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**Chemical, Geological, and
Hydrological Factors Governing
Radionuclide Migration from a
Formerly Used Seepage Trench:
A Field Study**

C. R. Olsen
P. D. Lowry
S. Y. Lee
I. L. Larsen
N. H. Cutshall

(ENVIRONMENTAL SCIENCES DIVISION
Publication No. 2202)

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CHEMICAL, GEOLOGICAL, AND HYDROLOGICAL FACTORS
GOVERNING RADIONUCLIDE MIGRATION FROM A FORMERLY
USED SEEPAGE TRENCH: A FIELD STUDY

C. R. Olsen, P. D. Lowry, S. Y. Lee,
I. L. Larsen, and N. H. Cutshall

Environmental Sciences Division
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ABSTRACT

A total of 3.2×10^7 L of intermediate-level liquid wastes (ILW) generated from routine Oak Ridge National Laboratory operations, were disposed in Trench 7 between 1962 and 1966. The disposed ILW contained about 10^7 GBq of fission nuclides (primarily ^{137}Cs and ^{90}Sr), activation products (primarily ^{60}Co), actinides (primarily ^{232}Th and ^{238}U decay series nuclides), and transuranics (primarily ^{241}Pu - ^{241}Am). Gamma-log profiles of the wells near ILW Trench 7 indicate that the waste liquids seeped along discrete layers parallel to bedding and along the strikes of faults and folds. Although most of the radioactivity has been retained by sorption reactions with the trench fill, soils, and weathered bedrock, groundwater characteristics in the vicinity of ILW Trench 7 are still greatly influenced by the constituents of the waste liquids disposed two decades ago. Most of the radioactivity measured in the groundwaters consisted of ^3H , ^{99}Tc , ^{60}Co , and ^{233}U . The mobility of ^{99}Tc , ^{60}Co , and ^{233}U has been attributed to low molecular weight anionic complexing. Concentrations of ^{90}Sr and ^{137}Cs in the groundwaters were extremely low. The lack of ^{90}Sr mobility is attributed to the chemical treatments and precautions taken to obtain and maintain an alkaline environment near the trench, which allows for ^{90}Sr sorption and precipitation. The lack of ^{137}Cs mobility is attributed to its strong tendency for being selectively sorbed by illite, the dominant clay mineral in the surrounding Conasauga bedrock and soils. Plutonium isotopic ratios indicate that the plutonium contamination near the trench results primarily from the migration of ^{242}Cm and ^{244}Cm and their subsequent decay to ^{238}Pu and ^{240}Pu rather than reflect the migration of plutonium itself.

Radionuclide concentrations in the groundwaters near the north end of ILW Trench 7 undergo seasonal variations, with the lowest activities occurring in fall and winter and the highest activities occurring in the spring and after prolonged rainstorm events. The rise in radioactivity in these wells correlates with a rise in the groundwater level and a concurrent increase in groundwater pH. This suggests that contamination may be leached from the trench or from the relict ILW migration layers when the groundwater level rises to saturate these zones or when perched water from precipitation seepage percolates into the trench or along these relict migration layers during drainage.

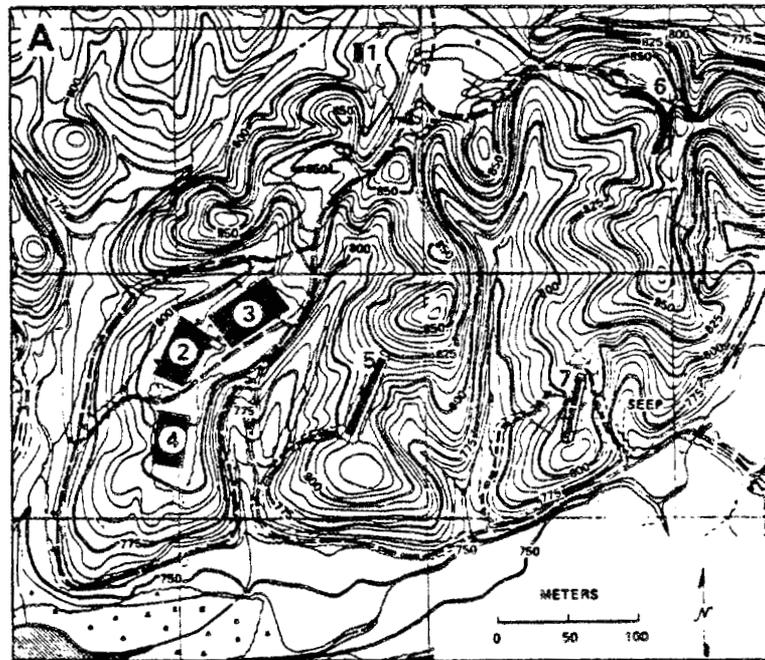
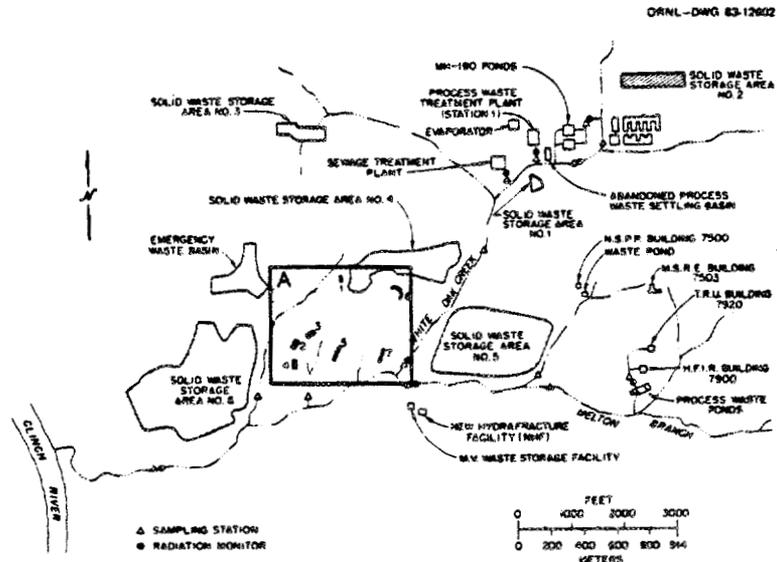
Although ILW Trench 7 has worked effectively to retain most of the disposed radioactivity, two suspected transport pathways from the trench to a nearby seep area have been identified and both appear to be associated with fault zones. Only the pathway near the north end of the trench appears to be leaching alkalinity and thus affecting the retention capacity for ^{90}Sr . A groundwater interceptor at the north end of ILW Trench 7 is one possible remedial action to help maintain a dry alkaline environment and ensure the integrity of the trench for nuclide retention. A temporal comparison of radionuclide activities in the soils and groundwaters near ILW Trench 7 indicates that the effects of present-day migration on the extent of soil and groundwater contamination are minor relative to the legacy of contamination from past seepage operations.

INTRODUCTION

From 1951 to 1966, shallow land seepage pits and trenches were used for the disposal of intermediate-level liquid wastes (ILW) at Oak Ridge National Laboratory (ORNL). These waste pits and trenches were located on ridge tops south of the main ORNL complex, near solid waste storage area 4 (Fig. 1) and were excavated in the weathered zone of the shales and limestones which compose the middle formations of the Conasauga Group (de Laguna et al. 1958; Webster 1976; Haase and Vaughan 1981). The excavated trenches were back-filled with crushed limestone to enhance ^{90}Sr sorption and were covered with compacted earth to reduce radiation intensity. Waste liquids (adjusted to a pH of about 12 with NaOH) were allowed to percolate through the weathered earthen material (pH of about 5), and radionuclide migration was retarded by sorption reactions with the fill, soil, and bedrock (Lomenick et al. 1967). Over one million curies (4×10^7 GBq) of fission nuclides, having some activation products, actinides, and transuranics, were disposed in this manner prior to the implementation of deep-well hydrofracture methods for ILW disposal at ORNL (Duguid et al. 1977).

For the most part, these seepage pits and trenches worked effectively, retaining most of the radioactivity and allowing over 1.8×10^8 L of water to percolate away from these sites. The legacy of highly contaminated soils in the vicinity of these ILW disposal sites has been examined periodically to ensure that no nuclide mobilization has occurred (Means et al. 1976; Cutshall et al. 1982). In particular, ILW Trench 7 has been suspect because of the occurrence of a nearby alkaline seep (pH of about 8), which contains relatively high concentrations of ^3H (15,000 Bq/L), ^{99}Tc (3,200 Bq/L), ^{60}Co (1,700 Bq/L), ^{233}U (18 Bq/L), ^{244}Cm (0.17 Bq/L), ^{241}Am (0.08 Bq/L), and ^{238}Pu (0.03 Bq/L).

This report summarizes our findings concerning (1) the operational history and nuclide inventory for ILW Trench 7; (2) the chemical forms for several of the radionuclides migrating from the trench; and (3) the geochemical, geological, and hydrological processes which promote their migration. This information is necessary for assessing the long-term hazards associated with these formerly used disposal sites; planning corrective measures to reduce nuclide migration; and developing effective site



ILW WASTE PITS AND TRENCHES

Fig. 1. Location map of seepage pits and trenches.

selection, design, operation, and monitoring strategies in waste management. In addition, this study provides actual field data on the chemical forms and environmental processes affecting radionuclide migration in soils and bedrock. These data are necessary for validating geochemical and transport models and for eliminating some of the uncertainty associated with extrapolating laboratory data to natural environments.

Site Geology

The Conasauga Group of interbedded mudstones, shales, and limestones is of Cambrian age and underlies the four open pits and three covered trenches illustrated in Fig. 1. The mudstones and shales are largely composed of quartz, illite, and vermiculite, lithified primarily with a calcite cement. The bedding layers extend east-west, dip south, and are highly fractured and folded (de Laguna et al. 1958). The weathered bedrock is broken into small prisms by numerous joints and extends to a depth of 6 to 9 m. Although the weathering process has leached out much of the carbonate the bedrock retains its structural features.

