	0.01	< 0.01	< 0.01	0.02	< 0.01					
COBALT	MG/L	< 0.05	-	-	-	-					
CONDUCTANCE	UMHO/CM	2500.	2550.	2500.	2400.	2900.					
COPPER	MG/L	< 0.02	-	-	-	< 0.01					
FLUORIDE	MG/L	4.4	4.3	4.2	3.65	4.3					
GROSS ALPHA	PCI/L	-	-	0.0	18.	0.					23.
GROSS BETA	PCI/L	-	-	1.9	15.	5.					14.
IRON	MG/L	< 0.03	0.05	< 0.03	0.12	< 0.01					
LEAD	MG/L	< 0.01	-	-	-	0.10					
MAGNESIUM	MG/L	1.20	0.99	0.94	0.88	1.13					
MANGANESE	MG/L	0.02	0.01	< 0.01	< 0.01	< 0.01					
MERCURY	MG/L	< 0.0002	-	-	-	0.0002					
MOLYBDENUM	MG/L	0.10	< 0.1	< 0.01	0.02	< 0.01					
NICKEL	MG/L	< 0.04	-	-	-	-					
NITRATE	MG/L	5.6	0.4	< 1.0	< 0.1	2.1					
NITRITE	MG/L	< 0.1	-	-	-	-					
ORG. CARBON	MG/L	62.	-	< 1.	125.	74.3					
PH-210	PCI/L	0.0	1.7	-	-	-					
PH	SU	8.84	8.34	8.0	8.4	8.21					
PHOSPHATE	MG/L	< 0.1	-	-	-	-					
PO-210	PCI/L	0.0	0.5	-	-	-					
POTASSIUM	MG/L	2.01	0.90	0.92	1.02	1.1					
RA-226	PCI/L	0.1	0.1	0.4	0.2	0.5			0.1		0.3
RA-228	PCI/L	0.0	1.1	-	1.0	0.0			0.9		0.7
SELENIUM	MG/L	0.076	< 0.002	< 0.005	0.027	0.007					
SILICA	MG/L	5.	-	-	-	-					
SILVER	MG/L	< 0.01	-	-	-	< 0.01					
SODIUM	MG/L	936.	742.	700.	698.	834.					
STRONTIUM	MG/L	0.6	-	-	-	-					
SULFATE	MG/L	619.	615.	630.	624.	577.					
SULFIDE	MG/L	-	-	-	-	9.9					
TEMPERATURE	C - DEGREE	18.	16.5	16.0	14.3	16.5					
TH-230	PCI/L	0.3	0.5	-	-	-					
TIN	MG/L	< 0.005	-	-	-	-					
TOTAL SOLIDS	MG/L	2000.	2130.	1930.	1930.	2210.					

Table D.5.15 Chemical analyses of groundwater, Green River, Utah, tailings site (Continued)

FORMATION OF COMPLETION: SANDSTONE
 HYDRAULIC FLOW RELATIONSHIP: DOWN GRADIENT

PARAMETER	UNIT OF MEASURE	LOCATION ID - SAMPLE ID AND LOG DATE				
		582-01 09/12/86	582-01 03/13/87	582-01 10/02/87	582-01 01/10/88	582-01 07/18/88
		PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
URANIUM	MG/L	< 0.0003	0.0026	< 0.003	< 0.0003	< 0.0003
VANADIUM	MG/L	0.19	-	< 0.01	< 0.01	< 0.01
ZINC	MG/L	0.008	-	< 0.005	0.01	< 0.005

Table D.5.15 Chemical analyses of groundwater, Green River, Utah, tailings site (Continued)

FORMATION OF COMPLETION: SANDSTONE
 HYDRAULIC FLOW RELATIONSHIP: DOWN GRADIENT

----- LOCATION ID - SAMPLE ID AND LOG DATE -----

849-04 10/26/87 849-04 04/05/88

PARAMETER	UNIT OF MEASURE	PARAMETER VALUE+/-UNCERTAINTY				
ALKALINITY	MG/L CaCO3	500.		547.		
ALUMINUM	MG/L	< 0.4		< 0.4		
AMMONIUM	MG/L	0.4		0.3		
ANTIMONY	MG/L	-		-		
ARSENIC	MG/L	< 0.04		0.002		
BALANCE	%	-		-		
BARIUM	MG/L	-		-		
BORON	MG/L	0.5		0.62		
CADMIUM	MG/L	-		-		
CALCIUM	MG/L	24.		6.63		
CHLORIDE	MG/L	146.		630.		
CHROMIUM	MG/L	< 0.04		0.02		
COBALT	MG/L	-		-		
CONDUCTANCE	UMHO/CM	3300.		3450.		
COPPER	MG/L	-		-		
FLUORIDE	MG/L	2.9		5.58		
GROSS ALPHA	PCI/L	0.0	18.	0.	9.	
GROSS BETA	PCI/L	0.0	19.	0.	14.	
IRON	MG/L	< 0.03		0.44		
LEAD	MG/L	-		-		
MAGNESIUM	MG/L	14.6		4.34		
MANGANESE	MG/L	< 0.04		0.04		
MERCURY	MG/L	-		-		
MOLYBDENUM	MG/L	0.04		0.04		
NICKEL	MG/L	-		-		
NITRATE	MG/L	6.5		< 0.4		
NITRITE	MG/L	-		-		
ORG. CARBON	MG/L	12.		108.		
PB-240	PCI/L	-		-		
PH	SU	8.0		8.2		
PHOSPHATE	MG/L	-		-		
PO-240	PCI/L	-		-		
POTASSIUM	MG/L	2.6		4.3		
RA-226	PCI/L	0.3	0.2	0.2	0.2	
RA-228	PCI/L	0.0	1.4	0.6	0.9	
SELENIUM	MG/L	< 0.005		0.049		
SILICA	MG/L	-		-		
SILVER	MG/L	-		-		
SODIUM	MG/L	4460.		908.		
STRONTIUM	MG/L	-		-		
SULFATE	MG/L	2420.		578.		
SULFIDE	MG/L	-		-		
TEMPERATURE	C - DEGREE	16.0		14.3		
TH-230	PCI/L	-		-		
TIN	MG/L	-		-		
TOTAL SOLIDS	MG/L	3820.		2480.		

D-164

Table D.5.15 Chemical analyses of groundwater, Green River, Utah, tailings site (Concluded)

FORMATION OF COMPLETION: SANDSTONE
 HYDRAULIC FLOW RELATIONSHIP: DOWN GRADIENT

PARAMETER	UNIT OF MEASURE	LOCATION ID - SAMPLE ID AND LOG DATE	
		849-01 10/26/87	849-01 01/05/88
		PARAMETER VALUE+/-UNCERTAINTY	PARAMETER VALUE+/-UNCERTAINTY
URANIUM	MG/L	0.009	< 0.0003
VANADIUM	MG/L	< 0.01	< 0.01
ZINC	MG/L	< 0.005	0.02

MAPPER DATA FILE NAME: GRN01*UDPGWQ102192

Table D.5.16 Background groundwater quality summary for the top hydrostratigraphic unit, Green River, Utah, tailings site

Constituent ^a	Number of analyses ^b	Arithmetic mean (X)	Standard deviation x2 (2s)	Statistical concentration range (X±2s)	Observed concentration range	Proposed EPA groundwater MCL
Chromium (mg/l)	11	0.04	0.07	<0.01-0.11	0.03-0.14	0.05
Molybdenum (mg/l)	11	0.11	0.13	<0.01-0.24	<0.01-0.20	0.10
Nitrate (NO ₃) (mg/l)	11	45	84	<1-129	9-140	44
Selenium (mg/l)	11	0.147	0.272	<0.005-0.419	<0.005-0.380	0.010
Radium-226 and 228 (pci/l)	6	0.9	1.4	0.0-2.3	0.0-1.7	5.0
Uranium-234 and 238 (mg/l)	11	0.0118	0.0051	0.0067-0.0169	0.0081-0.0167	0.0440
Gross alpha (pCi/l)	5	9.6	31.8	0.0-41.4	0.0-41.0	15

^aAll constituents listed are included in the proposed EPA groundwater standards (40 CFR 142) and have EPA National and State of Utah Primary Drinking Water Standards, with the exception of molybdenum, which does not have a maximum concentration limit in Utah. Arsenic, barium, cadmium, lead, mercury, and silver are also included in the proposed EPA groundwater standards, and the EPA National and State of Utah Primary Drinking Water Standards. However, because these constituents were found to be below detection limits for the first two rounds of water sampling in June, 1986, and September, 1986, they were excluded from subsequent sampling rounds and are not considered to be present as contamination at the Green River site.

^bThe background wells included in the analyses are GRN01-563 and 707. The analyses may include the results from one or more of the following rounds of sampling: 6/86; 9/86; 3/87; 10/87; 1/88; 5/88; and 7/88; depending on if the well(s) were in existence at the time of sampling.

Table D.5.17 Background groundwater quality summary for the upper-middle hydrostratigraphic unit, Green River, Utah, tailings site

Constituent ^a	Number of analyses ^b	Arithmetic mean ^c (\bar{X})	Standard deviation $\times 2^c$ ($2s$)	Statistical concentration range ^c ($\bar{X} \pm 2s$)	Observed concentration range	Proposed EPA groundwater MCL ^d
Chromium (mg/l)	5	0.02	0.03	<0.01-0.05	<0.01-0.05	0.05
Molybdenum (mg/l)	5	0.02	0.03	<0.01-0.05	<0.01-0.05	0.1
Nitrate (NO ₃) (mg/l)	5	36	86	<1-122	<1-93	44
Selenium (mg/l)	5	0.66	1.92	<0.005-2.58	<0.005-2.50	0.01
Radium-226 and 228 (pCi/l)	4	ND	ND	ND	0.1-0.8	5.0
Uranium-234 and 238 (mg/l)	5	0.0109	0.0274	<0.003-0.0383	<0.003-0.0380	0.044
Gross alpha (pCi/l)	4	ND	ND	ND	0.0-21.0	15

^aAll constituents listed are included in the proposed EPA groundwater standards (40 CFR 192) and have EPA National and State of Utah Primary Drinking Water Standards, with the exception of molybdenum, which does not have a maximum concentration limit in Utah. Arsenic, barium, cadmium, lead, mercury, and silver are also included in the proposed EPA groundwater standards, and the EPA National and State of Utah Primary Drinking Water Standards. However, because these constituents were found to be below detection limits for the first two rounds of water sampling in June, 1986, and September, 1986, they were excluded from subsequent sampling rounds and are not considered to be present as contamination at the Green River site.

^bThe background wells included in the analyses are GRN01-816 and 806. The analyses may include the results from one or more of the following rounds of sampling: 6/86; 9/86; 3/87; 10/87; 1/88; 5/88; and 7/88; depending on if the well(s) were in existence at the time of sampling. If less than five analyses were available, a statistical analysis was not performed.

^cND = not determined because number of analyses is less than five.

^dMCLs are the same for EPA National and State of Utah Primary Drinking Water Standards.

D-167

Table D.5.18 Background groundwater quality summary for the lower-middle hydrostratigraphic unit, Green River, Utah, tailings site

Constituent ^a	Number of analyses ^b	Arithmetic mean (\bar{X})	Standard deviation x2 (2s)	Statistical concentration range ($\bar{X} \pm 2s$)	Observed concentration range	Proposed EPA groundwater MCL ^c
Chromium (mg/l)	12	0.03	0.06	<0.01-0.09	<0.01-0.09	0.05
Molybdenum (mg/l)	12	0.10	0.14	<0.01-0.24	<0.01-0.22	0.1
Nitrate (NO ₃) (mg/l)	12	68	116	<1-184	1-173	44
Selenium (mg/l)	12	0.088	0.196	<0.005-0.284	<0.005-0.320	0.01
Radium-226 and 228 (pCi/l)	7	1.7	2.6	0.0-4.3	0.1-3.9	5.0
Uranium-234 and 238 (mg/l)	12	0.046	0.080	<0.003-0.126	<0.003-0.146	0.044
Gross alpha (pCi/l)	7	70	110	0-180	4-150	15

^aAll constituents listed are included in the proposed EPA groundwater standards (CFR 40 192) and have EPA National and State of Utah Primary Drinking Water Standards, with the exception of molybdenum, which does not have a maximum concentration limit in Utah. Arsenic, barium, cadmium, lead, mercury, and silver are also included in the proposed EPA groundwater standards, and the EPA National and State of Utah Primary Drinking Water Standards. However, because these constituents were found to be below detection limits for the first two rounds of water sampling in June, 1986, and September, 1986, they were excluded from subsequent sampling rounds and are not considered to be present as contamination at the Green River site.

^bThe background wells included in the analyses are GRN01-562, 811, and 813. The analyses may include the results from one or more of the following rounds of sampling: 6/86; 9/86; 3/87; 10/87; 1/88; 5/88; and 7/88; depending on if the well(s) were in existence at the time of sampling.

^cMCLs are the same for EPA National and State of Utah Primary Drinking Water Standards.

Table D.5.19 Background groundwater quality summary for the bottom hydrostratigraphic unit, Green River, Utah, tailings site

Constituent ^a	Number of analyses ^b	Arithmetic mean (\bar{X})	Standard deviation x2 (2s)	Statistical concentration range ($\bar{X} \pm 2s$)	Observed concentration range	Proposed EPA groundwater MCL ^c
Chromium (mg/l)	19	0.03	0.04	<0.01-0.07	<0.01-0.07	0.05
Molybdenum (mg/l)	19	0.05	0.08	<0.01-0.13	<0.01-0.14	0.1
Nitrate (NO ₃) (mg/l)	19	1	2	<1-3	<1-6	44
Selenium (mg/l)	19	0.022	0.060	<0.005-0.082	<0.005-0.106	0.01
Radium-226 and 228 (pCi/l)	16	0.7	1.5	0.0-2.2	0.0-3.0	5.0
Uranium-234 and 238 (mg/l)	19	0.0019	0.0032	<0.003-0.0051	<0.003-0.0049	0.044
Gross alpha (pCi/l)	16	3.7	16.8	0.0-20.5	0.0-30.0	15

^aAll constituents listed are included in the proposed EPA groundwater standards (UMTRA, 52 FR36000) and have EPA National and State of Utah Primary Drinking Water Standards, with the exception of molybdenum, which does not have a maximum concentration limit in Utah. Arsenic, barium, cadmium, lead, mercury, and silver are also included in the proposed EPA groundwater standards, and the EPA National and State of Utah Primary Drinking Water Standards. However, because these constituents were found to be below detection limits for the first two rounds of water sampling in June, 1986, and September, 1986, they were excluded from subsequent sampling rounds and are not considered to be present as contamination at the Green River site.

^bThe background wells included in the analyses are GRN01-586, 587, 588, 817, and 818. The analyses may include the results from one or more of the following rounds of sampling: 6/86; 9/86; 3/87; 10/87; 1/88; 5/88; and 7/88; depending on if the well(s) were in existence at the time of sampling.

^cMCLs are the same for EPA National and State of Utah Primary Drinking Water Standards.

Table D.5.20 Summary of maximum and minimum observed concentrations in the top hydrostratigraphic unit from tailings seepage, Green River, Utah, tailings site

Constituent	Number of analyses ^a	Observed maximum	Observed minimum	Proposed EPA standard
Chromium (mg/l)	12	0.040	0.005	0.050
Molybdenum (mg/l)	17	0.270	0.005	0.100
Nitrate (NO ₃) (mg/l)	17	440	1	44
Selenium (mg/l)	17	0.410	0.001	0.010
Radium-226 and 228 (pCi/l)	11	3.8	0.0	5.0
Uranium-234 and 238 (mg/l)	17	2.23	0.0419	0.0440
Gross alpha (pCi/l)	5	950	20	15

^aIncludes analyses from on-site monitor wells 702, 704, 705, and 808.

Table D.5.21 Summary of maximum and minimum observed concentrations in the upper-middle hydrostratigraphic unit from tailings seepage, Green River, Utah, tailings site

Constituent	Number of analyses ^a	Observed maximum	Observed minimum	Proposed EPA standard
Chromium (mg/l)	5	0.050	0.005	0.050
Molybdenum (mg/l)	8	0.200	0.010	0.100
Nitrate (NO ₃) (mg/l)	8	2480	2	44
Selenium (mg/l)	8	0.370	0.0025	0.010
Radium-226 and 228 (pCi/l)	7	2.0	0.9	5.0
Uranium-234 and 238 (mg/l)	8	3.110	0.437	0.044
Gross alpha (pCi/l)	1	980	980	15

^aIncludes analyses from on site monitor well 701.