Soils formed from the Conasauga Group are acidic (pH ~5), clay-rich Ultisols, having relatively low hydraulic conductivities (Cutshall et al. 1982). Illitic clays are abundant and are extremely effective sorption substrates for ^{137}Cs (Tamura and Jacobs 1960). Amorphous iron and manganese oxide coatings on soil particles and weathered bedrock also have an extremely high sorption capacity for many of the waste radionuclides (Tamura 1965; Means et al. 1978b; Cerling and Turner 1982). The sorption capacity of Conasauga bedrock and soils has been studied extensively for a wide variety of radionuclides (Struxness et al. 1956; Cowser and Parker 1958; Tamura 1972; Duguid 1976; Means et al. 1976; Spalding 1980; Bondietti 1982). The pits and trenches drain into White Oak Creek, which is monitored continuously before it enters the Clinch River (Pickering et al. 1966; Lomenick et al. 1967).

History of Early Seepage Operations

The first experimental pit (Pit 1) was opened in 1951, and wastes were transferred to the pit by truck (Struxness et al. 1956). Pits 2, 3, and 4

(Fig. 1) became operational in 1952, 1955, and 1956 respectively, and wastes were pumped to these disposal sites through a welded steel pipeline. During operation of the pits, it was noted that most of the liquid wastes percolated in a direction parallel to the bedding and that very little of the liquid was observed to move across the bedding (de Laguna et al. 1961). Consequently, long narrow trenches were excavated at right angles to the beds to provide more effective drainage. Trench 5 began operation in 1960 and received more than 30×10^6 L of ILW and 0.3×10^6 Ci ($\sim 10^7$ GBq) of activity before being covered with a mound of Conasauga shale and capped with an asphaltic-concrete surface in 1966 (Duguid et al. 1977). Although Trench 5 operated satisfactorily, it could handle only about one-half of the ORNL-generated ILW. Trench 6 (Fig. 1) was brought into operation in 1961 but received wastes for only a short period because of radionuclide breakthrough. The breakthrough was thought to have occurred because the water table rose above the bottom of the trench and the resultant shallow-depth groundwater flow was channeled (perhaps through fractures) into a topographic draw just south of the trench (de Laguna et al. 1961). The water table under Trench 5 also rose 3 to 5 m during its operation but still remained well below the level of the trench bottom. Because of the failure of Trench 6, ILW Trench 7 was excavated in 1962.

Design Criteria for ILW Trench 7

A test hole was drilled in the fall of 1961 so that the groundwater level at the proposed site for ILW Trench 7 could be measured. The hole was located near what is now the northern end of Trench 7B (Fig. 2). The water level in this hole was at an elevation of 236.2 m (~ 10 m below the surface) on December 4, 1961. On February 26, 1962, the water level in this well rose about 4.5 m to an elevation of 240.7 m, which was near the proposed level for the trench bottom.

Initially, ILW Trench 7 was designed to be a composite of three sections, each 30.5 m (100 ft) long, 4.6 m (15 ft) deep, 1.2 m (4 ft) wide at the bottom, and 4.6 m (15 ft) wide at the top. The third section (Trench 7C) was omitted because a second test well, drilled in May 1962 about 30.5 m north of the first well, had a water level elevation of

LONGITUDINAL SECTION

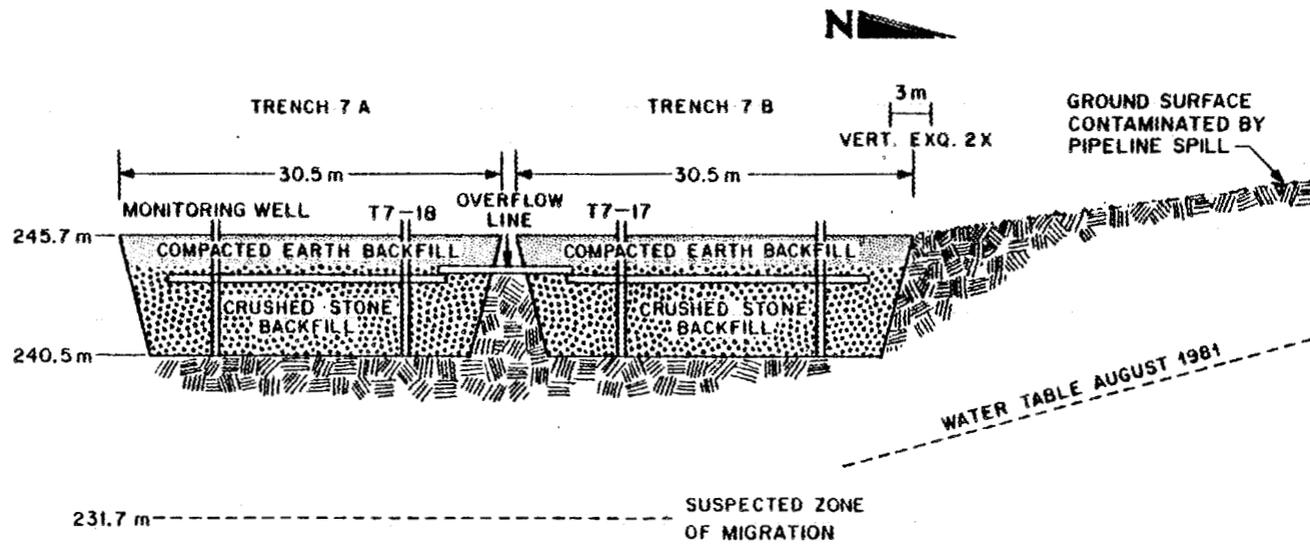


Fig. 2. Design criteria for ILW Trench 7.

242.6 m, which was a few meters above the proposed bottom for Trench 7C. By eliminating segment C, the disposal capacity was expected to be nearly halved, but this reduction was considered necessary because of the general rise in the groundwater table to the north and its large seasonal fluctuations.

The design criteria for ILW Trench 7 are illustrated in Fig. 2, which shows the approximate location of the water table in August 1981. Note the sharp rise in the groundwater table to the north of ILW Trench 7 and the table's nearly horizontal position below the trench bottom. The inflection point in the groundwater level (given as the suspected zone of migration in Fig. 2) appears to be related to a large limestone fold in the bedrock, and its significance for radionuclide migration will be discussed later. The trench was backfilled with 3 m of crushed limestone (CaCO_3); waste liquids were added to one segment and then added to the other segment, which provided time for waste seepage from the first.

The chemical composition of the ILW discharged to the pits and trenches is presented in Table 1. The liquid wastes as generated were acidic, containing high concentrations of HNO_3 , H_2SO_4 , and HCl , but were chemically treated and adjusted to a pH of about 12 with NaOH prior to disposal. Pretreatment of the wastes consisted of precipitating calcium as CaCO_3 , adding about 5,000 kg of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ and $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$ to about 150,000 L of waste liquid, and adding Na_3PO_4 to the ILW to attain a phosphate concentration of about 150 ppm (de Laguna et al. 1961). The trench itself was pretreated by filling it with 50,000 gal (1.9×10^5 L) of a 4% NaOH solution and allowing it to seep out. It was noted by Lasher (Sept. 1962) that the seepage rate of the pretreatment solution from ILW Trench 7 was about four times faster than the pretreatment seepage rate from Trench 5. The chemical treatments and pH adjustment were designed to enhance strontium precipitation and removal from the waste solution and its sorption with calcium carbonates and phosphates in the trench. ILW Trench 7 received wastes from October 1962 until April 1966, after which time deep-well hydrofracture methods were used for ILW disposal.

Table 1. Composition of ORNL
intermediate-level waste discharged
to the seepage pits and trenches

Constituent	Concentration	
	(mg/L)	(M)
OH^-	3,600	0.21
NO_3^-	4,760	0.744
HCO_3^-	<1	<0.000016
$\text{CO}_3^{=}$	2,600	0.043
$\text{SO}_4^{=}$	1,280	0.013
$\text{PO}_4^{=}$	150	0.0016
NH_4^+	700	0.04
Na^+	4,350	0.19
K^+	45	0.0012
Ca^{++}	12	0.0003
Mg^{++}	<10	<0.0004
Al	165	0.006
Fe	<0.5	<0.000009
Cu	<3	<0.00005
Total solids	50,000	

Radionuclide Inventory for ILW Trench 7

Table 2 lists the monthly quantities of liquid waste and activities of ^{137}Cs , ^{60}Co , total Sr, and ^{106}Ru disposed in Trench 7A and Trench 7B. These data have been summarized from monthly reports on radioactive waste disposal at ORNL (Lasher October 1962 to April 1966). Table 3 is a summary inventory of radionuclides (including transuranics) disposed in ILW Trench 7. Data on the amounts and forms of transuranics disposed in ILW Trench 7 were difficult to obtain. Records indicate that about 150 g of Pu (Duguid et al. 1977) and about 334 g of ^{233}U may have been disposed in ILW Trench 7 (C. Helton, personal communication). The disposal of 62 curies (≈ 2300 GBq) of ^{242}Cm was also indicated in the monthly waste disposal report for May 1965:

Curium-242 was detected this month in the east seep stream from Trench 7 and in the White Oak Dam discharge to Clinch River. Although the amount released was not significant and will not become serious because of the small amount (62 curies) put into that trench, it has become apparent that the trench cannot be used for disposal of large quantities of curium. Arrangements have been made to hold curium-bearing wastes in storage tanks until the waste evaporator is put into operation and trench disposal of waste is discontinued.

Disposal records do not exist for many of the nuclides listed in Table 3. Estimates of their input have been calculated from radiochemical analyses of ILW Trench 7 sludge (Table 4), using the ratio of the activity of the unrecorded nuclide to that of ^{90}Sr or ^{137}Cs and thus normalizing their input, assuming total retention of ^{90}Sr or ^{137}Cs . This assumption is supported by the earlier work of Lomenick et al. (1967). Based on several cores collected in ILW Pits 2 and 3, Lomenick et al. showed that most of the ^{90}Sr and ^{137}Cs was associated with the sludges and first few centimeters of weathered shale and that nearly all of the ^{90}Sr and about 85% of the ^{137}Cs discharged to these pits were retained. The almost total retention of ^{90}Sr and ^{137}Cs is also supported by the lack of these nuclides in the groundwaters near ILW Trench 7 (see Results section).