Table D.5.22 Permeability test results and physical properties from tailings samples, Green River, Utah, tailings site^a

Test pit or borehole number	Sample interval (feet)	USCS class ^b	Tailings type	In situ moisture content (percent)	Dry density (pcf) ^c	Saturated hydraulic conductivity (cm/s)	Type of test
542	0.5-1.5	SP-SM	Sand	--	--	5.8×10^{-4}	cd
572	3.5-4.5	SP-SC	Sand	1.6	--	--	--
	6.5-7.5	SP-SC	Sand	4.0	--	--	--
	9.5-10.5	SP-SM	Sand	5.6	--	--	--
	12.8-13.5	SP-SM	Sand	15.5	--	--	--
574	2.5-3.5	SP-SM	Sand	1.2	103.6	--	--
	7.0-7.5	SP-SM	Sand	4.7	86.7	--	--
575	2.5-3.0	SP-SM	Sand	1.3	97.6	--	--
	7.0-8.0	SM	Sand	4.7	--	--	--
	13.0-14.0	SP-SM	Sand	5.0	--	--	--
578	2.5-3.0	SP-SM	Sand	2.2	90.1	--	--
	5.5-6.5	SP-SM	Sand	3.4	--	--	--
	7.0-8.0	SM	Sand	6.1	--	--	--
	10.0-11.0	SC	Sand	5.3	--	--	--
T-01	--	SP-SM	Sand	--	--	2.7×10^{-5}	T ^e
T-02	--	SP-SM	Sand	--	--	2.8×10^{-4}	T
T-03	--	SP-SM	Sand	--	--	1.3×10^{-4}	T

^aBorehole locations are shown on Figure D.5.1. Blanks indicate the properties were not determined.

^bUnified Soil Classification System; SP is poorly graded sands, gravelly sands; SM is silty sands, sand-silt mixtures; SC is clayey sands, sand-clay mixtures.

^cpcf = pounds per cubic foot.

^dC = constant-head test; the sample was remolded to average 92 percent of standard Proctor density.

^eT = triaxial permeability tests; sample was remolded to 95 percent of standard Proctor density.

Table D.5.23 Chemical analyses for lysimeter GRN01-714^a

Parameter	9/11/86	3/12/87
Aluminum	6300	1840
Ammonium	14	11
Antimony	-	0.003
Arsenic	-	0.03
Barium	-	0.1
Boron	0.5	0.1
Cadmium	-	0.032
Calcium	457	385
Chloride	113	2900
Chromium	2.61	1.14
Cobalt	-	30.9
Copper	-	45.8
Fluoride	0.1	0.2
Iron	2200	267
Lead	-	0.02
Magnesium	2640	1090
Manganese	360	122
Mercury	-	0.
Molybdenum	0.2	0.10
Nickel	-	25.3
Nitrate	4500	2
Nitrite	-	0.1
Phosphate	-	0.1
Potassium	0.19	16.0
Selenium	0.092	0.208
Silica	-	60
Silver	-	0.01
Sodium	89.2	111
Strontium	-	0.1
Sulfate	56200	16000
Tin	-	0.005
Total dissolved solids	80800	26100
Uranium	675	221
Vanadium	-	178
Zinc	-	259

^aAll values in mg/l. See Figure D.5.1 for the location of lysimeter 714.

Table D.5.24 Analyses of Cedar Mountain Formation groundwater,
Green River, Utah^a

Species and parameter	Monitor well 562	Monitor well 581	Monitor well 584	Monitor well 701	Monitor well 813
Magnesium	124	883	134	197	114
Calcium	328	221	467	520	253
Sodium	1870	1680	1680	1115	1910
Potassium	7.39	2.51	3.27	20.50	7.24
Sulfate	4330	2460	3160	2870	4200
Chlorine	150	180	130	94	130
Alkalinity (as calcium carbonate)	660	979	266	407	671
Silica	9.70	8.8	9.2	18.0	9.2
Sulphur	<0.10	45.4	<0.1	<0.1	<0.1
Iron ²⁺	<0.03	<0.03	<0.03	<0.03	<0.03
Iron ³⁺	0.045	<0.01	0.045	0.045	0.040
Nitrate	103	0.2	0.2	1570	22.7
Ammonium	<0.1	0.8	0.6	45.2	<0.1
Nitrite	0.66	<0.03	<0.03	0.07	1.48
Molybdenum	0.07	0.02	0.01	0.09	0.13
Selenium	0.16	0.09	0.11	0.55	0.13
Arsenic	0.01	0.02	0.01	0.02	0.02
Total dissolved solids	7190	4630	4930	6680	6920
Temperature(°C)	16.5	15.7	15.9	16.5	17.5
pH	6.88	7.25	7.96	6.68	6.88
Eh (field, V)	+0.274	-0.133	-0.080	+0.272	+0.274

^aAll concentrations are in mg/l unless noted otherwise. °C = degrees Celsius; V = volts.

Table D.5.25 Field measured and theoretical redox potentials (Eh) controlling uraninite precipitation within the Cedar Mountain Formation, Green River, Utah

Monitor well	pH	Field Eh (volts)	Uraninite S.I. ^a	Calculated Eh (volts)	Uraninite S.I. ^a	Log PCO ₂
581	7.25	-0.133	2.19	-0.107	0	-2.0
584	7.96	-0.080	0.02	-0.106	0	-2.0

Speciation of dissolved uranium (mg/l)

	Total U	U(OH) ₅ ⁻	UO ₂ CO ₃ ⁰	UO ₂ (CO ₃) ₂ ²⁻	UO ₂ (CO ₃) ₃ ⁴⁻
581	0.001	0.0007	6.14 x 10 ⁻⁷	0.0001	0.0001
584	0.001	0.001	2.04 x 10 ⁻⁶	0.003	0.0005

^aS.I. refers to saturation index. S.I. = $\text{Log } 10 \frac{\text{activity product}}{\text{solubility product}}$

Table D.5.26 Field pH, field Eh, total uranium, and saturation indices for Cedar Mountain Formation, Green River, Utah^a

Well number	Field pH	Field Eh (volts)	Total uranium (mg/l)	Dominant form	Saturation index						
					Uraninite	Coffinite	Calcite	Gypsum	Pyrite	Amorphous Fe(OH) ₃	CO ₂
584	7.96	-0.080	<0.001	UO ₂ (CO ₃) ₃ ⁴⁻ U(OH) ₅ ⁻	+0.02	-0.89	-0.02	-0.85	+0.01	-0.68	-2.0
581	7.25	-0.133	<0.001	U(OH) ₅ ⁻	+1.83	+1.34	-0.42	-4.63	+0.01	-3.82	-2.0
701	6.68	+0.272	2.690	UO ₂ (CO ₃) ₂ ²⁻	-5.75	-6.08	+0.03	+0.28	-94.60	+2.71	-2.0
562	6.88	+0.274	0.076	UO ₂ (CO ₃) ₃ ⁴⁻	-8.85	-9.43	+0.06	+0.35	-98.20	+3/65	-2.0
813	6.88	+0.274	0.079	UO ₂ (CO ₃) ₃ ⁴⁻	-8.76	-9.26	+0.06	+0.13	-98.50	+3/62	-2.0

^aCalculated by PHREEQE Model (Parkhurst et al., 1980). Saturation indices = log (IAP/K_T).

Table D.5.27 Chemical analysis of batch leach and column extraction solutions from tailings, buffer material, and windblown soil samples, Green River, Utah

D-176

PARAMETER	UNIT OF MEASURE	LOCATION ID - SAMPLE ID AND LOG DATE			
		825-01 04/10/89 (a)	826-01 04/10/89 (a)	827-01 04/10/89 (a)	828-01 04/10/89 (a)
		PARAMETER VALUE +/- UNCERTAINTY	PARAMETER VALUE +/- UNCERTAINTY	PARAMETER VALUE +/- UNCERTAINTY	PARAMETER VALUE +/- UNCERTAINTY
ALUMINUM	MG/L	-	0.06		
AMMONIUM	MG/L	0.25	0.22	< 0.05	< 0.05
ANTIMONY	MG/L	0.009	0.004		0.17
ARSENIC	MG/L	0.033	0.043	0.002	0.010
BARIUM	MG/L	0.06	0.07	0.040	0.032
BERYLLIUM	MG/L	< 0.005	< 0.005	0.08	0.06
CADMIUM	MG/L	0.0030	< 0.0001	< 0.005	< 0.005
CALCIUM	MG/L	71.	57.	< 0.0001	< 0.0001
CHLORIDE	MG/L	8.	7.	59.	60.
CHROMIUM	MG/L	< 0.01	< 0.01	7.	6.
COBALT	MG/L	< 0.02	< 0.02	< 0.01	< 0.01
COPPER	MG/L	0.04	0.02	< 0.02	< 0.02
FLUORIDE	MG/L	0.4	0.3	0.04	0.06
IRON	MG/L	0.02	0.03	0.3	0.4
LEAD	MG/L	0.003	0.001	< 0.02	< 0.02
MAGNESIUM	MG/L	9.	8.	< 0.001	< 0.001
MANGANESE	MG/L	< 0.01	< 0.01	8.	8.
MERCURY	MG/L	< 0.0001	< 0.0001	< 0.01	< 0.01
MOLYBDENUM	MG/L	0.007	0.004	< 0.0001	< 0.0001
NICKEL	MG/L	< 0.02	< 0.02	0.003	0.002
NITRATE	MG/L	1.8	0.2	< 0.02	< 0.02
POTASSIUM	MG/L	8.	7.	0.3	2.0
SELENIUM	MG/L	0.011	0.010	8.	7.
SILICA	MG/L	13.3	11.4	0.009	0.011
SODIUM	MG/L	29.	24.	11.7	11.1
STRONTIUM	MG/L	0.71	0.60	23.	22.
SULFATE	MG/L	187.	152.	0.62	0.63
THALLIUM	MG/L	< 0.001	< 0.001	156.	169.
TIN	MG/L	< 0.001	< 0.001	< 0.001	< 0.001
TOTAL SOLIDS	MG/L	388.	302.	< 0.001	0.001
URANIUM	MG/L	0.182	0.177	295.	315.
VANADIUM	MG/L	0.24	0.25	0.168	0.172
ZINC	MG/L	0.02	0.02	0.24	0.22
				< 0.01	0.02

Table D.5.27 Chemical analysis of batch leach and column extraction solutions from tailings, buffer material, and windblown soil samples, Green River, Utah

PARAMETER	UNIT OF MEASURE	LOCATION ID - SAMPLE ID AND LOG DATE			
		829-01 04/28/89 (b)	830-01 04/28/89 (c)	831-01 04/28/89 (c)	832-01 04/28/89 (c)
		PARAMETER VALUE +/- UNCERTAINTY	PARAMETER VALUE +/- UNCERTAINTY	PARAMETER VALUE +/- UNCERTAINTY	PARAMETER VALUE +/- UNCERTAINTY
ALUMINUM	MG/L	< 0.05	< 0.05	< 0.05	< 0.05
AMMONIUM	MG/L	0.42	0.14	0.12	0.35
ANTIMONY	MG/L	0.004	0.001	0.002	0.007
ARSENIC	MG/L	0.011	0.004	0.003	0.003
BARIUM	MG/L	0.02	0.02	0.02	0.02
BERYLLIUM	MG/L	< 0.005	< 0.005	< 0.005	< 0.005
CADMIUM	MG/L	< 0.0001	0.0001	< 0.0001	< 0.0001
CALCIUM	MG/L	661.	550.	560.	511.
CHLORIDE	MG/L	4.	19.	16.	25.
CHROMIUM	MG/L	< 0.01	< 0.01	< 0.01	< 0.01
COBALT	MG/L	< 0.02	< 0.02	< 0.02	< 0.02
COPPER	MG/L	0.01	0.01	0.26	0.03
FLUORIDE	MG/L	0.5	1.5	1.6	1.6
IRON	MG/L	< 0.02	< 0.02	< 0.02	< 0.02
LEAD	MG/L	< 0.001	< 0.001	< 0.001	< 0.001
MAGNESIUM	MG/L	33.	138.	128.	150.
MANGANESE	MG/L	0.08	< 0.01	< 0.01	< 0.01
MERCURY	MG/L	< 0.0001	< 0.0001	< 0.0001	< 0.0001
MOLYBDENUM	MG/L	0.082	0.063	0.063	0.058
NICKEL	MG/L	< 0.02	< 0.02	< 0.02	< 0.02
NITRATE	MG/L	12.8	12.5	12.3	12.4
POTASSIUM	MG/L	5.	1.	1.	1.
SELENIUM	MG/L	0.170	0.091	0.091	0.074
SILICA	MG/L	6.4	22.8	21.7	23.0
SODIUM	MG/L	18.	150.	126.	209.
STRONTIUM	MG/L	1.00	3.70	4.00	5.00
SULFATE	MG/L	1720.	2231.	2165.	2437.
THALLIUM	MG/L	< 0.001	< 0.001	< 0.001	< 0.001
TIN	MG/L	0.017	0.022	0.018	0.027
TOTAL SOLIDS	MG/L	2412.	3126.	3052.	3520.
URANIUM	MG/L	2.800	0.168	0.398	0.077
VANADIUM	MG/L	0.07	0.02	0.02	0.04
ZINC	MG/L	0.03	0.03	0.04	0.02

D-177

Table D.5.27 Chemical analysis of batch leach and column extraction solutions from tailings, buffer material, and windblown soil samples, Green River, Utah

		LOCATION ID - SAMPLE ID AND LOG DATE							
		833-01 05/08/89 (d)		834-01 05/08/89 (d)		835-01 05/08/89 (d)		836-01 05/08/89 (b)	
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE +/- UNCERTAINTY		PARAMETER VALUE +/- UNCERTAINTY		PARAMETER VALUE +/- UNCERTAINTY		PARAMETER VALUE +/- UNCERTAINTY	
ALUMINUM	MG/L	<	0.05	<	0.05	<	0.05	<	0.05
AMMONIUM	MG/L		0.57		0.22		0.62		0.30
ANTIMONY	MG/L		0.008		0.002		0.009		0.008
ARSENIC	MG/L		0.012		0.02		0.005		0.002
BARIUM	MG/L		0.02		0.02		0.02		0.04
BERYLLIUM	MG/L	<	0.005	<	0.005	<	0.005	<	0.005
CADMIUM	MG/L		0.0031		0.0033		0.0028	<	0.0001
CALCIUM	MG/L		607.		656.		655.	<	135.
CHLORIDE	MG/L		5.		5.		5.		6.
CHROMIUM	MG/L	<	0.01	<	0.01	<	0.01	<	0.01
COBALT	MG/L	<	0.02	<	0.02	<	0.02	<	0.02
COPPER	MG/L		0.03		0.02		0.03		0.03
FLUORIDE	MG/L		0.6		0.6		0.7		1.0
IRON	MG/L	<	0.02	<	0.02	<	0.02	<	0.02
LEAD	MG/L	<	0.001	<	0.001	<	0.001	<	0.001
MAGNESIUM	MG/L		32.		32.		26.		22.
MANGANESE	MG/L		0.02		0.01		0.01	<	0.01
MERCURY	MG/L	<	0.0001	<	0.0001	<	0.0001	<	0.0001
MOLYBDENUM	MG/L		0.083		0.088		0.091		0.006
NICKEL	MG/L	<	0.02	<	0.02	<	0.02	<	0.02
NITRATE	MG/L		14.7		16.2		16.5	<	0.4
POTASSIUM	MG/L		4.		4.		4.		1.
SELENIUM	MG/L		0.167		0.183		0.187		0.005
SILICA	MG/L		7.0		6.9		5.5		8.9
SODIUM	MG/L		20.		22.		21.		31.
STRONTIUM	MG/L		0.99		1.00		1.09		1.97
SULFATE	MG/L		1655.		1712.		1712.		521.
THALLIUM	MG/L	<	0.001	<	0.001	<	0.001	<	0.001
TIN	MG/L		0.017		0.015		0.018		0.007
TOTAL SOLIDS	MG/L		2325.		2305.		2350.		750.
URANIUM	MG/L		0.296		0.306		0.316		0.010
VANADIUM	MG/L		0.07		0.07		0.07		0.01
ZINC	MG/L		0.04		0.02		0.02		0.01

0-178

Table D.5.27 Chemical analysis of batch leach and column extraction solutions from tailings, buffer material, and windblown soil samples, Green River, Utah