Table 2. ILW Trench 7 disposal records

Month	Year	Section A					Section B				
		Volume (m ³)	¹³⁷ Cs (GBq)	⁶⁰ Co (GBq)	Total Sr (GBq)	¹⁰⁶ Ru (GBq)	Volume (m ³)	¹³⁷ Cs (GBq)	⁶⁰ Co (GBq)	Total Sr (GBq)	¹⁰⁶ Ru (GBq)
OCT	1962	245	31,265	74	740	1,591	245	32,338	74	703	1,554
NOV	1962	191	5,180	37	111	2,701	195	14,837	37	111	2,775
DEC	1962	371	22,311	333	555	8,954	242	14,541	222	370	5,846
JAN	1963	329	57,498	1,591	1,221	1,221	321	56,351	1,554	1,184	1,184
FEB	1963	204	74,407	3,367	259	1,147	179	86,802	3,922	333	1,332
MAR	1963	204	58,608	851	481	3,922	179	52,096	740	407	3,478
APR	1963	148	16,909	481	962	740	368	41,292	1,184	2,294	1,776
MAY	1963	382	108,817	555	8,806	999	413	121,619	629	9,842	1,110
JUN	1963	413	62,567	1,369	14,689	629	458	65,860	1,443	15,466	666
JUL	1963	872	284,160	2,886	6,734	20,128	475	142,080	1,443	15,466	666
AUG	1963	294	46,768	555	98,124	6,438	362	57,535	666	120,768	7,918
SEP	1963	241	102,490	1,369	54,390	4,662	342	153,735	2,035	81,585	6,993
OCT	1963	177	42,920	148	2,294	259	329	80,475	296	4,292	444
NOV	1963	360	33,263	74	888	925	250	22,866	74	629	629
DEC	1963	377	84,545	259	5,402	740	354	79,328	259	5,069	703
JAN	1964	559	138,750	259	5,513	2,701	409	92,500	148	3,663	1,813
FEB	1964	696	155,400	296	888	962	334	103,600	222	592	666
MAR	1964	617	27,750	185	3,441	333	425	18,500	148	2,294	222
APR	1964	632	14,430	370	144,300	74	323	9,620	259	96,200	37
MAY	1964	668	104,451	1,665	77,589	1,184	369	69,634	1,110	51,726	777
JUN	1964	519	46,102	148	18,648	296	266	23,051	74	9,324	148
JUL	1964	519	162,800	185	17,020	148	312	81,400	111	8,510	74
AUG	1964	642	224,257	629	30,784	481	460	162,393	444	22,311	370
SEP	1964	555	198,172	814	64,269	481	352	114,330	481	37,074	259
OCT	1964	548	861,360	222	23,014	481	387	610,130	185	16,280	74
NOV	1964	310	42,254	74	6,105	222	308	42,254	74	6,105	222
DEC	1964	240	113,590	74	3,256	74	264	136,308	111	3,885	74
JAN	1965	566	36,926	481	29,341	111	399	27,010	333	21,756	74
FEB	1965	531	2,923	333	8,510	111	334	1,813	222	5,328	74
MAR	1965	698	145,669	1,110	24,087	74	321	65,786	518	10,878	37
APR	1965	801	251,748	37	33,300	333	308	97,902	37	12,950	148
MAY	1965	418	83,176	111	3,071	592	338	65,490	111	2,442	481
JUN	1965	329	26,196	185	4,440	74	425	33,189	222	5,587	111
JUL	1965	338	42,069	444	20,202	222	347	42,069	444	20,202	222
AUG	1965	201	106,227	703	49,617	111	477	259,666	1,739	121,286	222
SEP	1965	187	141,525	481	3,848	74	381	267,325	888	7,289	111
OCT	1965	229	139,120	629	6,845	185	415	236,504	1,036	11,655	296
NOV	1965	170	56,462	111	3,367	37	294	112,924	222	6,734	111
DEC	1965	148	20,646	37	18,130	37	363	51,578	111	45,288	111
JAN	1966	333	18,019	370	9,620	37	303	18,019	370	9,620	37
FEB	1966	545	63,492	4,329	76,997	296	420	50,283	3,441	60,939	148
MAR	1966	462	66,341	222	19,129	185	420	60,051	185	17,279	148
APR	1966	53	21,460	111	5,624	37	53	32,190	148	8,436	37

Source: Summarized from monthly reports for radioactive waste disposal at ORNL (Lasher, October 1962 to April 1966).

Table 3. Radionuclide inventory in ILW Trench 7
(Total liquid waste input = 3.2×10^7 L)

Nuclide	Half-life (years)	Time of transfer (GBq) ^a	Decay corrected (GBq) ^b	Minimum (GBq) ^c	Maximum (GBq) ^d
⁶⁰ Co	5.3	5.7×10^4	3.5×10^3	3.1×10^3	9.5×10^5
⁹⁰ Sr	2.9×10^1	1.8×10^6	1.1×10^6	1.1×10^6	3.4×10^8
⁹⁹ Tc	2.1×10^5	?	?	4.6	1.4×10^3
¹⁰⁶ Ru	1.0	1.2×10^5	0.0	0.0	0.0
¹²⁵ Sb	2.8	?	?	$<2.3 \times 10^2$	$<7.3 \times 10^4$
¹³⁷ Cs	3.0×10^1	8.2×10^6	5.1×10^6	1.7×10^4	5.1×10^6
¹⁵⁴ Eu	8.8	?	?	$<3.8 \times 10^2$	$<1.1 \times 10^5$
¹⁵⁵ Eu	5.0	?	?	$<2.0 \times 10^2$	$<6.2 \times 10^4$
²³² U	7.2×10^1	?	?	1.2	3.6×10^1
²³³ U	1.6×10^5	1.2×10^2	1.2×10^2	2.2×10^1	6.9×10^3
²³⁵ U	7.0×10^5	?	?	1.0×10^{-3}	4.4
²³⁸ U	4.5×10^9	?	?	2.7×10^{-2}	1.2×10^2
²³⁸ Pu	8.8×10^1	5.3×10^{2e}	3.6×10^{2e}	1.4×10^2	4.4×10^4
²³⁹ Pu	2.4×10^4	2.9×10^{2e}	2.9×10^{2e}	7.3×10^1	2.3×10^4
²⁴⁰ Pu	6.6×10^3	1.8×10^{2e}	1.8×10^{2e}	4.6×10^1	1.4×10^4
²⁴¹ Pu	1.4×10^1	?	?	7.3×10^5	2.3×10^8
²⁴¹ Am	4.3×10^2	?	?	1.6×10^4	5.1×10^6
²⁴² Pu	3.8×10^5	4.3×10^{-1e}	4.3×10^{-1e}	1.1×10^{-1}	3.3×10^1
²⁴² Cm	0.5	2.3×10^3	0.0	0.0	0.0
²⁴⁴ Cm	1.8×10^1	?	?	5.9×10^2	1.8×10^3

^aActivity (1 GBq = 0.027 Ci) summarized from monthly reports for radioactive waste disposal at ORNL (Lasher, October 1962 to April 1966).

^bActivity corrected for the amount of radioactive decay between disposal and November 9, 1982.

^cCalculated from radiochemical analyses of trench sludge (Table 4) and normalized assuming total retention of ⁹⁰Sr.

^dCalculated and normalized assuming total retention of ¹³⁷Cs.

^eCalculated assuming that the reported 150.8 grams of plutonium disposed of in ILW Trench 7 was composed of 83.4% (²³⁹Pu) 14.1% (²⁴⁰Pu) 2.0% (²⁴²Pu) and 0.5% (²³⁸Pu) and did not include the beta-emitting isotope (²⁴¹Pu).

Table 4. Radionuclide concentrations
in ILW Trench 7 sludge

Nuclide	Measurement technique ^a	Trench 7A (Bq/g)	Trench 7B (Bq/g)	Average (Bq/g)
⁶⁰ Co	γ	4.3 × 10 ⁵	0.9 × 10 ⁵	2.6 × 10 ⁵
⁹⁰ Sr	β ⁻	13.5 × 10 ⁷	4.9 × 10 ⁷	9.2 × 10 ⁷
⁹⁹ Tc	η	5.9 × 10 ²	1.9 × 10 ²	3.9 × 10 ²
¹²⁵ Sb	γ	<3.3 × 10 ⁴	<0.7 × 10 ⁴	<2.0 × 10 ⁴
¹³⁷ Cs	γ	2.8 × 10 ⁶	8.8 × 10 ⁴	1.4 × 10 ⁶
¹⁵⁴ Eu	γ	5.5 × 10 ⁴	7.5 × 10 ³	3.1 × 10 ⁴
¹⁵⁵ Eu	γ	2.6 × 10 ⁴	0.9 × 10 ⁴	1.7 × 10 ⁴
²³² U	α	<1.0 × 10 ²	<1.0 × 10 ²	<1.0 × 10 ²
²³³ U	α	1.8 × 10 ³	1.9 × 10 ³	1.9 × 10 ³
²³⁵ U	Mass	1.8	5.3 × 10 ⁻¹	1.2
²³⁸ U	Mass	4.8 × 10 ¹	1.5 × 10 ¹	3.2 × 10 ¹
²³⁸ Pu	α	1.6 × 10 ⁴	0.7 × 10 ⁴	1.2 × 10 ⁴
²³⁹ Pu	α, Mass	6.5 × 10 ³	6.0 × 10 ³	6.3 × 10 ³
²⁴⁰ Pu		4.4 × 10 ³	3.3 × 10 ³	3.9 × 10 ³
²⁴¹ Pu	Mass	5.4 × 10 ⁷	7.0 × 10 ⁷	6.2 × 10 ⁷
²⁴¹ Am	γ	0.7 × 10 ⁶	2.1 × 10 ⁶	1.4 × 10 ⁶
²⁴² Pu	Mass	1.2 × 10 ¹	0.6 × 10 ¹	0.9 × 10 ¹
²⁴⁴ Cm	α	5.3 × 10 ²	4.7 × 10 ²	5.0 × 10 ²

^a γ (gamma spectrometry), β⁻ (beta spectrometry), α (alpha spectrometry), η (neutron activation analysis), and mass (calculated from the isotopic mass ratios, given in Table 5, and measured activities). The analyses were conducted by D. Costanzo and J. Cooper (Analytical Chemistry Division).