		LOCATION ID - SAMPLE ID AND LOG DATE			
		837-01 05/08/89 (b)		838-01 05/08/89 (b)	
PARAMETER	UNIT OF MEASURE	PARAMETER VALUE +/- UNCERTAINTY	PARAMETER VALUE +/- UNCERTAINTY	PARAMETER VALUE +/- UNCERTAINTY	PARAMETER VALUE +/- UNCERTAINTY
ALUMINUM	MG/L	0.26	<	0.05	
AMMONIUM	MG/L	0.39		0.21	
ANTIMONY	MG/L	0.001		0.007	
ARSENIC	MG/L	0.002		0.003	
BARIUM	MG/L	0.06		0.04	
BERYLLIUM	MG/L	< 0.005	<	0.005	
CADMIUM	MG/L	0.0004	<	0.0004	
CALCIUM	MG/L	139.		127.	
CHLORIDE	MG/L	9.		6.	
CHROMIUM	MG/L	< 0.01	<	0.01	
COBALT	MG/L	< 0.02	<	0.02	
COPPER	MG/L	0.04		0.02	
FLUORIDE	MG/L	1.1		1.1	
IRON	MG/L	0.18	<	0.02	
LEAD	MG/L	< 0.001	<	0.001	
MAGNESIUM	MG/L	25.		22.	
MANGANESE	MG/L	< 0.01	<	0.01	
MERCURY	MG/L	< 0.0001	<	0.0001	
MOLYBDENUM	MG/L	0.003		0.005	
NICKEL	MG/L	< 0.02	<	0.02	
NITRATE	MG/L	0.4		0.3	
POTASSIUM	MG/L	1.	<	1.	
SELENIUM	MG/L	0.004		0.006	
SILICA	MG/L	9.4		9.5	
SODIUM	MG/L	38.		31.	
STRONTIUM	MG/L	2.10		1.91	
SULFATE	MG/L	512.		480.	
THALLIUM	MG/L	< 0.001	<	0.001	
TIN	MG/L	0.006		0.007	
TOTAL SOLIDS	MG/L	705.		675.	
URANIUM	MG/L	0.060		0.010	
VANADIUM	MG/L	0.01		0.01	
ZINC	MG/L	0.02	<	0.01	

D-179

MAPPER DATA FILE NAME: GRN01*UDPSW0100236

^a 825-828: batch leach solution, windblown soils

^b 829, 836-838: batch leach solution, tailings

^c 830-832: column extract solution, buffer material; feed solution from 829

^d 833-838: batch leach solution, buffer material

REFERENCES

- Berner, R. A., 1963. "Electrode Studies of Hydrogen Sulfide in Marine Sediments," Geochim. Cosmochim. Acta., Vol. 27, pp. 563-575.
- Bouwer, H., 1978. Groundwater Hydrology, McGraw-Hill Book Company, New York, New York.
- Bouwer, H., and R. C. Rice, 1967. "A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells," in Water Resources Research, Vol. 12.
- Bruno et al. (J. Bruno, I. Casas, B. Lagerman, and M. Munoz), 1987. "The Determination of the Solubility of Amorphous $UO_2(s)$ and the Mononuclear Hydrolysis Constants of Uranium (IV) at 25 °C." In Scientific Basis for Nuclear Waste Management X, Materials Research Society Symposia Proceedings, Vol. 84, eds. J. K. Bates and W. B. Seefeldt, pp. 153-160, Materials Research Society, Pittsburgh, Pennsylvania.
- Buss, W. R., 1951. "Bibliography of Utah Geology to December 31, 1950," in Bulletin 40, Utah Geological and Mineral Survey, Salt Lake City, Utah.
- Buss, W. R., and N. S. Goeltz, 1974. "Bibliography of Utah Geology, 1950 to 1970," in Bulletin 103, Utah Geological and Mineral Survey, Salt Lake City, Utah.
- Casper, C., 1985. Personal communication with John B. Price, Sergeant, Hauskins & Beckwith, Technical Assistance Contractor to U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico, dated November 7, 1985.
- Chatham et al. (J. R. Chatham, R. B. Wanty, and D. Langmuir), 1981. "Groundwater Prospecting for Sandstone-Type Uranium Deposits: The Merits of Mineral - Solution Equilibria Versus Single Element Tracer Methods," Report No. GJBX - 129 (81) U.S. Department of Energy: Grand Junction Office, Colorado.
- Childers, B. S., and B. Y. Smith, 1970. "Abstracts of Theses Concerning the Geology of Utah to 1966," in Bulletin 86, Utah Geology and Mineral Survey, Salt Lake City, Utah.
- City of Green River, 1984. "Notice of Motion to Raise Water Rates," Green River, Utah.
- Cooper et al. (H. H. Cooper, Jr., J. D. Bredehoeft, and I. S. Papadopoulos), 1967. "Response of a Finite-Diameter Well to an Instantaneous Charge of Water," in Water Resources Research, Vol. 3.
- Cowart, J. B. and J. K. Osmond, 1980. "Uranium Isotopes in Groundwater as a Prospecting Technique," Report No. GJBX - 119 (80); U.S. Department of Energy: Grand Junction Office, Colorado.

- Day, Mark, 1988. Personal correspondence between Mark Day, Utah Department of Health, Salt Lake City, Utah, and public affairs officer, White Sands Missile Range, Alamogordo, New Mexico, November 1988.
- Deutsch, W. J. and R. J. Serne, 1984. "Uranium Mobility in the Natural Environment, Evidence from Sedimentary Roll-Front Deposits: Geochemical Behavior of Disposed Radioactive Waste," American Chemical Society Symposium Series 246, pp. 287-302.
- DOE (U.S. Department of Energy), 1988a. Environmental Assessment of Remedial Action at the Green River Uranium Mill Tailings Site, Green River, Utah, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- DOE (U.S. Department of Energy), 1988b. "Redox State of the Cedar Mountain Formation Aquifer, Green River UMTRA Site, Utah," UMTRA-DOE/AL-400641, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- DOE (U.S. Department of Energy), 1987a. Geochemical Modeling and Dilution Estimates for the Proposed Disposal Area, Green River, Utah, Tailings Site, summary report, prepared by DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- DOE (U.S. Department of Energy), 1987b. Albuquerque Operations Manual, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- DOE (U.S. Department of Energy), 1985. Albuquerque Operations Manual, prepared by DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- DOE (U.S. Department of Energy), 1983. Unpublished report, Environmental Assessment prepared by Ford, Bacon, and Davis Utah, Salt Lake City, Utah, and Sandia National Laboratories, Albuquerque, New Mexico, for the DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- DWR (Division of Water Resources), 1976. "Hydrologic Inventory of the San Rafael River Basin," Utah Department of Natural Resources, Salt Lake City, Utah.
- DWR (Division of Water Resources), 1975. "Hydrologic Inventory of the Price River Basin," Utah State Department of Natural Resources, Salt Lake City, Utah.
- FBDU (Ford, Bacon & Davis Utah Inc.), 1981. Engineering Assessment of Inactive Uranium Mill Tailings, Green River Site, Green River, Utah, DOE/UMT-0114, FBDU 360-14, UC-70, prepared by FBDU, Salt Lake City, Utah, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

- Ferris, J. G., and D. B. Knowles, 1963. "The Slug-Injection Test of Estimating the Coefficient of Transmissibility of an Aquifer," in Methods of Determining Permeability, Transmissibility and Drawdown, U.S. Geological Survey Water Supply Paper 1536-I.
- Freeze, R. A., and T. A. Cherry, 1979. Ground Water, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.
- GECR (Geochemistry and Environmental Chemistry Research, Inc.), 1983. Data for the Geochemical Investigation of UMTRA Designated Site at Green River, Utah, UMTRA-DOE/AL-0244, prepared by GECR, Rapid City, South Dakota, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- Howard, C. S., and S. K. Love, 1945. Quality of Surface Waters of the United States, 1943, with a Summary of Analyses of Streams in Colorado River, Pecos River, and Rio Grande Basins, 1925 to 1943, U.S. Geological Survey Water Supply Paper 970.
- Hsi, D. and D. Langmuir, 1985. "Adsorption of uranyl ion onto ferric oxyhydroxide: application of the surface complexation site - binding model," Geochim. Cosmochim. Acta., V.49, No. 9, pp. 1931-1941.
- La Pray, B. A. and L. S. Hamblin, 1980. Bibliography of U.S. Geological Survey Water-Resource Reports for Utah, Information Bulletin No. 27, Utah Department of Natural Resources, Salt Lake City, Utah.
- La Rue, E. C., 1916. Colorado River and Its Utilization, U.S. Geological Survey Water Supply Paper 395.
- Lindberg, R. D., and D. D. Runnells, 1984. "Groundwater Redox Reactions: An Analysis of Equilibrium State Applied to Eh Measurements and Geochemical Modeling," Science, V. 225, pp. 925-927.
- Lohman, S. W., 1972. Groundwater Hydraulics, U.S. Geological Survey Professional Paper 708.
- McClave, J. T. and F. H. Dietrich, II, 1979. Statistics, Dellen Publishing Company, San Francisco, California.
- Mohogheghi, A. and M. B. Goldhaber, 1982. "Kinetics of Uranyl Ion Reduction by Aqueous Sulfide," abstract 95/Annual Meeting of Geological Society of America, New Orleans, Louisiana, October 17-21, 1982.
- ONWI (Office of Nuclear Waste Isolation), 1985. Bibliography of Studies for the Salt Repository Project Office of the Civilian Radioactive Waste Management Program, April 1978-September 1984, prepared by Battelle Project Management Division, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, Ohio, for the U.S. Department of Energy, Washington, D.C.

- Parkhurst et al. (D. L. Parkhurst, D. C. Thorstenson, and L. N. Plummer), 1980. "PHREEQE-A Computer Program for Geochemical Calculations," USGS Water Resources Investigations 80-96, Washington, D.C., 210 p.
- Reeside, J. B., Jr., 1930. Descriptive Geology of the Green River Valley Between Green River, Wyoming, and Green River, Utah, USGS Water Supply Paper 618.
- Reeside, J. B., Jr., 1923. Notes on the Geology of the Green River Valley Between Green River, Wyoming, and Green River, Utah, USGS Professional Paper 132-C.
- Runnells, D. D. and R. D. Lindberg, 1981. "Hydrogeochemical Exploration for Uranium Ore Deposits, Use of the Computer Model WATEQFC," Journal of Geochemical Expl. V. 15, pp. 37-50.
- Rush et al. (F. E. Rush, M. S. Whitfield, and I. M. Hart), 1982. Regional Hydrology of the Green River-Moab Area, Northwestern Paradox Basin, Utah, U.S. Geological Survey Open File Report 82-107, Denver, Colorado.
- Ryan, J. L. and D. Rai, 1983. "The Solubility of Uranium (IV) Hydrated Oxide in Sodium Hydroxide Solutions under Reducing Conditions," Polyhedron, 2:947-952.
- State of Utah, 1985. Letter report on water rights, Department of National Resources, Water Rights, Price, Utah, available from UMTRA Project Document Control Center, PDCC File No. 10.19.2.5, U.S. Department of Energy, Albuquerque Operations Office, Albuquerque, New Mexico.
- Todd, D. K., 1980. Groundwater Hydrology, John Wiley and Sons, Inc., New York, New York.
- Tripathy, V. J., 1984. "Uranium (VI) Transport Modeling: Geochemical Data and Submodels," Ph.D. Dissertation, Stanford University, Stanford, California.
- USGS (U.S. Geological Survey), 1972. Publications of the U.S. Geological Survey, 1962-1970.
- USGS (U.S. Geological Survey), 1971 - 1985 (serial publication). Publications of the U.S. Geological Survey.
- USGS (U.S. Geological Survey), 1964. Publications of the U.S. Geological Survey 1879-1961.
- Waring, G. R., and M. M. Knechtel, 1936. "Groundwater in Part of Southeastern and Southwestern Colorado," U.S. Geological unpublished report.
- Weir et al. (J. E. Weir, Jr., E. B. Maxfield, and E. A. Zimmerman), 1983. Regional Hydrology of the Dolores River Basin, Eastern Paradox Basin, Colorado and Utah, Water Resources Investigations Report 83-4217.
- Walton, W. C., 1970. Groundwater Resource Evaluation, McGraw-Hill Book Company, New York, New York.

APPENDIX E
WATER RESOURCES PROTECTION STRATEGY

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
E.1 WATER RESOURCES PROTECTION STRATEGY SUMMARY	E-1
E.1.1 Design considerations.	E-1
E.1.2 Groundwater protection standards for disposal.	E-2
E.1.3 Performance assessment	E-4
E.1.4 Closure performance assessment	E-4
E.1.5 Groundwater performance monitoring program	E-4
E.1.6 Corrective action plan	E-5
E.1.7 Cleanup and control of existing contamination.	E-6
E.2 DISPOSAL CELL FEATURES TO PROTECT WATER RESOURCES	E-9
E.2.1 Design considerations.	E-9
E.2.1.1 Climate	E-12
E.2.1.2 Drainage of surface runoff and tailings water	E-13
E.2.2 Disposal cell design	E-14
E.2.2.1 Cell components	E-14
E.2.2.2 Disposal cell longevity	E-16
E.3 DISPOSAL AND CONTROL OF RADIOACTIVE MATERIALS AND NONRADIOACTIVE CONTAMINANTS	E-21
E.3.1 Groundwater protection standards for disposal.	E-21
E.3.1.1 Hazardous constituents.	E-21
E.3.1.2 Proposed concentration limits	E-24
E.3.1.3 Point of compliance	E-28
E.3.2 Performance assessment	E-28
E.3.2.1 Conceptual model and assessment	E-31
E.3.2.2 Impacts summary	E-35
E.3.3 Closure performance assessment	E-36
E.3.4 Groundwater performance monitoring program	E-36
E.3.4.1 Disposal cell moisture monitoring	E-36
E.3.4.2 Saturated zone monitoring	E-36
E.3.5 Corrective action plan	E-37
E.3.6 Cleanup and control of existing contamination.	E-40
E.3.6.1 Decoupling.	E-40
E.3.6.2 Potential restoration methods	E-41
REFERENCES FOR APPENDIX E	E-45

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
E.2.1	Diagrammatic cross section of proposed disposal cell and foundation, Green River, Utah, tailings site	E-10
E.2.2	Disposal cell cover system, Green River, Utah tailings site	E-11
E.3.1	Plan view of point of compliance and related disposal cell and compliance monitoring features, Green River, Utah, UMTRA Project disposal site	E-29
E.3.2	Cross section of point of compliance, Green River, Utah, UMTRA Project disposal site	E-30
E.3.3	Locations of wells and surface water sites to be sampled during remedial actions at the Green River, Utah, UMTRA Project site	E-38

LIST OF TABLES

<u>Table</u>		<u>Page</u>
E.1.1	Proposed concentration limits at the Green River, UMTRA Project disposal site.	E-3
E.3.1	Summary of hazardous constituents within uranium mill tailings at Green River, Utah	E-22
E.3.2	Descriptive statistical parameters for background water quality at the Green River UMTRA Project disposal site, Green River, Utah	E-25
E.3.3	Hydrologic properties and parameters of the van Genuchten retention function used to describe the disposal cell soils, Green River UMTRA Project site	E-33

E.1 WATER RESOURCES PROTECTION STRATEGY SUMMARY

The U.S. Department of Energy (DOE) must demonstrate compliance with the U.S. Environmental Protection Agency (EPA) standards for groundwater protection at inactive uranium mill tailings sites. These standards are contained in proposed revisions to Subparts A through C of 40 CFR 192 under Title I of the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA), as amended. Remedial action taken by the DOE must comply with the proposed standards until EPA promulgates them in final form (UMTRCA, Section 108). This section summarizes the water resources protection strategy for the Uranium Mill Tailings Remedial Action (UMTRA) Project site in Green River, Utah, and the elements of the strategy that demonstrate compliance with the proposed groundwater protection standards. Details of the water resources protection strategy are presented in Sections E.2 and E.3. Characterization of groundwater and hydrogeology at the Green River site is presented in detail in Section D.5 of Appendix D, and is summarized in Section 3.5 of the text of this remedial action plan.

The DOE will comply with the disposal standard (40 CFR 192.02(a)(3)) by constructing a disposal cell that will prevent any tailings leachate from mixing with groundwater within the required 1000-year design life of the cell. Specifically, either designated maximum concentration limits (MCLs) or background concentrations (whichever is greater) will not be exceeded in the uppermost aquifer (the upper- and lower-middle hydrostratigraphic units of the Cedar Mountain Formation) at the point of compliance (POC). The POC is the downgradient edges of the engineered disposal unit.

The following sections summarize the major elements of the groundwater protection strategy.

E.1.1 DESIGN CONSIDERATIONS

The tailings will be placed in a mostly below-grade cell. The base of the excavation will be at an elevation of about 4098 feet, which is nearly 40 feet below existing grade. Groundwater is 10 to 12 feet below the base of the excavation. The bottom six feet of the cell will be filled with a compacted, select clean fill soil to retard the movement of contaminants to groundwater from the overlying contaminated materials. Above the buffer will be a layer of compacted windblown tailings (which will be mixed with clean soils) and a layer of compacted tailings.

A cover system will be constructed over the tailings. From bottom to top, the cover system will consist of three feet of compacted radon barrier, six inches of clean, compacted filter bedding, and one foot of rock for erosion protection. Collectively, the cover layers will limit infiltration of precipitation to 2×10^{-8} cubic centimeters per square centimeters per second ($\text{cm}^3/\text{cm}^2\text{s}$) or less, will protect from catastrophic erosion by the Probable Maximum Flood (PMF), and will control the release of radon from the cell. Degradation of the infiltration/radon barrier from freezing (via reduced density) will not occur because it is expected that the barrier will never be saturated.

However, approximately 15 inches of the infiltration/radon barrier will lie beneath the calculated frost depth of 39 inches.

The disposal cell components (buffer, windblown materials, and tailings) will be placed at a moisture content that will result in an unsaturated hydraulic conductivity of 8×10^{-9} centimeters per second (cm^2/s), which is less than the calculated saturated hydraulic conductivity ($2 \times 10^{-8} \text{ cm}^2/\text{s}$) of the infiltration/radon barrier. By minimizing the amount of water used for compaction and dust control during construction, drainage of excess water from the cell will not be a concern (see Section E.2.1.2).

In terms of groundwater protection, the proposed disposal cell and protection strategy at the Green River site make maximum use of the following favorable natural conditions:

- o An arid climate (average annual precipitation is six inches per year; estimated ratio of yearly precipitation to actual evapotranspiration is one).
- o Consistent, uniform fracturing of the foundation bedrock to prevent any perching of water in the cell and to promote drainage of runoff from the toe of the cell.
- o Abundant, desirable secondary minerals on the fracture faces to attenuate any tailings seepage (although tailings seepage into the bedrock is not expected).
- o Strong, upward vertical hydraulic gradients in the saturated bedrock downgradient of the disposal site to minimize the downward migration of contamination (although contamination of the groundwater by tailings seepage is not expected).
- o A flow direction of groundwater beneath the disposal site toward the existing contamination from the old tailings pile.

In addition, the mostly below-grade disposal will maximize surface runoff and minimize infiltration into the disposal cell.

E.1.2 GROUNDWATER PROTECTION STANDARDS FOR DISPOSAL

There are three basic requirements for complying with the groundwater protection standard (40 CFR 192.02): (1) identification of the hazardous constituents within the disposal cell; (2) proposal of a concentration limit for each hazardous constituent; and (3) specification of the point of compliance.

Ten hazardous constituents (from Appendix IX of 40 CFR 264) within the tailings at the Green River site were identified from analyses of tailings pore water. These are cadmium, chromium, molybdenum, nickel, nitrate, selenium, uranium, vanadium, radium-226 and -228, and gross alpha activity. The proposed concentration limits for the ten hazardous constituents are listed in Table E.1.1, along with the U.S. Nuclear

Table E.1.1 Hazardous constituents and concentration limits for disposal at the Green River UMRAP site^a

Constituent	DOE proposed limits	Interim concentration limits
Arsenic	-	0.05 (MCL)
Cadmium	0.01 (MCL)	0.01 (MCL)
Chromium	0.09 (Background)	0.05 (MCL)
Lead	-	0.05 (MCL)
Methylene chloride	-	0.005 (Background)
Molybdenum	0.24 (Background)	0.1 (MCL)
Nickel	0.09 (Background)	0.06 (Background)
Nitrate	180 (Background)	60 (Background)
Selenium	2.50 (Background)	0.66 (Background)
Uranium-234/238	0.146 (Background)	0.044 (MCL)
Vanadium pentoxide	0.38 (Background)	0.09 (Background)
Radium-226/228	5.0 pCi/l (MCL)	5.0 pCi/l (MCL)
Gross alpha (excluding uranium and radon)	195 pCi/l (Background)	24.5 pCi/l (Background)

^aUnits are in milligrams per liter unless noted otherwise; pCi/l = picocuries per liter.

Regulatory Commission's (NRC) proposed interim concentration limits for hazardous constituents at the disposal site. Also, three additional hazardous constituents were included in the DOE's and NRC's list of constituents for the disposal unit. These constituents are arsenic, lead, and methylene chloride.

The concentration limits proposed by the DOE reflect the natural variability of the contaminant concentrations in background water quality samples from beneath the new disposal site. They are equal to one of the following: (1) the MCL for that constituent (established by the EPA); or (2) the maximum observed or statistical maximum background concentration for that constituent. The NRC's proposed interim concentration limits (see Table E.1.1) are statistical mean values rather than maximum values. The proposed interim concentration limits do not account for natural variability of the constituents as they presently occur in groundwater.

Natural variability in groundwater must be accounted for when sampling and analyzing for construction and performance monitoring, and in an assessment of what threshold concentration constitutes an excursion and subsequent corrective action. Therefore, the DOE will collect and analyze representative samples of groundwater from all monitor wells on a quarterly basis during construction of the disposal unit and collect and analyze representative samples of groundwater from the monitor wells and new wells at the point of compliance and background locations on a quarterly basis for two years after completion of the disposal unit. An excursion will therefore not be considered until the two years

of quarterly monitoring have been completed. The details of the monitoring program will be presented in the surveillance and maintenance (S&M) plan or another appropriate document upon NRC concurrence with the S&M plan or other document.

The point of compliance at the Green River site will be the entire northwest and northeast edges of the engineered cell. Approximately 60 feet of rock riprap and select fill material will lie between the compacted tailings and the point of compliance.

E.1.3 PERFORMANCE ASSESSMENT

The proposed disposal cell design is intended to prevent the introduction of contaminants into groundwater by providing for leachate travel times from the base of the contaminated soil to groundwater in excess of the design life (1000 years) of the cell.

The NRC UNSAT2 computer model (NRC, 1983) was used to estimate the redistribution of moisture within the disposal cell with time. Examination of the moisture distribution with time allows conclusions to be drawn regarding the steady state moisture conditions within the disposal cell, the travel time of contaminants through the disposal cell, and the flux at the bottom of the disposal cell. Based on the modeling, the travel time for contaminants exiting the bottom of the disposal cell is over 1100 years. (A more detailed discussion of the disposal cell performance is presented in Section E.3.2.) Because leachate percolating from the disposal cell is not expected to reach groundwater within the design life of the cell, no degradation of groundwater quality as a result of the remedial action is anticipated.

E.1.4 CLOSURE PERFORMANCE ASSESSMENT

The DOE must demonstrate compliance with the closure performance standard (40 CFR 192.02(a)(4)) by showing that the need for further maintenance of the disposal site and cell has been minimized and that the disposal unit minimizes or eliminates releases of hazardous constituents to groundwater.

Natural, durable materials will be used to construct the cell so that long-term performance is ensured. Safety factors and conservative design assumptions have been considered in the design so that the cell should operate for longer than the required 1000-year design life.

The previous section (E.1.3) discussed how the disposal cell will prevent the release of hazardous constituents from affecting groundwater at the Green River site.

E.1.5 GROUNDWATER PERFORMANCE MONITORING PROGRAM

The DOE is required to describe an integrated monitoring program to be conducted before, during, and after completion of the remedial

action to demonstrate that the initial performance of the cell complies with the groundwater protection standard and the closure performance standards.

The DOE will present a detailed groundwater monitoring program in the S&M plan for the Green River site. The main features of the monitoring program will include moisture monitoring in the tailings, windblown material and buffer layers, and saturated zone monitoring at the point of compliance. There is nothing that would physically preclude this program from being implemented.

An array of four neutron access holes for neutron logging will be used to monitor moisture within the tailings at different depths. The time-integrated moisture versus depth data will be used to estimate the unsaturated hydraulic conductivity of the tailings and the operative flux of moisture through the cell. The neutron access holes will also penetrate the windblown material and buffer layers. The schedule for neutron logging will be included in the Green River Surveillance and Maintenance Plan.

The compliance monitoring wells will be sampled quarterly during the first year following completion of the remedial action, semiannually for years two through six, and annually thereafter until the end of the performance monitoring period. Monitoring during the remedial action will take place semi-annually using wells placed during site characterization. The constituents to be analyzed from monitor well samples shall include all of the hazardous constituents presented in Section E.1.2, major anions and cations, and the standard suite of field parameters (alkalinity, pH, temperature, and specific conductance).

E.1.6 CORRECTIVE ACTION PLAN

The DOE is required to evaluate alternative corrective actions that could be implemented if the disposal monitoring program indicates that the disposal cell is not performing adequately (40 CFR 192.02(c)). The DOE should consider reasonable failure scenarios of the disposal cell and demonstrate that corrective actions could be implemented no later than 18 months after finding an exceedance of the groundwater protection standards.

The DOE has demonstrated that the disposal cell at Green River has been designed (and will be constructed) to perform for the mandated design life of 1000 years (see Section E.2.2.2). The design has incorporated standard safety factors and should therefore perform for at least 1000 years with minimal maintenance. There is therefore no "reasonable" failure scenario that would be related to catastrophic structural failure.

A potential "failure" of the cover system, in terms of groundwater protection, would be if the infiltration/radon barrier was not limiting infiltration to the design flux rate of 2×10^{-8} cm³/cm²s. The best-case corrective action for this condition at Green River would be first to assess the potential impacts to groundwater at the flux rate,

and then to assess the risks to human health and the environment should there be a potential impact. A preliminary risk assessment conducted for the Green River site (DOE, 1989a) indicated minimal pathways for human exposure to the potentially affected aquifers because of already poor quality groundwater within the aquifers. It is unlikely that any corrective action would be required at the Green River site such as reconstructing the cover system or active restoration of the affected aquifer(s) because of the minimal risk to human health or the environment. To finalize the preliminary risk assessment to include a specific failure scenario would take only a few months; this plus any other necessary corrective action (applying for alternate concentration limits (ACLs) for any hazardous constituents predicted to exceed the proposed concentrations limits) could be done within the 18-month action time frame. The worst-case corrective action scenario would require removal and replacement of the cover and possible groundwater cleanup.

An exceedance of the proposed concentration limit for any hazardous constituent at the point of compliance (as determined from saturated zone monitoring during the early stages of performance monitoring) would likely be a result of drainage of construction water. This would be verified by examining the moisture monitoring system in the tailings to be sure that excess moisture is not passing through the cell barrier. Since every effort will be made during construction of the cell to limit the amount of water added for compaction (per specific construction specifications) and dust suppression, an excursion at the point of compliance is considered highly unlikely, particularly when travel time of any contaminants through the bottom six feet of buffer (and foundation bedrock) is considered. Any excursion at the point of compliance detected by saturated zone monitoring would result in resampling and analysis at least once to verify the excursion. Details of these procedures will be presented in the S&M plan for Green River.

E.1.7 CLEANUP AND CONTROL OF EXISTING CONTAMINATION

The DOE and NRC consider that evaluation of groundwater cleanup of existing contamination (Subpart B of 40 CFR 192) at the Green River processing site should be deferred until after the EPA promulgates final groundwater protection standards, provided the DOE demonstrates that disposal may proceed independently of cleanup (Subpart B of the standards can be "decoupled" from Subpart A).

By defining existing and background water quality at both the processing and disposal sites, the DOE has demonstrated that the present water quality is distinguishable and any adverse impacts from the remedial action can be identified. In addition, construction of the disposal cell in no way precludes any future aquifer restoration activities from taking place, should active restoration be deemed necessary. Finally, because the period of construction is relatively short at Green River and the extent of existing contamination is almost entirely within the site boundaries (land owned by the State of Utah), there is very little or no risk that human health or the environment could be impacted by leaving the contamination in place during the interim period between remedial action and evaluation of groundwater cleanup.

There are several methods of restoring the affected aquifers at the Green River processing site if it ever becomes necessary to do so. Because the source of contamination will be removed when the tailings are placed and stabilized at the disposal site, and background quality of groundwater in the affected aquifers is poor, the most appropriate method of restoring the aquifers is probably to allow the contamination to flush naturally and disperse downgradient from the site. Natural flushing may be used as the sole method for restoration, or it may be used in conjunction with any of a number of active restoration methods.

E.2 DISPOSAL CELL FEATURES TO PROTECT WATER RESOURCES

This section discusses natural site features and design considerations important in the performance of a disposal cell for protecting water resources at Green River. Details of the proposed disposal cell cover are presented in Section E.2.2. Design details and specifications are presented in Appendix F.

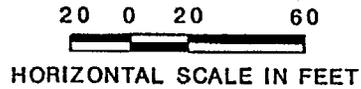
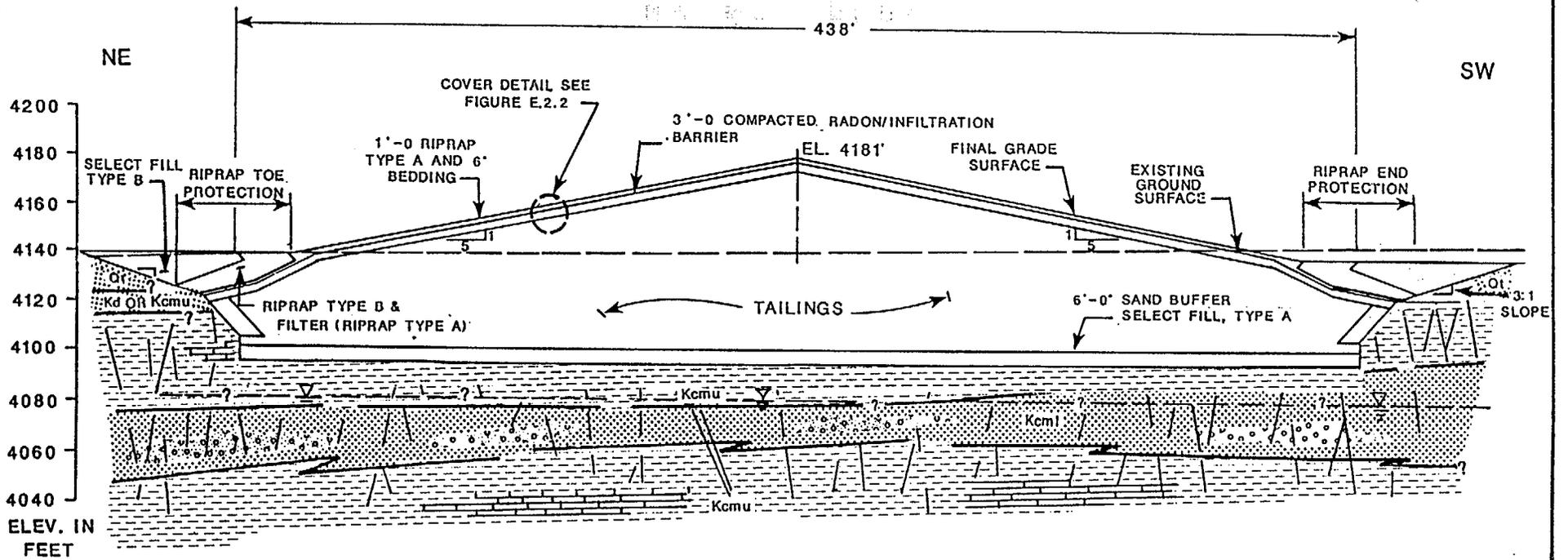
E.2.1 DESIGN CONSIDERATIONS

The disposal site is in a topographically high area 600 to 1200 feet south of the present tailings pile (see Figure D.5.1 of Appendix D). The present tailings surface is in the floodplain of Brown's Wash (elevation 4080 feet) and the proposed disposal site is 4140 feet in elevation at the existing grade. The tailings will be placed in a mostly below-grade disposal cell; the base of the excavation will be at an elevation of about 4098 feet. The disposal cell foundation (unsaturated bedrock) consists of moderately to highly fractured shale, mudstone, and limestone of the upper Cedar Mountain Formation to a depth of about 15 feet below the base of the excavation. Below this depth, the Cedar Mountain Formation is saturated and it consists of an additional 10 to 40 feet of moderately to highly fractured silty sandstone and sandstone conglomerate. A diagrammatic cross section of the proposed disposal cell and foundation is shown on Figure E.2.1. Figure E.2.2 shows the components of the cover system.

In terms of groundwater protection, the cell design makes maximum use of favorable natural conditions at the site. Some of the design and disposal site features and considerations include the following:

- o Mostly below-grade disposal of the tailings to limit the exposed area of the pile, and thereby minimize percolation of precipitation through the tailings.
- o Consistent, uniform, vertical fracturing of the foundation bedrock to prevent ponding ("bathtubbing") in the tailings, and promote drainage of runoff water from the toe of the cell.
- o Abundant, desirable, secondary minerals on the foundation fracture surfaces to attenuate tailings seepage in the unlikely event that seepage leaves the cell.
- o Strong, upward, vertical hydraulic gradients in the saturated bedrock downgradient of the disposal site to inhibit downward migration of contamination.
- o Flow direction in the shallow groundwater beneath the disposal site that is toward the present tailings pile and existing contamination.
- o Inclusion of a buffer layer to absorb contamination exiting the contaminated material and to separate contaminants further from groundwater.