The ILW Trench 7 sludge samples were collected from monitoring wells T7-18 (Trench 7A, Fig. 2) and T7-17 (Trench 7B, Fig. 2) on November 9, 1982. The two sludge samples were acid digested, and aliquots were analyzed for radionuclide activities (Table 4) and plutonium and uranium isotopic mass ratios (Table 5). Although nuclide activities (particularly ^{137}Cs) were consistently lower in the Trench 7B sample, nuclide activity and mass ratios were similar in the two samples. The average ^{90}Sr to ^{137}Cs activity ratio was more than two orders of magnitude greater than the ratio expected from disposal records (Table 2 and Table 3). One possible explanation is that the ^{90}Sr was concentrated in the sludge and the ^{137}Cs was primarily sorbed by the weathered shale, which was not representatively sampled. As a result, the calculated inventories normalized to ^{90}Sr in Table 3 are probably more accurate but should be considered minimum estimates, and the inventories normalized to ^{137}Cs should be considered maximum.

RESULTS FROM SAMPLING AND ANALYSIS

Groundwater, suspended matter, and soil samples have been collected from several wells (shown in Fig. 3) in the vicinity of ILW Trench 7 during 1981 and 1982. After the pH was measured, the groundwater samples were filtered through 0.45- μm millipore filters and the filtrate analyzed for ^3H , ^{90}Sr , ^{60}Co , ^{233}U , ^{232}U , and ^{137}Cs . These data are listed in Appendix A. Selected samples have also been analyzed for other radionuclides (including ^{99}Tc and transuranics), and water chemistry (including ΣCO_2 , trace elements, and major cations and anions). Data concerning the chemical properties of the water are listed in Appendix B and have been used to help identify the geochemical factors and complexes which may influence nuclide solubility. In addition, some ^{60}Co and groundwater quality data collected between 1973 and 1975, as part of an earlier study by Means et al. (1976), have been included in Appendixes A and B respectively. These earlier data have been used only to document temporal changes in groundwater contamination during the past decade and have not been incorporated into our data base. The suspended matter trapped on the 0.45- μm filters were analyzed for ^{137}Cs and ^{60}Co and the resulting data are listed in Appendix C.

Table 5. Plutonium and uranium isotopic mass ratios
in ILW Trench 7 sludge

Nuclide ^a	Trench 7A (Atom %)	Trench 7B (Atom %)	Average (Atom %)
²⁴² Pu	0.53	0.22	0.37
²⁴¹ Pu ^b	78.08	84.42	81.25
²⁴⁰ Pu	3.25	2.02	2.63
²³⁹ Pu	17.70	13.28	15.49
²³⁸ Pu	0.44	0.06	0.25
²³⁸ U	99.29	99.02	99.13
²³⁶ U	0.01	0.01	0.01
²³⁵ U	0.56	0.53	0.55
²³⁴ U	0.005	0.007	0.006
²³³ U	0.13	0.43	0.28

^aAnalyzed by R. L. Walker (Analytical Chemistry Division) who noted that a large amount of ²³²Th and a small amount of ²³⁷Np were also present in both samples.

^bThe abundance values for ²⁴¹Pu are unexpectedly high. No production method or decay scheme of reactor-produced nuclides that would yield plutonium of this composition has been identified. It is thought to be unlikely that a sufficient quantity of ²⁴¹Pu has been separated to cause such high values for ILW Trench 7 waste. The similarity of results for sections A and B preclude a sampling anomaly. Isobaric interference from ²⁴¹Am is not believed to be responsible for the results (R. L. Walker, personal communication). Until more sampling can be completed the results are reported as the best determinations available.

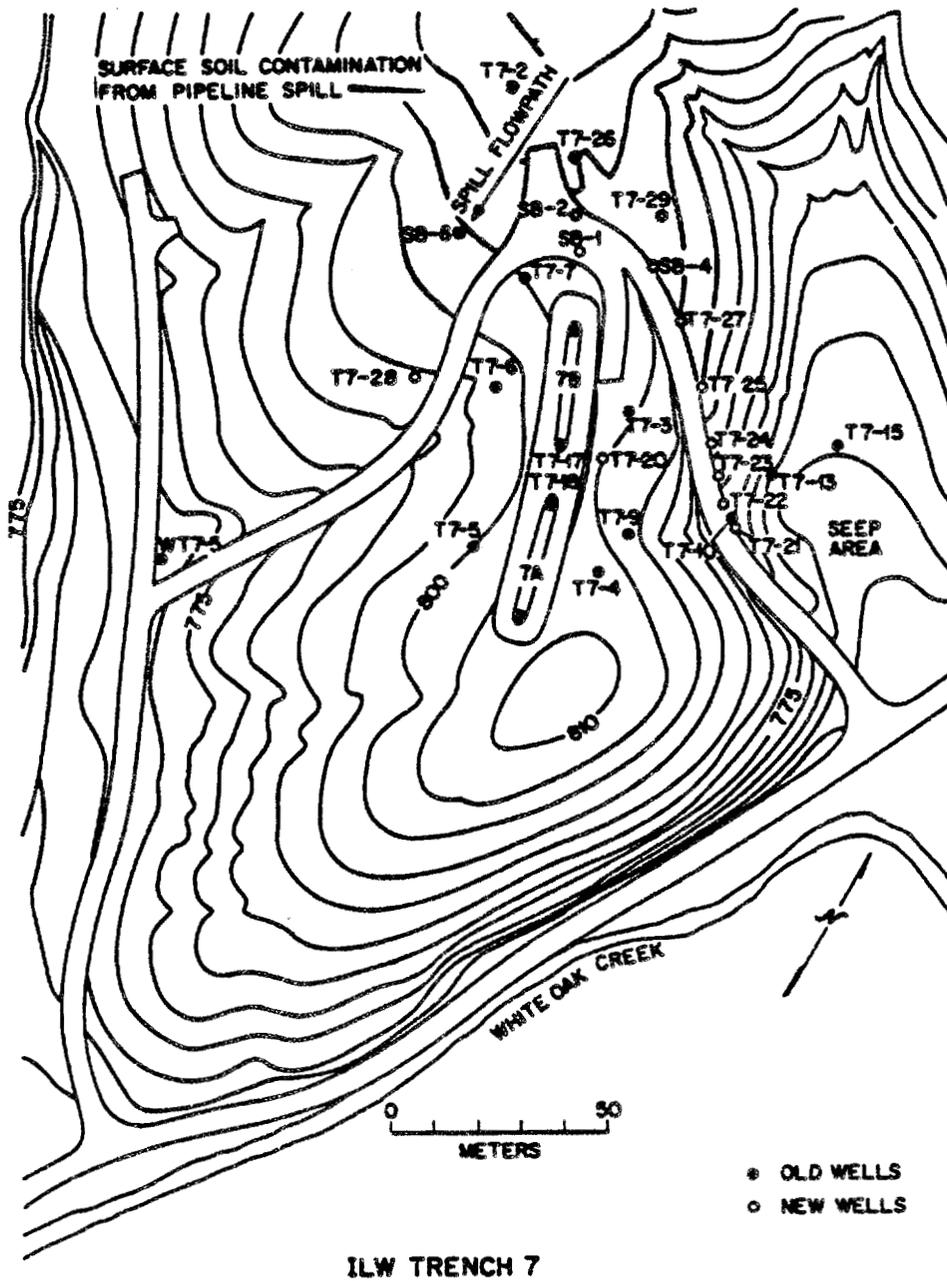


Fig. 3. Location map for the seep and wells near ILW Trench 7.

The wells identified with closed circles in Fig. 3 were drilled and cased prior to our investigation. Most of these old wells are 2 to 12 m deep and were drilled to just below the groundwater level. Several of these wells (including T7-4, T7-5, T7-6, T7-7, T7-9, and T7-13) will occasionally dry up during the summer. Wells T7-9 and T7-10 were located parallel to the strike of the bedrock and along a fault which is visible topographically as a result of surface-drainage erosion. In April 1982, a series of new wells (T7-21, T7-22, T7-23, T7-24, T7-25, and T7-26), each 15 m deep, was drilled parallel to the trench and between the trench and seep, to document migration pathways. Radionuclide and water chemical data, obtained after the completion of these wells, are also presented in Appendixes A and B, and will be discussed later.

An older well (T7-2), approximately 45 m to the north of ILW Trench 7 (Fig. 3), was located in an area contaminated by a leak in the ILW transfer line during trench operations (Duguid and Sealand 1975). Groundwater samples collected from this well and from a new 15-m well (T7-26), drilled near the same area in April 1982, showed high levels of ^{90}Sr and ^{137}Cs relative to other wells in the vicinity of ILW Trench 7 but did not contain high concentrations of ^{60}Co , ^{233}U , ^{99}Tc , Na^+ , NO_3^- , and SO_4^{2-} , which are typical of groundwaters contaminated by trench seepage (see next section). After the leak, which flowed in a southwesterly direction between wells T7-2 and WT7-5 (Fig. 3), the ^{137}Cs - and ^{90}Sr -contaminated surface soils were covered with uncontaminated fill. Recently, several other wells and soil borings (SB-1, SB-2, SB-4, SB-6, T7-27, and T7-29) have been drilled at the north end of the trench (Fig. 3) to obtain engineering information for evaluating the cost and effectiveness of a French-drain groundwater interceptor. These wells and soil borings were completed in November 1982, and only one set of groundwater samples has been collected and analyzed and is reported in appendixes A and B.