E-10

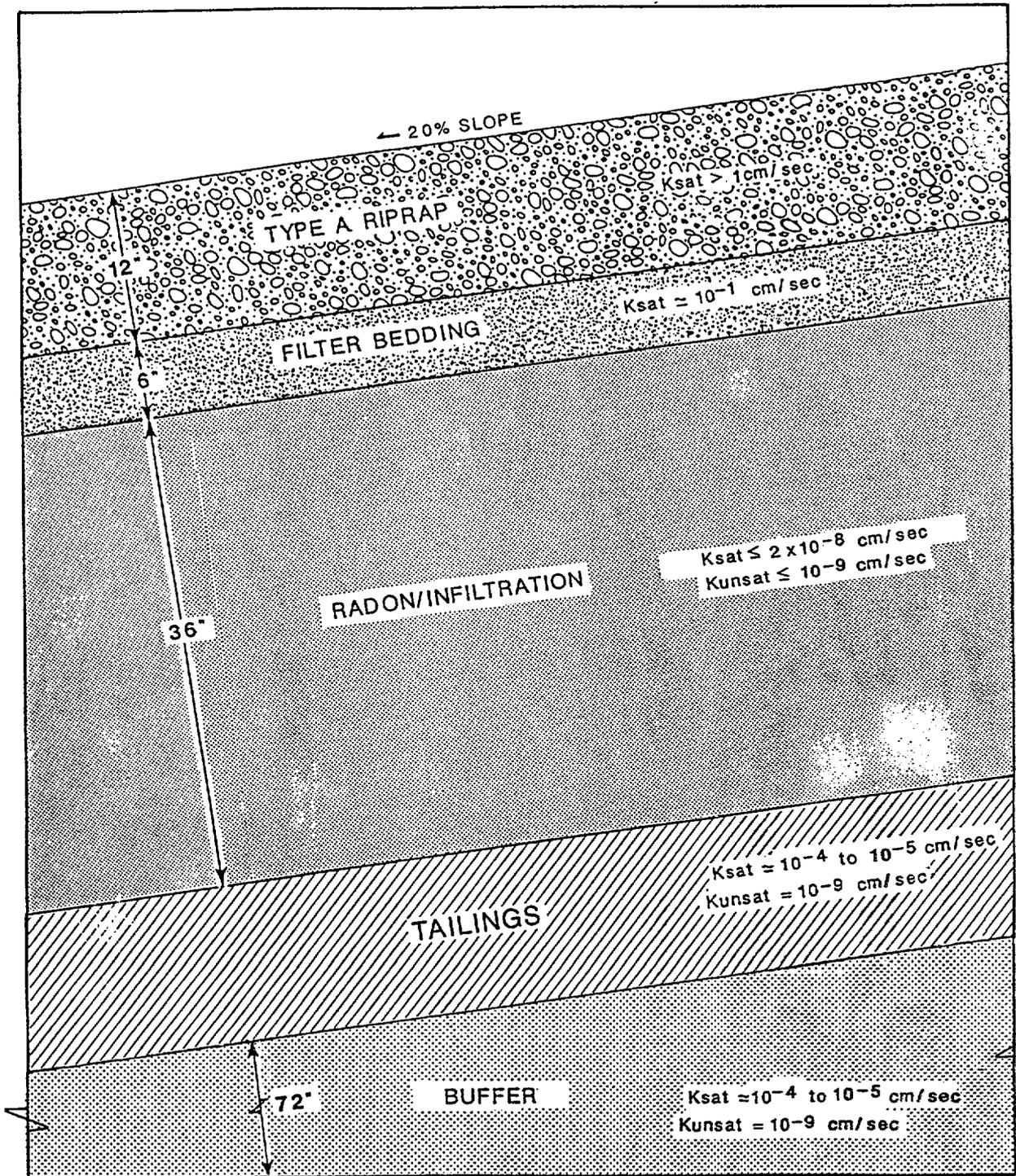


LEGEND

FORMATION	MATERIAL	SYMBOL
Qt TERRACE SEDIMENTS	SOILS	
Kd DAKOTA SANDSTONE	BEDROCK	
Kcmu CEDAR MOUNTAIN FORMATION UPPER-MIDDLE UNIT		
Kcml CEDAR MOUNTAIN FORMATION LOWER-MIDDLE UNIT		
	FRACTURES	
	POTENTIOMETRIC SURFACE	

NOTE: SEE APPENDIX F FOR DETAILED PLANS AND SPECIFICATIONS

FIGURE E.2.1
DIAGRAMMATIC CROSS SECTION OF PROPOSED DISPOSAL CELL AND FOUNDATION
GREEN RIVER, UTAH, TAILINGS SITE



NOTE: SEE SECTION E.2.2 FOR DETAILED DESCRIPTION OF COVER COMPONENT PROPERTIES; K_{sat}-SATURATED HYDRAULIC CONDUCTIVITY; K_{unsat}-UNSATURATED HYDRAULIC CONDUCTIVITY; cm/sec-CENTIMETER PER SEC; SEE FIGURE E.2.1 FOR LOCATION OF THIS DETAIL IN RELATION TO THE DISPOSAL CELL.

**FIGURE E.2.2
DISPOSAL CELL COVER SYSTEM
GREEN RIVER, UTAH, TAILINGS SITE**

- o Limiting the placement moisture content of the contaminated materials in order to prevent drainage of construction water.
- o Placement of a tight clay cap and surface drainage layers that promote runoff and limit infiltration.

The following sections describe in more detail the site-specific natural features and design considerations important in the optimum performance of the proposed cell design to protect groundwater.

E.2.1.1 Climate

Climate is an important design consideration because of its effects on the quantity of water available to percolate through the tailings and potentially move contaminants to groundwater. The Green River site is semiarid and is therefore well-suited for tailings disposal.

Climate at the Green River site is discussed in detail in the environmental assessment (DOE, 1988c). The average annual precipitation at Green River was six inches for the period 1951 through 1980. Other climatological data as excerpted from the environmental assessment are: the average annual pan evaporation (60 inches per year); the average annual temperature (52°F); and the average snowfall (10 inches per year).

C. W. Thornthwaite Associates (1964) and the DOE (1983) have calculated the net infiltration of annual precipitation to groundwater (deep percolation) for Green River, Utah. Both studies independently calculated the ratio of yearly precipitation to yearly actual evapotranspiration to be unity; that is, no water percolates to the groundwater from precipitation. In reality, there is some very small discrete quantity of water that reaches the groundwater system when climate conditions allow deep percolation (i.e., sustained rainfalls or melting snow cover; Walton, 1970). This natural recharge occurs in topographically low areas where soils remain saturated for long periods (Freeze and Cherry, 1979).

Rush et al. (1982) estimated that one percent or less of the average annual precipitation in the Green River, Utah, area recharges the upper groundwater system. Rush et al. (1982) note that the recharge estimate is conservatively high because all of the soils within the study area were assumed to be coarse-textured and, therefore, to have a high potential for deep percolation. In addition, this nominal recharge was estimated to occur in low-lying areas within the basin, principally in drainages. One percent of the average annual precipitation at Green River is equal to 1.4×10^{-9} inch per second (4.8×10^{-9} centimeters per second, or cm/s).

The consumptive use of precipitation by vegetation is nominal in the Green River area because of the lack of rain-

fall and consequent lack of vegetation. For this reason, the rock cover proposed for the Green River disposal cell is appropriate. It is reasonable to believe that the disposal cell will limit infiltration through the tailings to a rate that is equal to or less than the conservative estimate of basin recharge by Rush et al. (1982). Additional discussion regarding cover infiltration and performance is presented in Section E.3.2.

E.2.1.2 Drainage of surface runoff and tailings water

Drainage of surface runoff

Precipitation that falls directly on the disposal cell will either evaporate, infiltrate into the tailings, or run off the cell through the rock riprap or filter bedding. The disposal cell and foundation must act to prevent leachate generation by the runoff water that could potentially accumulate at the contact of the disposal cell cover with the foundation embankment.

A conservative estimate of the quantity of runoff from the disposal cell cover system is 15.2 centimeters per year (cm/yr) (equal to the average annual precipitation) multiplied by the total area of the cell (4.4 acres; 1.8×10^8 cm²). Theoretically, this runoff could create a ring of ponding (below-grade) around the toe of the pile (see Figure E.2.1). Should ponding occur, the minimum infiltration (drainage) rate will be proportional to the vertical hydraulic conductivity of the bedrock, under a gradient of unity. For drainage considerations, a value of 0.2 foot/day (7.1×10^{-5} cm/s) was chosen to be a conservative value of the bulk (fractured) vertical hydraulic conductivity of the fractured foundation bedrock beneath the disposal site. This value is equal to the lowest calculated bulk horizontal hydraulic conductivity of the upper-middle hydrostratigraphic unit (see Table D.5.8 of Appendix D). Therefore, the minimum drainage rate would equal 7.1×10^{-5} cm/s. Making allowances for the geometry of the cell and the porosity of the bedding layer (assumed to be 0.25), the maximum potential ponding depth around the periphery of the cell would equal 74 cm (29 inches), or about 23 inches (maximum) ponding into the Type A riprap. The width of this ponding ring around the perimeter of the cell is very small (approximately one percent of the area of the tailings) and thus the ponding would have no effect on infiltration or leachate generation.

This estimate of maximum potential ponding is very conservative because it assumes (1) the buffer layer beneath the tailings is non-existent, when in reality the buffer layer will help drain any runoff from the toe of the cell and prevent preferential flow paths from developing; (2) a minimum calculated bedrock hydraulic conductivity; (3) no evaporation;

and (4) no infiltration. A more likely condition is that a significant portion of the precipitation that falls on the cell will evaporate back to the atmosphere or infiltrate into the foundation rock and/or surrounding soil.

Drainage of tailings construction water

Tailings materials and windblown and other contaminated materials will be placed in the disposal cell in as dry of a moisture condition as practicable in order to minimize the potential impact of drainage of construction water. The discussion of analyses presented in Section E.3.2 shows that the actual placement moisture content of these materials will compare to the residual moisture contents determined from laboratory capillary retention data. Therefore, the drainage of tailings construction water has been considered in the overall groundwater compliance strategy.

E.2.2 DISPOSAL CELL DESIGN

The Green River disposal cell cover will consist of a series of layers on top of the compacted contaminated materials. Prior to placement of contaminated material, a layer of uncontaminated silty to clayey sand will be placed to cover the fractured bedrock surface of the excavation. The various layers, including the windblown and other contaminated materials and the unsaturated bedrock below the disposal cell, will act as a system that prevents contamination of the uppermost aquifer. The system is designed to limit the movement of moisture through the disposal embankment to less than the saturated hydraulic conductivity of the infiltration/radon barrier operating under a unit gradient.

In addition, the cover components prevent erosion of the disposal cell by stormwater runoff, limit the radon emanation into the atmosphere, and prevent ponding of water on the disposal cell surface by promoting rapid runoff of precipitation.

Figure E.2.1 shows a cross section of the tailings disposal cell. Details of the cover are shown in Figure E.2.2. The reasons for incorporating the individual components of the disposal cell and the design specification for each are discussed in this section. The performance of each component and the system are described in Section E.2.2.2.

E.2.2.1 Cell components

Cell geometry

The disposal cell surface area has been minimized by providing the deepest burial depth (below-grade) without compromising the depth from contaminated material to groundwater. Also, the steepest sideslope geometry that

optimizes rock sizes for erosion control has been used. The topslope area has been minimized to the extent allowed by conventional construction equipment. All of this results in an optimized pile geometry that will minimize the amount of time that precipitation remains on the cell.

Erosion barrier (riprap)

The rock riprap will protect the disposal cell from erosion up to Probable Maximum Precipitation (PMP) surface water flows. No other design feature except possibly vegetated earthen covers can perform this task. At Green River the amount of rainfall is insufficient to support a vegetated cover (see Section E.2.1.1). The riprap will also serve the following functions:

- o To prevent deep drying of the underlying infiltration/radon barrier and thus potential cracking.
- o To limit the amount of vegetation that can establish itself on the pile.
- o To provide frost protection to the underlying layers.

The quality of rock specified will meet NUREG/CR-4620 (Nelson et al., 1986) for durability and the layer will be sufficiently thick (12 inches) to provide adequate erosion protection (DOE, 1988b). Specifications for rock quality, placement criteria and placement details are contained in Section 2278 of the Final Design, Appendix F.

Bedding layer

The bedding layer will consist of six inches of clean sand and gravel. It will perform in three ways: (1) by acting as a separator between the infiltration/radon barrier and the rock riprap during construction; (2) by allowing rapid runoff of surface water from rainfall over the radon barrier; and (3) by providing frost protection for the underlying layers. The material will have a design hydraulic conductivity of greater than one cm/s and be specified to meet NUREG/CR-4620 (Nelson, et al., 1986) durability criteria. Specifications for grading and placement are contained in Section 2278 of the Final Design in Appendix F.

Infiltration/radon barrier

The infiltration/radon barrier will consist of three feet of bentonite-amended, compacted clay soil obtained from the Elgin borrow source. The soils will be modified with six

percent sodium bentonite and placed so that a minimum laboratory saturated hydraulic conductivity of 2×10^{-8} cm/s will be obtained. The upper portion of the infiltration/radon barrier along with the riprap and bedding material will act as frost protection to the lower portion. At least one foot of the infiltration/radon barrier will be maintained below the design frost depth. Specifications and details of the radon barrier processing, placement, and compaction are presented in Section 2200 of the Final Design, Appendix F.

Tailings

Tailings placed in the disposal cell will be compacted at a moisture content that is near the specific retention moisture content of the material. Compaction and environmental (dust control) water will be controlled so that the final in-place moisture content of the tailings is as near or below this value as practicable. The Final Design, Appendix F, provides specifications in Section 2200 for placement, compaction, and moisture control of contaminated materials.

Windblown and other contaminated material

The windblown and other contaminated material will be placed and compacted at a moisture content as near to the specific retention moisture content as practicable. These materials contain minor radioactive contamination but, as indicated by the laboratory batch and column leach tests, they do not provide significant contamination to the percolating water.

Buffer layer

Particle gradation of the buffer layer will be finer (as measured by the percent passing the No. 200 sieve) than the tailings. The upper eight to ten feet of disposal cell excavation is considered a suitable source for this buffer layer. The moisture content at placement for this layer is 11 to 17 percent, which is also the predicted long-term steady state moisture content. Placement and compaction specifications are contained in Section 2200 of the Final Design, Appendix F.

E.2.2.2 Disposal cell longevity

The EPA standards (40 CFR 192) require that the disposal cell be designed for 1000 years where reasonably achievable, and in any case for at least 200 years. Natural, stable materials will be used in construction so that the long-term performance is ensured. Design techniques will be used that are suitable for periods much longer than the 1000 years required.

Rock erosion protection has been sized and suitable durable material selected that will perform adequately over the design life of the disposal cell. Bedding material has been selected using the same durability criteria as that of the rock. The material is sized to drain water rapidly, and oversizing is employed to provide a margin of safety from plugging by wind-blown silts. Also, the bedding is bounded on top by larger diameter riprap; should some plugging occur, it will enhance runoff in the rock riprap layer.

The radon barrier clays will be protected from erosion by the rock erosion protection and the bedding layer. Uniformity of hydraulic conductivity will be ensured by the addition of a small percentage of sodium montmorillonite (bentonite). All material placement and compaction has been specified to ensure that the disposal cell will be constructed as designed.

The final Remedial Action Plan (RAP), construction documents, and associated calculations are all prepared as documentation of the disposal cell performance. The effect of freezing and thawing was not documented in these supporting calculations. The following discussion demonstrates that the disposal cell cover will provide adequate protection from freezing and thawing cycles. A separate calculation has been performed to support this discussion and is retained at the DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

In order to determine the effect of frost penetration upon the cover design, it is necessary to determine the depth of frost penetration for the site and cover materials. Data necessary to determine depth of freezing include the minimum and maximum temperatures at the site, the geometry of the cover (specifically the thickness of each component), the dry density of each component, and the moisture content(s) at which the cover is performing.

Weather data

Historical weather data are available for Green River, Utah, from the National Oceanographic and Atmospheric Administration (NOAA). The Green River weather station is 1.5 miles west-northwest of the disposal site and at 4070 feet above mean sea level. The original grade at the site is 4154 feet above mean sea level. Based on the topography of the area, it is reasonable to assume that the site and the weather reporting station are in similar climatic areas and are not influenced by microclimatic (topographic) effects. Thirty-eight years of temperature data are available, of which 20 years provide sufficient annual data to be usable for analysis.