Groundwater Chemistry

Average radionuclide and chemical characteristics of the groundwater in the vicinity of ILW Trench 7 are presented in Table 6 for wells shown in Fig. 3. The data indicate that the groundwater characteristics are

Table 6. Average groundwater composition for wells near ILW Trench 7
(Averaged from data given in Appendixes A and B, using only 1981 and 1982 data,
except for Well T7-9, which uses the average stable trace element data from Means et al., 1976)

Well ^a number	pH	Total Alk (µg/mL)	NO ₃ ⁻ (µg/mL)	SO ₄ ⁼ (µg/mL)	Cl ⁻ (µg/mL)	Na ⁺ (µg/mL)	K ⁺ (µg/mL)	Mg ⁺⁺ (µg/mL)	Ca ⁺⁺ (µg/mL)	Org C (µg/mL)	Total P (µg/mL)	³ H (Bq/L)	⁹⁰ Sr (Bq/L)	⁶⁰ Co (Bq/L)	²³³ U (Bq/L)
T7-2	6.9	38	0.1	16	— ^b	4	1.6	5.7	85	19.0	0.01	170	2,350	ND ^b	<0.01
T7-3	7.0	263	31	152	6.3	198	2.4	4.0	35	2.0	0.20	7,640	0.6	1,075	5.6
T7-9	6.6	38	21	400	3	215	3.2	4.1	3	2.2	0.03	—	—	90	<0.01
T7-10	6.6	177	4	23	4.3	18	2.9	7.1	108	10.2	0.02	3,170	2.6	275	0.13
T7-13	7.8	358	79	98	6.0	302	3.6	1.0	5	5.8	0.65	6,810	0.3	1,080	9.4
T7-15	7.0	37	2	42	2.5	20	0.7	1.7	14	1.9	0.01	—	—	20	<0.01
T7-20	8.0	292	19	139	6.0	183	4.9	4.8	28	6.6	2.70	5,100	1.0	790	12.9
T7-21	7.0	251	135	678	22.0	271	5.2	32.0	207	4.1	0.04	27,300	0.7	2,040	0.6
T7-22	7.7	289	67	218	15.3	241	5.2	9.2	57	5.9	0.28	14,000	0.3	1,040	2.7
T7-23	7.3	134	0.5	82	37	14	5.8	11.6	72	8.6	0.02	10,700	0.8	ND	<0.1
T7-24	8.1	288	63	170	10.9	213	3.7	6.7	33	7.5	0.48	8,490	0.4	1,315	9.4
T7-25	8.2	284	58	129	9.1	188	3.7	3.9	26	5.5	0.34	5,960	2.1	1,030	12.3
T7-26	7.1	200	—	13	2.6	6	2.6	6.6	60	4.5	0.11	85	67.6	14	<0.1
SB-1	6.8	—	—	<25	<5.0	6	3.9	7.3	99	—	<0.3	210	3.9	ND	<0.04
Seep stream	7.6	135	78	279	5.5	171	2.6	46.2	87	19.0	0.04	—	—	880	1.8

^aWell locations are shown in Fig. 3.

^bDash (—) indicates not analyzed; ND indicates not detected.

still greatly influenced by the constituents of the waste liquids (Table 1) disposed over two decades ago. Monitoring during seepage operations indicated that short-lived ^{106}Ru and stable NO_3^- passed through the Conasauga formation without being strongly sorbed and that the ingestion of high concentrations of nitrates was one of the major health risks to the native fauna (Struxness et al. 1957; Cowser 1962). Currently, nitrate concentrations in the groundwaters range from 0.1 to 150 $\mu\text{g}/\text{mL}$, with the highest concentrations occurring in wells which also contain the highest radionuclide activities (Appendix B). In addition, concentrations of several other constituents of the waste liquids, including Na^+ , Ca^{++} , Cl^- , and SO_4^{--} , correlate well with nuclide activities in the groundwaters (see Fig. 4 and Table 6). Although concentrations of OH^- and carbonate alkalinity were high in the waste liquids (Table 1), their concentrations in groundwater are primarily controlled by the pH buffering capacity of the Conasauga formation.

Typically uncontaminated groundwaters in the Conasauga shales and limestones have pH values of about 7. Rainfall in eastern Tennessee averages about 120 cm/year and is somewhat acidic, having typical pH values between 4 and 5. Groundwater pH in the vicinity of ILW Trench 7 may measure as high as 9.1 (Appendix A). The high pH and alkalinity in these waters probably reflect present-day leaching of the alkaline fill in the trench or the highly contaminated soils near the trench by interactions with rainfall or groundwater.

Dissolved oxygen was measured in the groundwaters of a 13-m well (T7-3) and a 2.5-m well (T7-13) by an iodometric titration method ($\text{Na}_2\text{S}_2\text{O}_5$). The samples were collected by sinking a nitrogen-purged, sealed bottle into the well water and releasing its cap. The samples collected on May 7, 1981, were analyzed within 2 h after collection. The results are listed in Table 7. Subsequent dissolved oxygen measurements in these wells were taken using an oxygen probe. As Table 7 shows, dissolved oxygen levels measured less than 1 ppm in the deeper well but ranged between 1 and 5 ppm in the shallower well, with the highest concentrations occurring immediately after a major rain storm.

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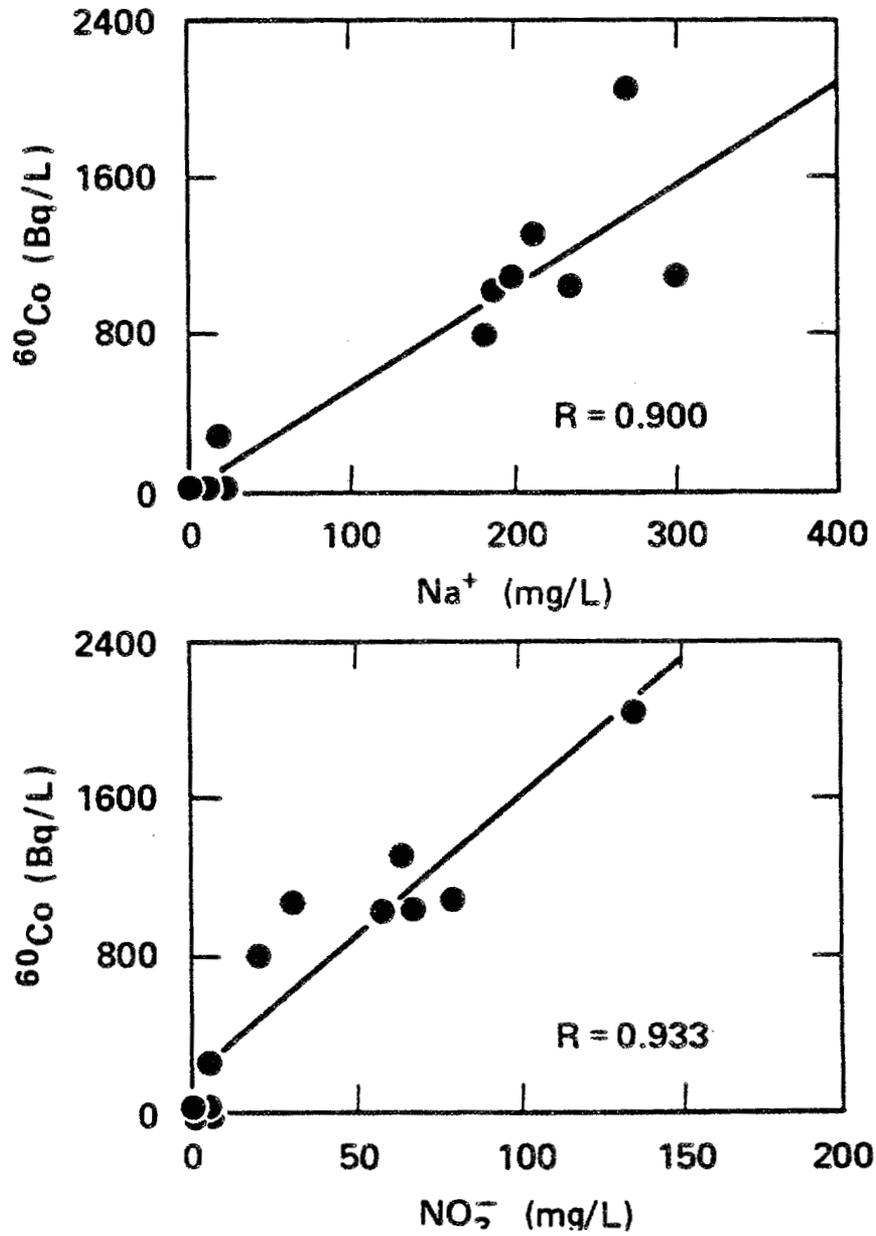


Fig. 4. Correlation of average ^{60}Co activities with average Na^+ and NO_3^- concentrations in groundwaters near ILW Trench 7.

Table 7. Dissolved oxygen in groundwaters from wells T7-3 and T7-13

Sample date	Well T7-3 ^a (ppm)	Well T7-13 ^b (ppm)	Method
7 May 81	0.63	1.71	Na ₂ S ₂ O ₅
15 May 81	0.2	2.4	Probe
29 May 81	0.3	1.3	Probe
9 Jun 81	0.2 ^c	5.0 ^c	Probe

^aWell T7-3 is a 13-meter well.

^bWell T7-13 is a 2.5-meter well.

^cSampled after a rain event.