Cover geometry and material properties

The cover geometry analyzed was presented in Section E.2.2.1. The 12-inch-thick erosion protection layer has a dry density of 140 pounds per cubic foot, and being free-draining, will have a low moisture content estimated at five percent. The sand and gravel bedding material is also free-draining. The estimated dry density is 130 pounds per cubic foot and the moisture content is five percent. Since these are estimates based on typical values for soil and rock, sensitivity analyses are performed to observe the effect of cover geometry and material properties on frost depth. The infiltration/radon barrier will be placed at a dry density of not less than 110 pounds per cubic foot and will operate unsaturated near the optimum moisture content of 15 percent. Since some variation in the long-term moisture content of this material is anticipated, sensitivity analyses are performed varying the moisture content of the radon barrier material. Since the cover will be designed to maintain at least one foot of radon barrier below the calculated frost depth, no other soil properties are required for the analysis.

Analytical techniques

Published literature on frost depth provides various regional frost depth maps of the United States. One such map shows a frost depth of 32 inches for the Green River vicinity (U.S. Navy, 1982). Discussions with the Green River city engineer indicate that foundations and pipes are typically buried 36 inches below ground. For detailed analyses of the disposal cell cover design, a computer program developed by the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory was used. The program listing, along with the methodology employed in performing the analyses, is presented in "The Effect of Freezing and Thawing on UMTRA Covers" (DOE, 1988b). Results of the analyses are on file at the UMTRA Project office in Albuquerque, New Mexico.

Statistical curve-fitting techniques were used to extrapolate the historic recorded temperatures to obtain a 200-year return interval for the required weather data. The least squares linear regression was used because it provides a good "fit" for the data. This resulted in a predicted nonexceedance freezing index value of 1080 degree days, a 47.5°F mean annual temperature, and a 137-day duration of freeze.

Additional conservatism was added to the analyses by assuming that the coldest and longest freezing period occurs simultaneously with a dry period. Thus, insulating factors such as snow and ice accumulations in riprap were ignored.

Results

Based upon the information and data presented in the previous sections, a frost depth of 38.7 inches was calculated for the Green River site. Variations of material properties for the rock riprap, bedding, and infiltration/radon barrier layers resulted in less than seven percent variance in the depth of freezing. Variations in climatic conditions as input parameters also resulted in less than seven percent variance in the depth of freezing.

The value selected for the depth of freezing is deeper than that used by local building officials and is considered a reasonable and conservative value for use at the Green River site. Although weather data are extrapolated for only 200 years, the calculated frost depth will have a longer return interval than 200 years since the insulating effect of snow was conservatively ignored.

E.3 DISPOSAL AND CONTROL OF RADIOACTIVE MATERIALS AND NONRADIOACTIVE CONTAMINANTS

E.3.1 GROUNDWATER PROTECTION STANDARD FOR DISPOSAL

For the Green River disposal site, three basic factors for complying with the groundwater protection standards are required (40 CFR 192.02). These are (1) determination of hazardous constituents within the disposal cell, (2) proposal of a concentration limit for each hazardous constituent, and (3) specification of the point of compliance. The following sections discuss these requirements.

E.3.1.1 Hazardous constituents

Appendix IX of 40 CFR 264 is a list of hazardous compounds and elements used in screening suspected contamination at land-based hazardous waste treatment, storage, and disposal facilities under the EPA's Resource Conservation and Recovery Act (RCRA) Program. The list in Appendix IX is also used to screen for contamination due to uranium mill tailings and ore processing. However, most of the hazardous compounds in Appendix IX are not normally associated with uranium mill tailings because they were intended primarily for screening RCRA hazardous waste sites. The proposed EPA groundwater standards for uranium mill tailings disposal at inactive sites (40 CFR 192) incorporate Appendix VIII of 40 CFR 264 by reference; Appendix VIII has been superseded by Appendix IX. In addition to the Appendix IX suite, molybdenum, nitrate, radium 226 and 228, uranium 234 and 238, and gross alpha activity are potentially hazardous constituents within uranium mill tailings, and should be considered during characterization (40 CFR 192.02(3)(i,ii)).

The hazardous constituents within the Green River tailings are related to both the uranium ore and the chemicals used in the milling process. Section D.5.2.8 of Appendix D, Site Characterization, discusses the milling process at Green River and the physical and chemical characteristics of the tailings. The following discussion of hazardous constituents within the Green River tailings is subdivided into inorganic and organic components. Table E.3.1 is a summary of the hazardous constituents identified within the Green River tailings.

Inorganic constituents

The inorganic constituents within the tailings at Green River are mostly metal and metalloid elements associated with the uranium ore. Those elements that should be considered include antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, selenium, silver, thallium, tin, and vanadium (40 CFR 264, Appendix IX). Of these elements, only

Table E.3.1 Summary of hazardous constituents within uranium mill tailings at Green River, Utah^a

Constituent	Concentration pore water ^b	Concentration subpile ^c	Detection limit ^d	EPA MCL ^e	Standard ^f
Cadmium	0.032	<0.001	0.001	0.010	Title I
Chromium	1.88	0.03	0.01	0.05	Title I
Molybdenum	0.15	0.27	0.01	0.1	Title I
Nickel	25.3	0.05	0.04	none	Title I
Nitrate	2251	440	1	44	Title I
Selenium	0.15	0.76	0.005	0.01	Title I
Uranium	448.0	2.23	0.003	0.044	Title I
Vanadium	178.0	0.24	0.01	none	Title I
Radium-226 and -228	NM	7.5 pCi/l	2.0 pCi/l	5.0 pCi/l	Title I
Gross alpha	NM	1200.0 pCi/l	0.2 pCi/l	15.0 pCi/l	Title I

^aAll concentrations are in mg/l unless noted otherwise.

^bData from lysimeter 714 (see Figure D.5.1 and Table D.5.22 of Appendix D). Values are arithmetic mean where two analyses are reported in Table D.5.22.

"NM" means not measured.

^cMaximum reported value from Table D.5.14 of Appendix D for on-site alluvial monitor wells 702 and 808.

^dLaboratory method detection limit.

^e"None" means there is no MCL for that constituent.

^f"Title I" refers to EPA proposed standards for remedial action at inactive (Title I) uranium processing sites (40 CFR 192). The MCLs established by 40 CFR 143 are the same as those in the State of Utah Drinking Water Standards for community water systems.

arsenic (0.05 milligrams per liter, or mg/l), barium (1.0 mg/l), cadmium (0.01 mg/l), chromium (0.05 mg/l), lead (0.05 mg/l), mercury (0.002 mg/l), and selenium (0.01 mg/l) have associated MCLs (see Table D.5.1). Other inorganic elements and associated MCLs include: (from 40 CFR 192.02(3)(i,ii)) molybdenum (0.10 mg/l); nitrate as NO₃ (44 mg/l); radium-226 and -228 activity (5.0 picocuries per liter, or pCi/l); uranium-234 and -238 (30 pCi/l activity or 0.044 mg/l); and gross alpha activity (15 pCi/l). Based on acidic (low pH) pore water samples of the Green River tailings (see Table D.5.22 of Appendix D), values of the following inorganic hazardous constituents are higher than the proposed MCLs (see Table E.3.1):

- o Cadmium.
- o Chromium.
- o Molybdenum.
- o Nitrate.
- o Selenium.
- o Uranium.

Concentrations for the following inorganic hazardous constituents without MCLs are higher than laboratory method detection limits (see Table E.3.1):

- o Nickel.
- o Vanadium.

Originally, beryllium and thallium were not analyzed for in groundwater, tailings, windblown soils, or buffer materials at the Green River site. Both of these elements exist in trace quantities in nature. However, recently the DOE has evaluated whether beryllium and thallium are hazardous constituents in the contaminated materials (see Table D.5.27 of Appendix D). Representative samples of tailings, windblown soils, and buffer materials were collected and analyzed for these constituents. Laboratory analyses indicate that neither beryllium nor thallium is present in the contaminated materials. Consequently, these two constituents will not be included in the list of hazardous constituents at the disposal site.

Ammonium contamination was identified in the top hydrostratigraphic unit beneath the present tailings pile (see Section D.5.2.7 of Appendix D). Ammonium was used in the milling process (see Section D.5.2.8 of Appendix D) and may be present in the groundwater beneath the tailings by the chemical reduction of nitrate within the tailings to ammonium. Ammonium is present in much lower concentrations within the tailings pore fluid (see Table D.5.22 of Appendix D) than in concentrations presently in groundwater beneath the tailings (see Figure D.5.19 of Appendix D). Ammonium is not considered a hazardous constituent per Appendix IX of 40 CFR 264 or 40 CFR 143 and it has no associated MCL.

Organic constituents

Any organic compounds within the tailings would be present from processing activities. As discussed in Section D.5.2.8 of Appendix D, the sand tailings at Green River were leached with acid, and excess acid was neutralized with ammonia.

As discussed in detail in Section D.5.2.7 of Appendix D, a priority organic pollutant scan and analyses specifically for volatile and semi-volatile organic compounds were conducted on a sample from a lysimeter and several monitor wells at the tailings site. The analytical results showed no compounds to be present in confirmable concentrations (TAC, 1988). However, methylene chloride will be included in the hazardous constituents list because it is the breakdown product of several organic compounds, and has the potential to exist at the disposal site. Therefore, the DOE has added methylene chloride to the hazardous constituents list. The priority pollutant scan results and the other organic analyses are on file in the DOE UMTRA Project Office in Albuquerque, New Mexico.

E.3.1.2 Proposed concentration limits

The DOE intends to comply with the proposed EPA groundwater standards by meeting MCLs or background concentrations for those constituents identified in Section E.3.1.1 and summarized in Table E.3.1. Specifically, the proposed concentrations are as shown in Table E.1.1. Section E.3.2 will demonstrate that the disposal cell will perform adequately to prevent any long-term adverse impacts to groundwater beneath, or peripheral to, the disposal site.

Arsenic and lead have not been identified as hazardous constituents of concern at the Green River site, but they can be derived from the uranium milling process and have been evident at other UMTRA Project sites in excess of their respective MCLs. Consequently, the DOE will include these elements on the hazardous constituents list.

The proposed concentrations listed in Table E.1.1 were selected with consideration of the distribution of constituents in the upper-middle and lower-middle hydrostratigraphic units, both of which subcrop beneath the proposed disposal site (see Sections D.5.2.3 and D.5.2.5 of Appendix D). The quality of water in these two units beneath the disposal area is similar (see Section D.5.2.6 of Appendix D). Table E.3.2 is a summary of the descriptive statistical parameters for the background water quality at the disposal site. Monitor wells used to define the background water quality beneath the disposal site include 816 in the upper-middle unit and 562 and 813 in the lower-middle unit (see Figure D.5.1 of Appendix D for

Table E.3.2 Descriptive statistical parameters for background water quality at the Green River UMTRA Project disposal site, Green River, Utah^a

Constituent	Number of samples, n	Arithmetic mean, \bar{X}	$\bar{X} + 2s^b$	Observed maximum	Skewness
Cadmium	4	0.003	0.007	0.005	0
Chromium	11	0.03	0.09	0.09	1.057
Molybdenum	11	0.11	0.24	0.22	0.290
Nickel	4	0.06	0.09	0.09	1.155
Nitrate	11	90	180	173	0.161
Selenium	11	0.383	1.779	2.50	2.478
Uranium	11	0.0538	0.1252	0.1460	1.303
Vanadium	10	0.08	0.30	0.38	2.326
Radium-226 and -228	5	2.1 pCi/l	4.5 pCi/l	3.9 pCi/l	0.438
Gross alpha	5	89 pCi/l	195 pCi/l	150 pCi/l	0.041

^aAll concentrations are in mg/l unless noted otherwise. See Table E.1.1 for proposed concentration limits. Samples include water quality analyses from monitor wells 562, 813, and 816 from sample rounds 6/86; 9/86; 2/87; 10/87; 1/88; 5/88; and 7/88. See Figure D.5.1 of Appendix D for location of wells.

^bMean value plus two standard deviations from the mean.

locations of the monitor wells). The following are detailed explanations of how the proposed concentration limits were determined.

Arsenic

The DOE does not propose a concentration limit for arsenic. Instead, the NRC's proposed interim concentration limit of 0.05 mg/l (MCL) will be utilized. This interim limit may be revised based on new monitoring data to be collected during and following construction of the disposal unit.

Cadmium

The DOE proposes an MCL of 0.01 mg/l for cadmium. Cadmium has been measured three times in monitor well 562, and once in well 813. The concentrations ranged from <0.001 to 0.005 mg/l.

Chromium

The DOE proposes a concentration of 0.09 mg/l for chromium. Chromium has been measured twice in the upper-middle

unit and nine times in the lower-middle unit. The observed concentration range was <0.01 to 0.09 mg/l. The mean was 0.03 mg/l. The value of the mean plus two standard deviations from the mean was 0.09 mg/l.

Lead

The DOE does not propose a concentration limit for lead. Instead, the NRC's proposed interim concentration limit of 0.05 mg/l (MCL) will be utilized. This interim limit may be revised based on new monitoring data to be collected during and following construction of the disposal unit.

Methylene chloride

The DOE does not propose a concentration limit for methylene chloride. Instead, the NRC's proposed interim concentration limit of 0.005 mg/l (background) will be utilized. This interim limit may be revised based on new monitoring data to be collected during and following construction of the disposal unit.

Molybdenum

The DOE proposes a concentration of 0.24 mg/l for molybdenum, which is the mean concentration of 11 analyses plus two standard deviations from the mean. Molybdenum has been measured twice in the upper-middle unit and nine times in the lower-middle unit. The observed concentration range for these was 0.02 to 0.22 mg/l.

Nickel

Nickel has neither a proposed MCL (per 40 CFR 192), an EPA secondary drinking water limit, nor a state of Utah drinking water maximum concentration limit. Nickel has been measured three times in monitor well 562 and once in well 813. The arithmetic mean of the four values was 0.06 mg/l. The observed values ranged from 0.05 to 0.09 mg/l. The DOE proposes a concentration of 0.09 mg/l for nickel, which is the mean value plus two standard deviations from the mean; it is also the maximum observed value from the four analyses.

Nitrate

Nitrate has been measured twice in the upper-middle unit and nine times in the lower-middle unit. The observed concentration range for these analyses was 12 to 173 mg/l. The arithmetic mean of the eleven analyses was 90 mg/l. The DOE proposes a concentration of 180 mg/l for nitrate, which is the mean value plus two standard deviations from the mean.

Selenium

Selenium has been measured twice in the upper-middle unit and nine times in the lower-middle unit. Selenium concentrations have been highly variable in both of the units; the observed concentration range for the available analyses was <0.005 to 2.5 mg/l. The arithmetic mean of the eleven analyses was 0.383 mg/l. The DOE proposes a concentration of 2.5 mg/l for selenium, which is the maximum observed value from the 11 analyses.

Uranium

Uranium has been measured twice in the upper-middle unit and nine times in the lower-middle unit. The observed concentration range for the available analyses was 0.0074 to 0.146 mg/l. The arithmetic mean of the eleven analyses was 0.0538 mg/l. The mean value plus two standard deviations from the mean was equal to 0.125 mg/l. The DOE proposes a concentration for uranium of 0.1460 mg/l, which is the maximum observed concentration for uranium in the 11 background analyses.

Vanadium

Vanadium has been measured twice in the upper-middle unit and eight times in the lower-middle unit. The range of the available analyses was <0.01 to 0.38 mg/l. The arithmetic mean of the analyses was 0.08 mg/l. The mean value plus two standard deviations from the mean was equal to 0.30 mg/l. The DOE proposes a concentration for vanadium of 0.38 mg/l, which is the maximum observed concentration of the 10 background analyses.

Radium-226 and -228

The DOE proposes an MCL of 5.0 pCi/l for radium -226 and -228. Radium activity has been measured once in the upper-middle unit and four times in the lower-middle unit. The observed activity range for radium was 0.8 to 3.9 pCi/l for the five analyses.

Gross alpha

Gross alpha activity has been measured once in the upper-middle unit and four times in the lower-middle unit. Gross alpha activity ranged from 21.0 to 150.0 pCi/l for the five analyses. The arithmetic mean value of the analyses was 89.0 pCi/l. The DOE proposes an activity of 195 pCi/l for gross alpha, which is the mean value plus two standard deviations from the mean.

Natural variation

The DOE-proposed concentration limits and NRC-proposed interim concentration limits discussed in this section will be reviewed and updated following the two-year interim monitoring period following completion of the remedial action as necessary to reflect the additional background data. The measured concentrations have a natural variability associated with them and must be adequately assessed for planning purposes. Construction and performance monitoring will be discussed in more detail in Section E.3.4. A corrective action plan for the disposal site will be discussed briefly in Section E.3.5. Final details of performance monitoring and corrective action plans will be presented in a separate document (surveillance and maintenance plan) for the Green River site.

E.3.1.3 Point of compliance

The point of compliance at the Green River disposal site will be the entire northwest and northeast edges of the engineered cell as shown in Figures E.3.1 (plan view) and E.3.2 (cross section). Details of the number of monitor wells at this location and the frequency of sampling will be discussed briefly in Section E.3.4 and in detail in the forthcoming surveillance and maintenance plan for the Green River disposal site.

E.3.2 PERFORMANCE ASSESSMENT

The proposed disposal cell design as described in Section E.2 will prevent the introduction of contaminants into the groundwater by providing for leachate travel times from the base of tailings to the bottom of the disposal cell of between 450 to in excess of 1100 years. Due to the lack of understanding of the behavior of seepage in the vadose zone below rock-covered areas, as well as limitations of currently available groundwater (infiltration) models, a conservative approach to evaluating the pile performance was taken.

Travel time was estimated from the base of the tailings through the windblown and other contaminated material, and through the buffer layer. Credit for travel through the windblown and other contaminated material was taken because laboratory batch and column leaching tests on these materials indicate that they contain no significant leachable contamination (see the set of calculations accompanying this RAP). Travel time through the foundation bedrock cannot be accurately estimated due to fracturing. Because any leachate percolating through the tailings is not expected to reach groundwater within the design life of this cell, no degradation of groundwater quality as a result of remedial action is anticipated.

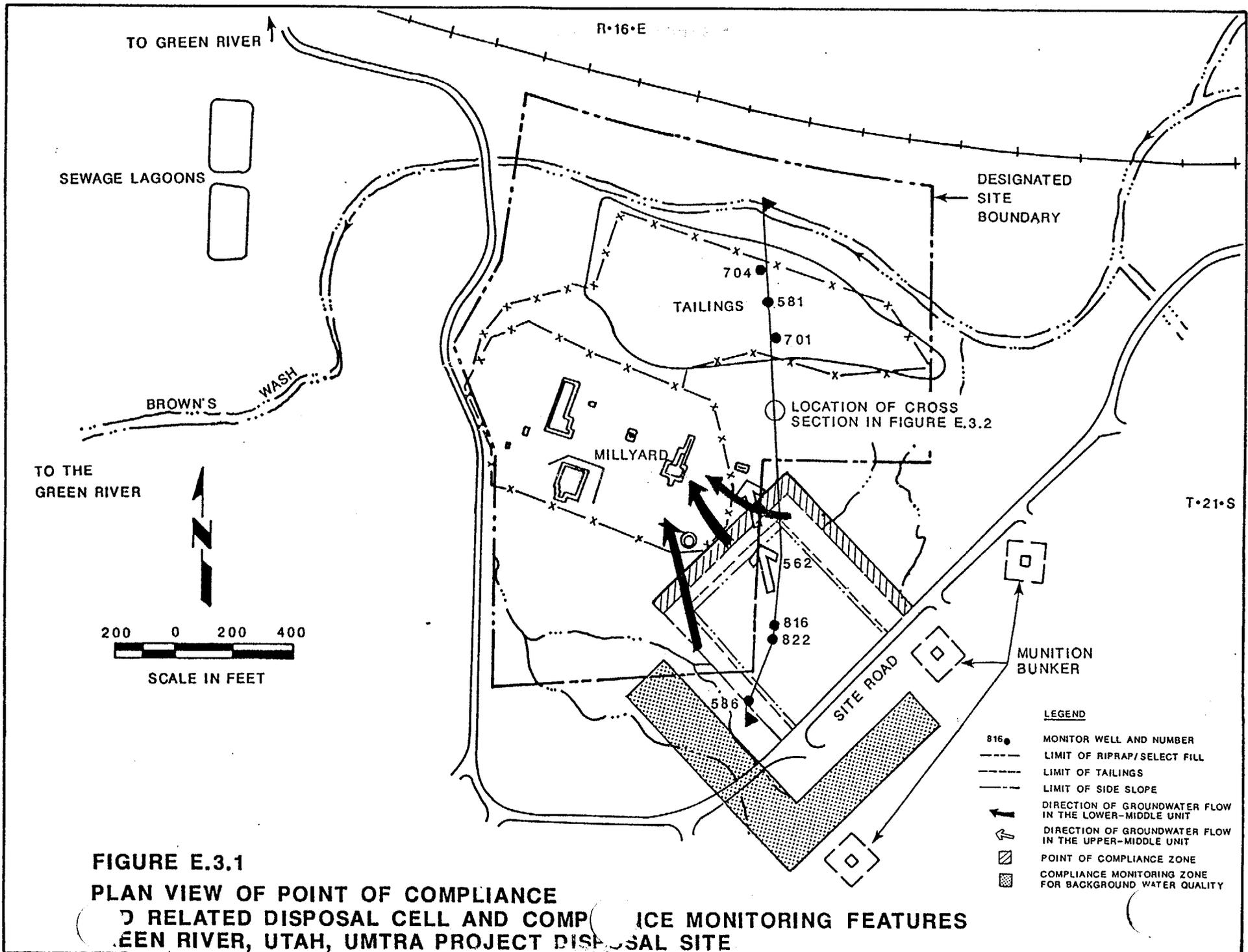


FIGURE E.3.1

PLAN VIEW OF POINT OF COMPLIANCE

**RELATED DISPOSAL CELL AND COMPLIANCE MONITORING FEATURES
GREEN RIVER, UTAH, UMTRA PROJECT DISPOSAL SITE**

- LEGEND**
- 816 ● MONITOR WELL AND NUMBER
 - - - - - LIMIT OF RIPRAP/SELECT FILL
 - - - - - LIMIT OF TAILINGS
 - - - - - LIMIT OF SIDE SLOPE
 - ↑ DIRECTION OF GROUNDWATER FLOW IN THE LOWER-MIDDLE UNIT
 - ↑ DIRECTION OF GROUNDWATER FLOW IN THE UPPER-MIDDLE UNIT
 - ▨ POINT OF COMPLIANCE ZONE
 - ▨ COMPLIANCE MONITORING ZONE FOR BACKGROUND WATER QUALITY

This section describes the analyses performed to evaluate seepage through the disposal cell and summarizes the impacts on disposal cell performance. The calculations performed for these analyses are retained in the DOE UMTRA Project Office, in Albuquerque, New Mexico.

E.3.2.1 Conceptual model assessment

In order to estimate the travel time of contaminated water to the groundwater and to evaluate the sensitivity of these analyses and associated assumptions, several approaches were used to predict the cell performance. Analyses of the redistribution of moisture through the cell were performed using UNSAT2 computer code (NRC, 1983). In addition, simplifying assumptions were made by assuming that the steady state travel time will be controlled by the least permeable layer (in this case the cover) and that the materials will operate at a flux equivalent to this saturated hydraulic conductivity under a unit gradient.

System geometry and boundary conditions

Figures E.2.1 and E.2.2 are diagrammatic cross sections depicting the cell cover, tailings, windblown, and other contaminated material, buffer layer, and foundation soils and bedrock. Detailed information about each of those components is provided in Section E.2.2 and D.4 of Appendix D.

It is assumed that moisture redistribution occurs in a vertical direction or one dimensional flow, due to the relative homogeneity of the materials and the large lateral extent of the cell in relation to its thickness. The cover layering consists of three feet of compacted infiltration/radon barrier, over 25 feet of compacted tailings, which in turn overlies 25 feet of compacted windblown and other contaminated material. Under this material is a six-foot-thick compacted buffer layer overlying 14 feet of bedrock between the base of the cell and the uppermost aquifer. Other aspects of the cover system and cell geometry are discussed in detail in Appendix B.

Other boundary conditions used for the UNSAT2 modeling include the presence of continuously available free water to the top of the infiltration/radon barrier. This is conservative, since historical meteorological data indicate that water from precipitation is only available four percent of the time. This includes time for water to run off the cell following a rainfall event. Therefore, the upper boundary assumption is conservative. A lower boundary suction equivalent to 14 feet of suction was applied to the bottom of the cell, representing maximum capillary forces as influenced by the saturated condition in the uppermost aquifer. Since the bedrock is fractured between the cell base and the water table

it is doubtful that full capillary forces will be developed. Varying this lower boundary between zero and minus 21 feet pressure head resulted in no significant change in the cell performance. The use of full capillary force due to the proximity of the uppermost aquifer is a conservative assumption.

For the simplified analysis it was assumed that water is continuously available to the top of the infiltration/radon barrier, that the infiltration/radon barrier operates in a fully saturated condition, and that the flux below the radon barrier is equivalent to the saturated hydraulic conductivity of the infiltration/radon barrier operating at a unit gradient.

Material properties

The results of capillary retention tests, saturated hydraulic conductivity tests, and mechanical properties tests for the compacted infiltration/radon barrier, compacted tailings, compacted windblown and other contaminated material, and buffer are presented in Appendix D and Appendix G. Material properties were selected that are considered representative of the materials used to construct the disposal cell. Variations of material properties were assessed in selecting values used in the analyses. These material assessment calculations are retained in the DOE UMTRA Project Office, Albuquerque, New Mexico.

The measured retention data for each soil were used to estimate coefficients for van Genuchten's retention function using the RETC program (van Genuchten, 1984). The fitted retention function was then used to predict the unsaturated hydraulic conductivity as a function of moisture content. Results of the application of the RETC program to the retention data discussed above are on file at the DOE UMTRA Project Office, in Albuquerque, New Mexico. The parameters used to describe each soil are presented in Table E.3.3.

Part of this travel-time-related compliance strategy involves use of the windblown and other contaminated materials as part of the storage capacity of the percolating contaminated water. Therefore, this material should not be capable of producing contaminants when leached. In order to verify that this is indeed the condition of the windblown and other contaminated material, a series of batch and column leach tests were performed on samples considered representative of this material (see Appendix H). The results and interpretation of these tests are on file at the DOE UMTRA Project Office, Albuquerque, New Mexico. These tests confirm that the windblown and other contaminated material are not capable of producing significant amounts of contaminated leachate.

Table E.3.3 Hydrologic properties and parameters of the van Genuchten retention function used to describe the disposal cell soil Green River UMTRA Project site

Parameter	Soil description			
	Infiltration/ radon barrier	Tailings	Windblown and other contaminated material	Buffer
Compaction density, pcf (% of optimum)	100	90	95	96
Saturated water content (%)	32.0	45.0	33.0	33.0
Residual water content (Vol. %)	26.9	3.0	2.5	2.5
α (fitted parameter) (1/cm)	0.0060	0.0050	0.0034	0.0034
N (fitted parameter)	2.313	2.326	2.250	2.250
Saturated hydraulic conductivity (cms)	2×10^8	6×10^4	1×10^4	1×10^4

Analytical procedures

Immediately after construction, capillary gradients created by contrasts in pore size and differences in initial moisture content between the foundation, buffer, and tailings would produce flux between these soils, and redistribution of moisture within each soil type. At some time after cell closure, moisture contents within the tailings, buffer layer, and foundation soils will be in equilibrium with the average flux through the infiltration/radon barrier. A combination of capillary and gravitational forces would produce a constant flux throughout the disposal cell profile. By placing the tailings at or near the steady state moisture content of the material, the drainage of contaminated water added due to construction will be minimized. However, it is not practical to specify the exact moisture content of the material as the residual moisture content is a low value (three percent) for the tailings and some water may be required for control of fugitive dust or other health concerns during construction.

One method of analyzing the cell performance that accounts for such transient seepage is the use of the UNSAT2 computer code (NRC, 1983). Boundary conditions and material properties used for the analysis are discussed in the previous two subsections. Analyses were performed setting the initial suctions of the tailings at values equivalent to volumetric moisture content of five percent (residual moisture content) and 7.1 percent (that obtained during construction). For the buffer and windblown and other contaminated material, the initial suction was set at an equivalent volumetric moisture content equal to 10.6 percent (that obtained during construction). The radon barrier initial suction was set equal to a moisture content equivalent to that of optimum plus three percent. The results of these analyses indicate that the flux from the bottom of the cell reaches steady state at $8 \times 10^{-9} \text{ cm}^3/\text{cm}^2\text{s}$ after 100 years for the tailings placed at a higher higher moisture content. Equilibrium was not reached for the lower moisture content material. However, there is little difference in flux rate between the two placement moisture contents for flux rates greater than $8 \times 10^{-9} \text{ cm}^3/\text{cm}^2\text{s}$.

A closer examination of the modeling indicates that the higher flux rate exiting the bottom of the cell, which occurs during the first 30 to 40 years, is a result of drainage of excess moisture from the buffer. The tailings do not show a change in moisture content from placement conditions until long after the equilibrium flux from the bottom of the cell has been established. Therefore, the rate of contaminant movement prior to equilibrium can be considered equal to the unsaturated hydraulic conductivity of the lowermost tailings material operating at a head equal to the suction imposed in

the material. For the Green River tailings placed at 7.1 percent volumetric moisture content this corresponds to 5×10^{-9} cm/s at a gradient of near unity. Thus, the placement of tailings materials at or slightly above the long-term moisture content will result in no significant movement of contaminants from the tailings above those predicted for steady state conditions.

Based on the steady state flux rate predicted by UNSAT2 (8×10^{-9} cm³/cm²s) and the flux rate equivalent to the saturated hydraulic conductivity of the radon barrier acting under a unit gradient (2×10^{-8} cm³/cm²s), the travel time through the windblown material and buffer is calculated to be 1130 and 450 years, respectively. The details and analyses described above are retained in the DOE UMTRA Project Office, Albuquerque, New Mexico.

Discussion

The steady state groundwater travel time through the buffer is estimated to exceed 1000 years and in any case more than 450 years. Because this estimate assumes that the bedrock foundation drains freely, it is considered to be a conservative lower bound. As discussed above, lack of data on the unsaturated hydraulic properties of the bedrock precludes a better estimate of lower boundary pressure, or an accurate estimate of travel time through the four meters of bedrock separating the buffer from the water table. However, assuming an effective porosity of five percent, transport of any hazardous constituents from the base of the buffer to the water table under a flux of 2×10^{-8} cm/s will require an additional 120 years.

Because the placement moisture contents for each soil will be equal to or less than those used in the analyses, transient redistribution of water within the cell will not create downward flow of contaminants which exceed the steady state rate. Steady state velocities will therefore provide a conservative estimate of travel time. Furthermore, the conservative upper boundary assumptions made for the analyses cause the predicted travel times to be greatly overestimated. If no downward flow is assumed during periods when water is not present atop the pile, the travel time can be extended by a factor of 25.

E.3.2.2 Impacts summary

No degradation of groundwater quality will occur as a result of the proposed remedial action for at least 450 years and probably in excess of 1000 years at the Green River UMTRA Project site.

E.3.3 CLOSURE PERFORMANCE ASSESSMENT

The DOE must demonstrate compliance with the closure performance standard (40 CFR 192.02(a)(4)) by showing that the need for further maintenance of the disposal site and cell has been minimized and that the disposal unit minimizes or eliminates releases of hazardous constituents to the groundwater.

The durability and longevity of the cell has been demonstrated and discussed in Section E.2.2.2. Section E.3.2 demonstrates and discusses the adequacy of the disposal cell design to protect groundwater resources at the Green River site.

E.3.4 GROUNDWATER PERFORMANCE MONITORING PROGRAM

The DOE will present a detailed groundwater monitoring program in the S&M plan for the Green River site. This section briefly describes the program and demonstrates that implementing such a program is feasible at the Green River site. The main features of a performance monitoring program include tailings moisture monitoring and saturated zone monitoring. These features are described as follows.

E.3.4.1 Disposal cell moisture monitoring

A disposal cell moisture monitoring program will be implemented to demonstrate that the net flux of moisture through the tailings, windblown materials, and buffer is near 2×10^{-8} cm/s, as described in detail in Section E.3.2. Details of such a system will be presented in the S&M plan.

A higher cell moisture flux at the Green River site would pose a low relative risk to humans or the environment. Four neutron access holes for neutron moisture logging will be used to monitor moisture within the tailings, windblown materials, and buffer layer at different depths. The time-integrated moisture versus depth data will be used to estimate the unsaturated hydraulic conductivity of the materials. This type of monitoring equipment has been used successfully at the Shiprock UMTRA Project site (DOE, 1989a; Section E.3.2) to relate moisture content (percent saturation) of the infiltration/radon barrier to unsaturated hydraulic conductivity of the radon barrier.

E.3.4.2 Saturated zone monitoring

The upper- and lower-middle hydrostratigraphic units of the Cedar Mountain Formation will be monitored using standard monitor wells at the designated point of compliance (see Section E.3.1.3). There is nothing at the Green River site that would physically preclude wells from being installed at the designated point of compliance.

The pattern of monitor wells (or well pairs) will be presented in the S&M plan. Because of the fractured nature of the Cedar Mountain Formation, wells or well pairs shall be spaced closer together than if the aquifer was homogeneous and isotropic. Well or well pair spacing likely will be on the order of 80 to 100 feet apart at the point of compliance. This relatively greater density of wells is consistent with the procedures outlined in the "Guidance for UMTRA Project Surveillance and Maintenance" (DOE, 1986).