Table 8 presents a comparison of the elemental chemistry in two groundwater samples collected from Well T7-3 on September 30, 1981. Precautions were taken not to expose one of the samples to the atmosphere during collection, filtration, and acidification with HNO_3 , but no precautions were taken with the second sample. This experiment was conducted to determine whether exposure to oxygen during our sampling procedures was significantly changing the chemical characteristics of the groundwater. It is apparent from the data in Table 8 that the elemental chemistry of both samples is almost identical. Radionuclide analyses for these samples and for two other samples, collected from Well T7-13 and treated similarly, are listed in Table 9. There are no differences in ^{60}Co , ^{233}U , and ^{238}Pu activities attributable to filtration in nitrogen versus natural atmospheres. In addition, the distribution of plutonium between its oxidized and reduced states appears to be unaffected by exposure to the atmosphere. Approximately 70% of the "dissolved" plutonium in the T7-3 groundwater was in oxidized Pu(V), Pu(VI) rather than reduced Pu(III), Pu(IV) oxidation states. The large difference in the total ^{238}Pu activity in the T7-3 N_2 sample (2 mBq/L) relative to that in the T7-3 O_2 sample (6 mBq/L) may represent solubilization of particulate ^{238}Pu by oxidation prior to filtration or an error associated with the yield determination for (V, VI) ^{238}Pu in the T7-3 N_2 sample. The latter explanation is supported by the anomalously low $^{238}\text{Pu}/^{239,240}\text{Pu}$ activity ratio in the T7-3 N_2 sample relative to measured ratios in all other samples.

Concentrations of ^3H , ^{90}Sr , ^{137}Cs , ^{60}Co , ^{233}U , and ^{232}U in filtered groundwater samples collected in the vicinity of ILW Trench 7 are listed in Appendix A. In addition, selected samples have been analyzed for transuranics and ^{99}Tc . These data are listed in Tables 10 and 11 respectively. The most abundant transuranic radionuclide in the groundwaters is ^{233}U , and its concentration ranges from 1,000 to 18,000 mBq/L. "Dissolved" ^{238}Pu activities range from 5 to 60 mBq/L, with the highest measured activities occurring in Well T7-13 near the seep area. The concentrations of "dissolved" ^{241}Am and ^{244}Cm are respectively about 80 and 170 mBq/L (Table 10). Concentrations of long-lived ^{99}Tc range from about 100 to 3,700 Bq/L and are strongly correlated with the activities

Table 8. Groundwater chemistry of Well T7-3
(Samples taken on September 30, 1981)

Element	Chemical concentrations ($\mu\text{g/mL}$)	
	Nitrogen atmosphere	Natural atmosphere
Na	200.	200.
Ca	44.	43.
Cl	7.	12.
Si	6.6	6.4
K	4.4	4.5
Mg	3.8	3.8
Total P	0.41	0.40
Pb	0.48	0.49
Zn	0.36	0.41
Sb	0.39	0.40
Fe	0.050	0.042
Mn	0.028	0.029
Sr	0.053	0.052
Co	<0.013	<0.013

Table 9. Radionuclide activities in groundwaters: nitrogen vs natural atmospheric treatment

Collection date	Nuclide	Units	Activities in Well T7-3		Activities in Well T7-13	
			Nitrogen	Natural	Nitrogen	Natural
17 Jul 81	^{60}Co	(Bq/mL)	1.36 ± 0.13	1.37 ± 0.05	1.24 ± 0.07	1.20 ± 0.03
	^{233}U	(Bq/mL)	4.20 ± 0.24	4.77 ± 0.30	6.57 ± 0.22	6.55 ± 0.23
30 Sep 81	^{60}Co	(Bq/mL)	1.36 ± 0.01	1.37 ± 0.02	— ^a	—
	$^{238}\text{Pu(III,IV)}$	(mBq/L)	1.1 ± 0.2	1.4 ± 0.2	—	—
	$^{238}\text{Pu(V,VI)}$	(mBq/L)	0.8 ± 0.3	4.6 ± 0.5	—	—
	$^{239,240}\text{Pu(III,IV)}$	(mBq/L)	0.33 ± 0.16	0.32 ± 0.10	—	—
	$^{239,240}\text{Pu(V,VI)}$	(mBq/L)	0.80 ± 0.16	0.90 ± 0.22	—	—

^aDashes (—) indicate not analyzed.

Table 10. Transuranics in ILW Trench 7 groundwater

Well number	Sample date	^{238}Pu (mBq/L)	$^{239,240}\text{Pu}$ (mBq/L)	^{244}Cm (mBq/L)	^{241}Am (mBq/L)	^{233}U (Bq/L)
Seep	22 Feb 80	1.7 ± 0.1	— ^a	—	—	3.5 ± 0.2
	09 Dec 80	5.0 ± 1.7	2.2 ± 0.8	100 ± 10	75 ± 8	1.1 ± 0.1
T7-13	22 Feb 80	10.0 ± 1.7	0.7 ± 0.7	—	—	3.5 ± 0.2
	02 Apr 81	53.3 ± 1.7 (III, IV)	2.2 ± 0.3 (III, IV)	—	—	10.2 ± 0.3
		4.3 ± 0.3 (V, VI)	0.3 ± 0.1 (V, VI)	—	—	—
07 May 81	22.0 ± 1.5 (III, IV)	—	172 ± 7	80 ± 5	15.4 ± 0.3	
	5.3 ± 0.5 (V, VI)	—	—	—	—	
T7-3	03 Apr 81	4.7 ± 0.2 (III, IV)	0.3 ± 0.1 (III, IV)	—	—	3.1 ± 0.1
		6.2 ± 0.7 (V, VI)	0.3 ± 0.1 (V, VI)	—	—	—
	30 Sep 81	1.4 ± 0.2 (III, IV)	0.3 ± 0.1 (III, IV)	—	—	—
4.6 ± 0.5 (V, VI)		0.9 ± 0.1 (V, VI)	—	—	—	

^aDashes (—) indicate not analyzed.

Table 11. ^{99}Tc , ^{60}Co and ^{233}U in ILW Trench 7 groundwater

Well number	Sample date	Water pH	^{99}Tc (Bq/L)	^{60}Co (Bq/L)	^{233}U (Bq/L)
SB-1	22 Nov 82	6.8	2 ± 1	0 ± 0	0.04 ± 0.02
T7-3	19 Jul 82	6.9	$1,000 \pm 100$	$1,140 \pm 26$	18.0 ± 2.0
	22 Nov 82	7.2	910 ± 30	800 ± 11	5.4 ± 0.3
T7-5	22 Nov 82	6.5	270 ± 10	245 ± 26	0.10 ± 0.02
T7-13	19 Jul 82	8.1	$1,500 \pm 100$	$1,830 \pm 7$	17.0 ± 1.0
	22 Nov 82	8.1	660 ± 30	$1,330 \pm 59$	15.0 ± 1.0
T7-20	19 Jul 82	8.9	170 ± 10	945 ± 33	5.9 ± 0.4
	22 Nov 82	7.7	170 ± 10	600 ± 48	16.0 ± 1.0
T7-21	19 Jul 82	7.1	$3,200 \pm 100$	$2,340 \pm 7$	0.7 ± 0.1
	22 Nov 82	6.9	$3,700 \pm 100$	$1,860 \pm 4$	0.4 ± 0.1
T7-22	22 Nov 82	7.8	500 ± 10	830 ± 4	2.6 ± 0.2
T7-23	22 Nov 82	7.3	1 ± 1	0 ± 0	0.2 ± 0.1
T7-24	19 Jul 82	8.1	400 ± 10	$1,450 \pm 19$	11.0 ± 1.0
	22 Nov 82	8.5	500 ± 10	$1,100 \pm 7$	10.4 ± 0.5
T7-25	22 Nov 82	7.4	250 ± 10	310 ± 56	4.6 ± 0.4
T7-26	22 Nov 82	7.1	2 ± 1	0 ± 0	0.2 ± 0.1
T7-27	22 Nov 82	6.6	41 ± 1	0 ± 0	0.5 ± 0.1

of ^3H and ^{60}Co (Table 11 and Appendix A). ^3H , ^{60}Co , and ^{99}Tc comprise most of the radioactivity in the ILW Trench 7 groundwaters. Although approximately 10^{16} Bq of ^{137}Cs and ^{90}Sr were disposed in ILW Trench 7 (Table 3), the activities of ^{90}Sr in the groundwaters were extremely low (generally <1 Bq/L), and ^{137}Cs could not be detected, which indicates activities of more than two orders of magnitude lower than those of ^{60}Co (Appendix A). Several other radionuclides have been measured in groundwaters near the seep area, including ^{129}I (~ 50 mBq/L) and ^{125}Sb (~ 50 Bq/L).

Suspended Matter Chemistry

Groundwater samples, collected from the wells shown in Fig. 3, were filtered through millipore (0.45- μm pore size) filters, and the suspended matter was analyzed for ^{60}Co and ^{137}Cs (Appendix C). Suspended matter concentrations typically ranged from 10 to 50 mg/L. Approximately 1.5 g of suspended material was filtered from a 40-L sample collected from Well T7-13 on April 16, 1982. A portion of this particulate sample was examined under a transmission electron microscope and analyzed mineralogically by x-ray diffraction. The transmission electron micrograph (Fig. 5) indicates that the suspended matter is primarily composed of small (<2 - μm diam), irregular, thinly-layered silicate minerals. The x-ray diffractogram (Fig. 6) indicates that these layered silicates are illitic mica and vermiculite, having 1.0 and 1.4 nm spacings respectively after magnesium saturation and ethylene glycol solvation.

Another portion of this 1.5-g suspended particulate sample was treated with a sodium citrate-bicarbonate-dithionite solution to determine what fraction of the sorbed ^{60}Co was associated with surface Fe-Mn oxide phases (CBD extraction in Jackson 1969). Results from this treatment indicate that approximately 50% of the sorbed ^{60}Co is associated with Fe-Mn oxide phases.

It is evident from the data in Appendix C that the distribution of ^{60}Co between suspended particulate and "dissolved" phases varies significantly in the groundwaters near ILW Trench 7. Average ^{60}Co distribution data for individual wells are listed and compared in Table 12. The average particle-to-water distribution of ^{60}Co ranges from about 5×10^2

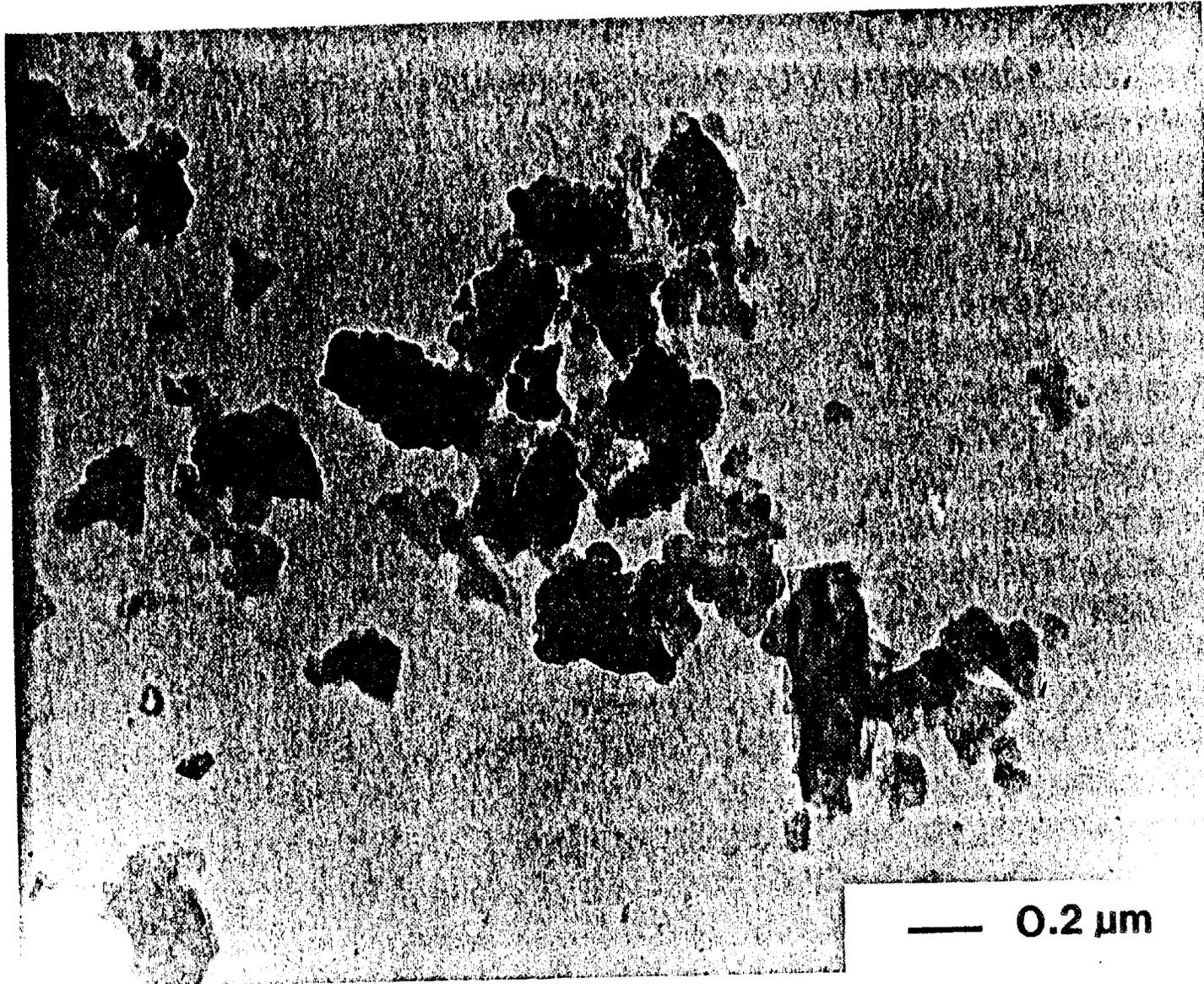


Fig. 5. Transmission electron micrograph of suspended matter from Well T7-13 groundwater.

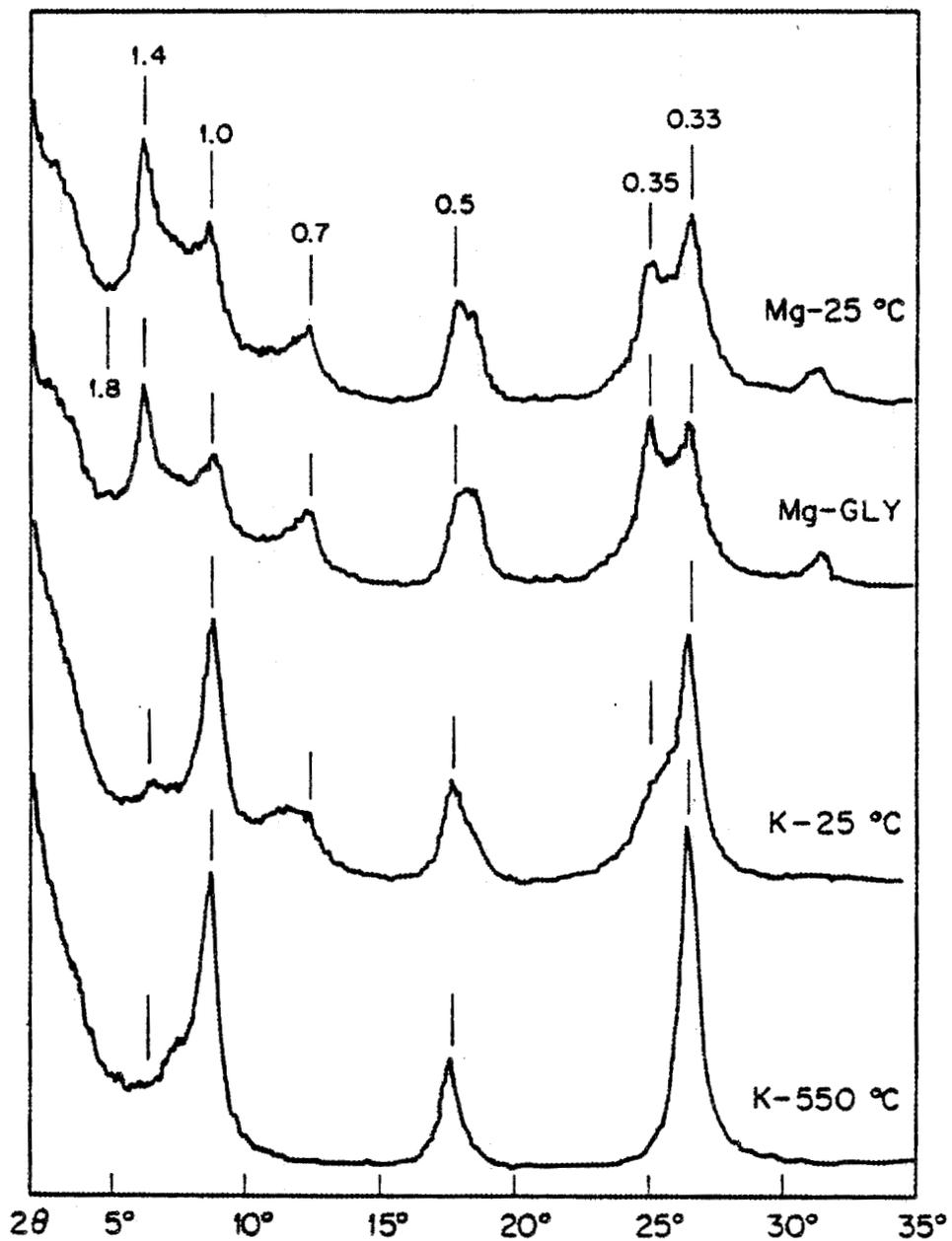


Fig. 6. X-ray diffractograms of the suspended matter from Well T7-13 groundwater.

Table 12. Average ^{60}Co distribution data for
groundwaters near ILW Trench 7
(Data averaged from numbers given in Appendix C)

Location	Well number	$\left(\frac{^{60}\text{Co Bq/g of particles}}{^{60}\text{Co Bq/mL of water}} \right)$
Near trench	T7-20	10,680
	T7-3	2,740
Half-way between trench and seep	T7-21	460
	T7-22	5,930
	T7-24	4,420
	T7-25	2,990
Near seep	T7-13	670

in wells T7-21 and T7-13 to about 1×10^4 in groundwaters of Well T7-20 (near the trench). These data imply that either the chemical form and reactivity of ^{60}Co differ in Well T7-20 relative to the other wells or that additional ^{60}Co may be transported to Well T7-20 in association with particles. This latter explanation is supported by the ^{137}Cs distribution data in Table 13. Although "dissolved" ^{137}Cs could be detected only in groundwater samples collected from wells T7-2 and T7-26 in the area contaminated by the pipeline break (Appendix C), particulate ^{137}Cs was frequently detected on suspended matter collected from wells located within a few meters of the trench (see Fig. 3 and Table 13).

Radionuclides in Soils and Bedrock

The vertical distribution of gamma activity in the soils and weathered bedrock have been measured by gamma-logging several of the wells drilled in April 1982. The gamma log for Well T7-20 (drilled near the trench) is illustrated in Fig. 7. Three large gamma peaks (primarily ^{60}Co and bremsstrahlung) occur in discrete layers above the groundwater table (Fig. 7). The largest peak occurs at a depth of 5-m, which is coincident with the depth of the trench bottom. These peaks probably represent relict migration paths of the waste liquids during past seepage operations. Currently, they may also serve as preferred flow pathways for runoff and seepage during periods of heavy rainfall. This mechanism may account for the measured increases in groundwater radioactivity observed in the spring and in other periods of prolonged rainfall (see discussion on Transport Pathways and Processes). The large gamma peak at 5 m (Fig. 7) also supports evidence for the particulate transport of ^{60}Co and ^{137}Cs between the trench and Well T7-20 as indicated in the previous section.