Performance monitoring frequency is also outlined in the guidance document (DOE, 1986). Compliance wells shall be sampled quarterly the first year following completion of remedial action activities, semi-annually for years two through six, and annually thereafter until the end of the performance monitoring period.

Monitoring during remedial action activities shall take place semi-annually. Samples shall be taken from the wells shown in Figure E.3.3. The wells shown in Figure E.3.3 will be retained for post-closure monitoring, but they will not be sampled as frequently as the proposed performance monitoring wells at the point of compliance. Figure E.3.3 also shows surface water sites to be sampled.

The constituents to be analyzed shall include all of the hazardous constituents listed in Table E.3.1 and E.1.1. In addition to these, major anions and cations will be analyzed together with the standard suite of field parameters. A detailed list of constituents will be presented in the S&M plan.

As discussed in Section E.3.1.2, a natural variability is associated with the proposed concentration limits for the hazardous constituents at the Green River site. This natural variability must be considered when defining excursions, and should be updated as more background water quality data become available. This approach is consistent with the S&M guidance document (DOE, 1986). Details on the variability of concentrations for each hazardous constituent will be presented in the S&M plan. Also, more background water quality data will be available at that time, and will be considered in the analysis of variability.

E.3.5 CORRECTIVE ACTION PLAN

The DOE is required by 40 CFR 192.02(c) to provide an evaluation of alternative corrective actions that could be implemented if the disposal monitoring program indicates that the disposal unit is not performing adequately. The DOE should consider reasonable failure scenarios of the disposal unit and demonstrate that corrective actions could be implemented no later than 18 months after finding an exceedance of the groundwater protection standard.

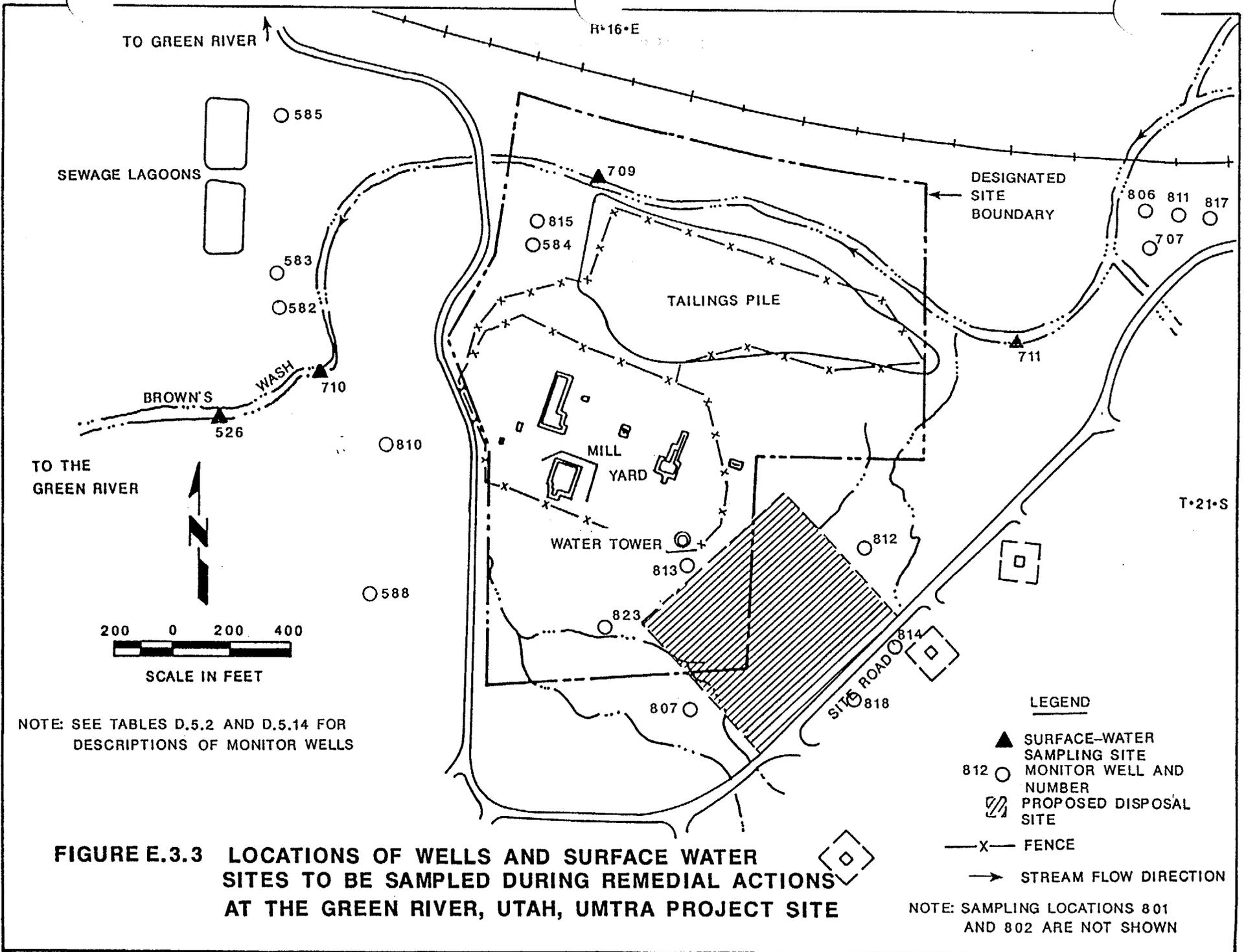


FIGURE E.3.3 LOCATIONS OF WELLS AND SURFACE WATER SITES TO BE SAMPLED DURING REMEDIAL ACTIONS AT THE GREEN RIVER, UTAH, UMTRA PROJECT SITE

As discussed previously in Section E.2.2, the Green River disposal cell has been designed and will be constructed to perform for the mandated design life of 1000 years. The design of the cell has incorporated standard safety factors, and should therefore perform for a period of greater than 1000 years with minimal maintenance. With this in mind, there is no "reasonable" failure scenario for the Green River cell that would be related to structural instability or failure. It is conceivable, however very unlikely, that the net flux of moisture through the cell could exceed the anticipated steady state flux of 2×10^{-8} cm/s (see Section E.3.2). The disposal cell moisture monitoring program planned at Green River (see Section E.3.4.1) is designed to provide early warning of this condition. If it is determined that the moisture profile within the tailings is wetter than anticipated (within some reasonable bounds to be specified in the S&M plan), an assessment of the projected flux rate through the cell at that higher moisture content will be made to determine the potential effects on groundwater, if any.

If it is determined that there are potential adverse effects to groundwater quality, a risk assessment will be performed to determine the potential threat to human health and the environment, if any. A preliminary risk assessment has already been done for the Green River site (DOE, 1989b). The risk assessment could be finalized to include any specific constituents or pathways into the analysis in two to three months. Based on the findings of the preliminary risk assessment, the ambient water quality upgradient and peripheral to the disposal site is not usable. Therefore it is likely that any exceedences of the proposed concentration limits (see Section E.3.1.2) will not constitute an additional threat to human health and the environment. In addition, the disposal site lies immediately upgradient of the present tailings pile and existing contamination. Institutional control of existing contamination from uranium milling processes at Green River, or active restoration of the contaminated aquifers, would necessarily include any potential contamination releases from the disposal cell. The need for aquifer restoration at the Green River site will be addressed in a separate process to comply with Subpart B of the final EPA groundwater standards. Section E.3.6 addresses this subject in greater detail.

Finally, geochemical conditions in the potentially affected aquifers at the Green River site immediately downgradient of the disposal cell are favorable for attenuating redox-sensitive contaminants. This condition is presently reducing uranium and nitrate concentrations in the upper-middle unit beneath the existing tailings pile. Geochemical conditions are discussed in detail in Section D.5.2.9 of Appendix D.

In summary, a corrective action plan for the Green River disposal site contains the following main elements:

- (1) Monitor moisture flux through disposal cell.
- (2) If moisture content exceeds the acceptable value (to be specified in the S&M plan), assess the potential impacts of the higher cell moisture flux.

- (3) Request ACLs for any constituents predicted to exceed the proposed concentration limits (based on a risk assessment) or provide for corrective actions such as cover redesign and construction (e.g., with a CLAYMAX infiltration barrier) if a positive health risk is assessed.

Any exceedence of the proposed concentration limits at the point of compliance, as determined from saturated zone monitoring during the early stages of performance monitoring, would likely be a result of the drainage of water applied to the tailings during construction. Since every effort is being made to minimize this condition (see Section E.2.1.2), an excursion at the point of compliance is considered unlikely, especially when the travel time through the buffer material and foundation bedrock are considered (see Section E.3.2). If there is an excursion at the point of compliance, the corrective action plan would be the same as that for the unsaturated zone monitoring system.

The corrective action plan for the Green River disposal site will also be presented in the S&M plan.

E.3.6 CLEANUP AND CONTROL OF EXISTING CONTAMINATION

Subpart B of 40 CFR 192 requires that the DOE perform a groundwater cleanup evaluation of existing contamination at the Green River processing site. The DOE and NRC consider that evaluation of groundwater cleanup should be deferred until after the EPA promulgates final groundwater protection standards, provided that disposal may proceed independently of cleanup. This section addresses two issues: (1) demonstration that the DOE may proceed with disposal independently of cleanup ("decoupling"); and (2) potential restoration methods that could be employed at the Green River site should restoration be deemed necessary.

E.3.6.1 Decoupling

Section D.5.2.7 of Appendix D addresses the extent of existing groundwater contamination from uranium milling activities at the Green River processing site. Sections E.3.1.3 and E.3.4 address the programs to monitor groundwater quality peripheral to the disposal cell during and after remedial actions. Given that the water quality has been established at both the old tailings site and at the disposal site, the DOE has demonstrated that existing contamination and any future contamination resulting from disposal activities can be distinguished and appropriate corrective actions can be taken to control any contamination resulting from disposal activities (see Section E.3.5).

Finally, because the period of construction activities is relatively short at the Green River site, and the extent of existing contamination is mostly within the site boundaries, there is little chance that human health or the environment

could be affected by leaving the contamination as is during the interim period between remedial action activities and the evaluation of groundwater cleanup.

E.3.6.2 Potential restoration methods

Active restoration methods fall into two general categories: (1) above-ground removal methods, wherein the contaminated water is removed from the aquifer, treated, and either disposed of, used, or reinjected into the aquifer; and (2) in situ methods, such as the addition of chemical lixivants to mobilize the contamination in the subsurface aquifer system. An aquifer restoration program at the Green River site may involve one or more of the restoration methods discussed below.

Extraction

Contaminated groundwater can be extracted with wells or trenches. The use of trenches is limited to relatively shallow contamination (generally less than 50 feet deep) and is most useful in materials with low permeability. For most cases where the contamination is in permeable materials and in cases of low permeability but deep contamination, wells are the preferred extraction method.

Treatment

The need for treatment prior to discharge or reinjection into an aquifer depends upon the concentrations of contaminants in the extracted groundwater and the regulations regarding discharge of effluent to surface and groundwater. Various methods for treating the contaminated water are available. Most of the treatment methods are chemical. These include chemical precipitation, coagulation, ion exchange, flocculation, neutralization, sorption, and reverse osmosis. Contamination can be separated physically from water using evaporation ponds. Biological treatment can be used to transform nitrate to nitrogen gas and oxygen gas. The preferred treatment methods depend on the specific mix of contaminants, the concentration of the contaminants, the general water quality, the volumetric flow of the treatment stream, and the available area for treatment facilities.

In situ treatment

In addition to above-ground treatment, two in situ treatment methods may be applied. These are lixiviant injection and permeable treatment beds or walls. Both methods can be used to cause reducing geochemical conditions, which would cause the

trace metal contaminants to precipitate or absorb out of solution into the solid phase. Although chemical reduction could reduce solute concentrations to less than the appropriate concentration limits, dissolution or desorption could occur as the geochemical environment reequilibrates. Therefore, chemical reduction does not provide long-term assurances that adequate water quality could be maintained. The preferred in situ treatment would result in mobilizing contaminants by causing oxidizing conditions so that contaminants can be removed expeditiously from the subsurface. Permeable treatment beds or walls cannot be used effectively for this purpose.

A lixiviant is a solution of complexing species (either ions or molecules) that enhance the solubility of species (metals) to be removed from the aquifer during restoration. Injection of oxidizing lixiviants containing hydrogen peroxide or oxygen to oxidize the system and sodium bicarbonate to increase the pH may be useful for removing contaminants that may leach from the solid phase. Although this technology is unproven, it may be the only practicable method to remove trace metal contamination, primarily in the solid phase, that leaches to the groundwater at concentrations above the acceptable concentration limits.

Lixiviants would be introduced by injection or infiltration upgradient of the contamination. The lixiviant would move through the contaminated zone, interact with the liquid and solid phases, become impregnated with contaminants, and be extracted at the leading edge of the contaminant plume.

Discharge

Following the extraction, or extraction and treatment, of contaminated water, the water would be discharged. Options for discharge include:

- o Discharge to surface water.
- o Infiltration.
- o Injection in shallow wells.
- o Injection in deep wells.

Natural flushing

Natural flushing is a passive restoration method whereby dissolved or precipitated contaminants in groundwater are dispersed or removed over time by the natural flow of groundwater. Under Subpart B of the proposed EPA standards, passive restoration may be permitted if it can be demonstrated that natural flushing can occur within a period of 100 years or

less and that the groundwater is not now and is not projected to be used for a community water supply (or other substantial use) within this period. Natural flushing may be employed as the sole method for aquifer restoration, or it may be used in conjunction with any of the active restoration methods described above. Natural flushing may be the most logical way to approach groundwater restoration at the Green River site.

REFERENCES

- C. W. Thornthwaite Associates (Laboratory of Climatology), 1964. "Average Climatic Water Balance Data of the Continents," Part VII, United States, in Publications in Climatology, Vol. XVII, No. 3, Technical Report No. 7, National Science Foundation, Contract C266, Centerton, New Jersey.
- DOE (U. S. Department of Energy), 1989a. "Moisture Contents and Unsaturated Conditions in UMTRA Project Radon Barriers," DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- DOE (U. S. Department of Energy), 1989b. Preliminary draft, Alternate Concentration Limits, Supplemental Standards, and Institutional Controls for the Department of Energy's UMTRA Project, report in progress by the DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- DOE (U. S. Department of Energy), 1988a Technical Approach Document, UMTRA-DOE/AL-050425.0002, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- DOE (U. S. Department of Energy), 1988b. "Effect of Freezing and Thawing on UMTRA Covers," UMTRA-DOE/AL-400642.0000, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- DOE (U. S. Department of Energy), 1988c. "Environmental Assessment of Remedial Action at the Green River Uranium Mill Tailings Site, Green River, Utah," DOE/AL-0343, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- DOE (U. S. Department of Energy), 1986. Guidance for UMTRA Project Surveillance and Maintenance, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- DOE (U. S. Department of Energy), 1983. Unpublished report, Environmental Assessment prepared by Ford, Bacon and Davis Utah, Salt Lake City, Utah, and Sandia National Laboratories, Albuquerque, New Mexico, for the DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- Freeze, R. A., and T. A. Cherry, 1979. Ground Water, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.
- Hurlbut, C. S., and C. Klein, 1977. Manual of Mineralogy, 19th Edition, John Wiley and Sons, New York, New York.
- NRC (U. S. Nuclear Regulatory Commission), 1983. "Documentation and User's Guide: UNSAT2--Variably Saturated Flows Model, Final Report," NUREG/CR-3990 WWL/TM-1791-1, U.S. Nuclear Regulatory Commission, Washington, D.C.
- Nelson et al. (J. D. Nelson, S. R. Abt, R. L. Volpe, D. vanZyl, N. E. Hinkle, and W. P. Staub), 1986. "Methodologies for Evaluating Long-Term Stabilization Design of Uranium Mill Tailings Impoundments," NUREG/CR-4620, U.S. Nuclear Regulatory Commission, Washington, D.C.

- Rush et al. (F. E. Rush, M. S. Whitfield, and I. M. Hart), 1982. Regional Hydrology of the Green River-Moab Area, Northwestern Paradox Basin, Utah, U.S. Geological Survey Open File Report 82-107, Denver, Colorado.
- USGS (U.S. Geological Survey), 1970. The Natural Atlas of the United States of America, Department of the Interior, Washington, D.C.
- U.S. Navy (Department of the Navy, Naval Facilities Engineering Command), 1982. "Design Manual 7.1," NAVFAC DM-7.1, Alexandria, Virginia.
- van Genuchten, R., 1978. "Calculating the Unsaturated Hydraulic Conductivity With a New Closed-Form Analytical Model," Department of Civil Engineering, Princeton University. Report No. 78-WR-08.
- Walton, W. C., 1970. Groundwater Resource Evaluation, McGraw-Hill Book Company, New York, New York.