Similar gamma profiles (Fig. 8) have also been measured in the soils and bedrock of the wells recently drilled along the road approximately halfway between the trench and seep area (Fig. 3). The gamma profile for Well T7-24 (Fig. 8) is almost identical to that for Well T7-20 (Fig. 7), except that, as Fig. 8 shows, the largest gamma peak in Well T7-24 now occurs at a depth of 9 m, which is just below the groundwater

Table 13. Distribution data for ^{137}Cs in groundwaters near ILW Trench 7

Well number	Sample date	Water (Bq/mL)	Suspended matter (Bq/g)	$\left(\frac{^{137}\text{Cs Bq/g of particles}}{^{137}\text{Cs Bq/mL of water}} \right)$
T7-20	29 Apr 82	ND ^a	96	— ^a
T7-20	10 Jun 82	ND	23	—
T7-20	23 Jun 82	ND	256	—
T7-20	09 Jul 82	ND	145	—
T7-20	19 Jul 82	ND	97	—
T7-20	26 Jul 82	ND	56	—
T7-20	02 Aug 82	ND	888 ^b	—
T7-20	11 Aug 82	ND	74	—
T7-20	25 Aug 82	ND	158	—
T7-20	10 Sep 82	ND	10	—
T7-20	06 Oct 82	ND	38	—
T7-20	20 Oct 82	ND	25	—
T7-20	22 Nov 82	ND	132	—
T7-20	07 Jan 83	ND	265	—
T7-20	20 Jan 83	ND	714	—
T7-20	02 Feb 83	ND	659	—
T7-20	18 Feb 83	ND	899	—
T7-03	31 Aug 81	ND	54	—
T7-03	10 Jun 82	ND	289	—
T7-03	22 Nov 82	ND	94	—
T7-05	23 Jun 82	ND	559	—
T7-05	30 Sep 82	ND	270	—
T7-10	21 Sep 82	ND	23	—
T7-26	22 Nov 82	ND	63	—
T7-2	29 May 81	0.006	1617	2.7×10^5
T7-2	31 Aug 81	0.006	1602	2.7×10^5

^aND indicates not detected; dashes (—) indicate no calculation possible.

^bSample collected after a major and prolonged rainfall event (see Table 17).

GAMMA LOG FOR WELL T7-20

ORNL-DWG 83-1556

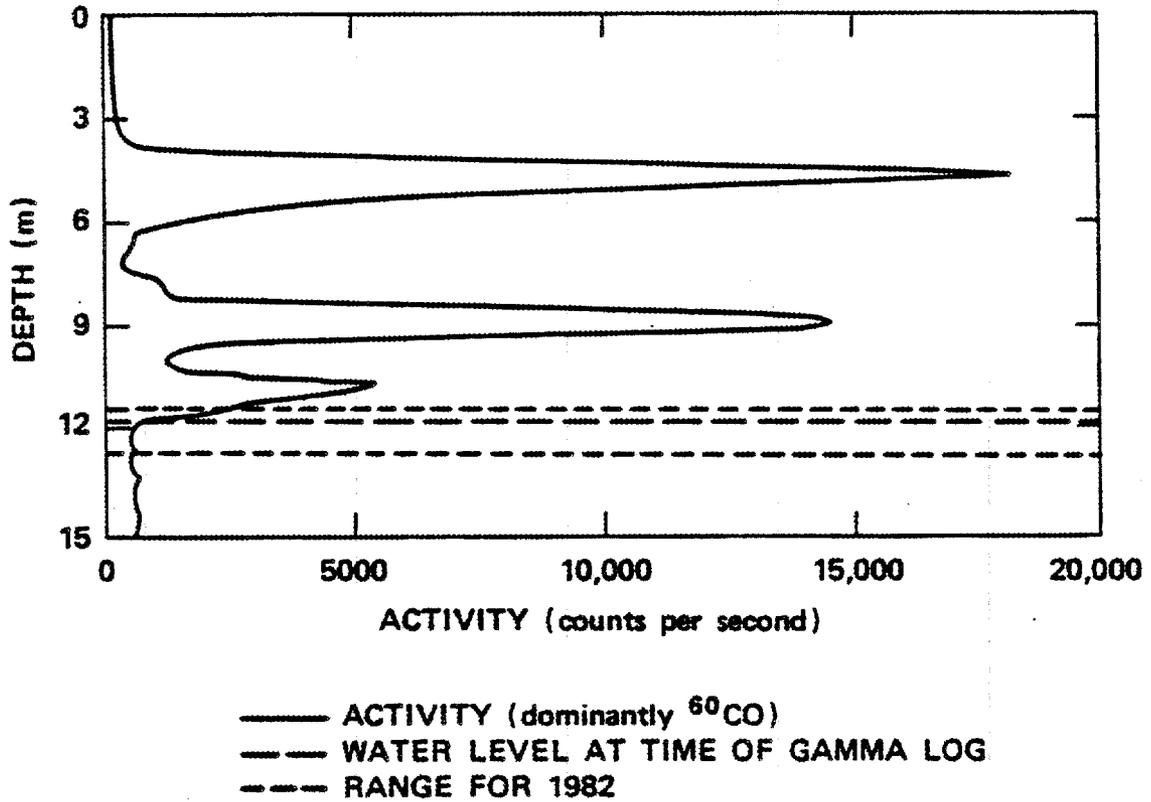


Fig. 7. The vertical distribution of gamma activity in the weathered bedrock of Well T7-20.

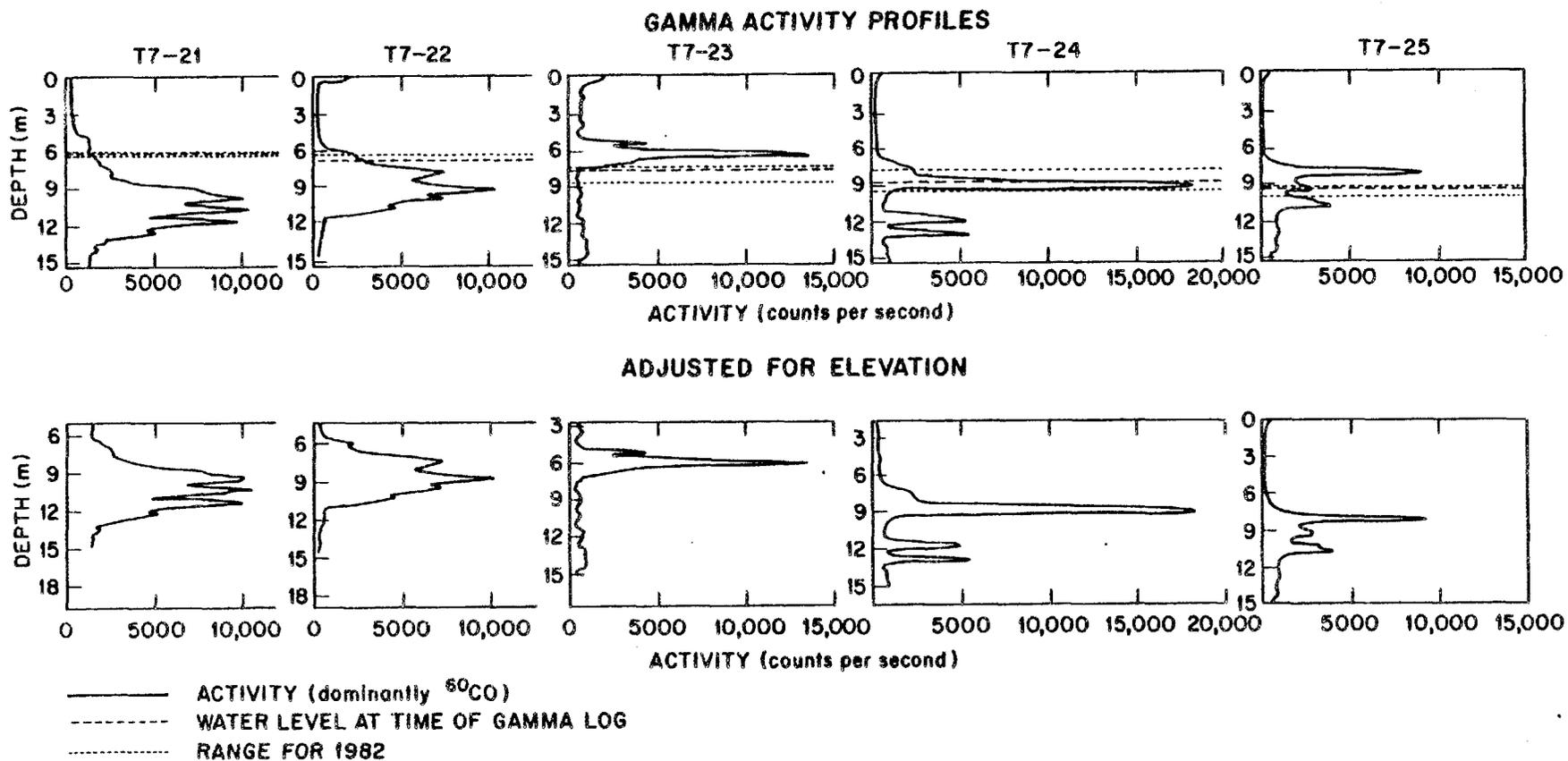


Fig. 8. Gamma activity profiles in the weathered bedrock of wells located between the trench and seep area.

level at this location. It is significant to note that the wells which show the greatest amount of groundwater contamination (T7-21 and T7-24, Table 6) are those in which the migration layers occur at or below the groundwater table.

Table 14 reports radionuclide activities, measured in sediment samples collected from the bottoms of wells T7-3, T7-9, and T7-13 and in a surface soil sample collected in the seep area. Although groundwater nuclide activities in wells T7-3 (near the trench) and T7-13 (near the seep) are similar (Table 6), sediment activities are about an order of magnitude greater near the trench. The isotopic mass ratios of ^{238}Pu , ^{239}Pu , and ^{240}Pu have also been determined on the T7-3 sediment sample. The ^{238}Pu to ^{239}Pu mass ratio is 0.3 ± 0.03 , and the ^{239}Pu to ^{240}Pu ratio is 0.4 ± 0.004 . These ratios are very different from the Pu isotopic mass ratios measured in the trench sludge (Table 5) and indicate that the weathered bedrock is highly enriched in ^{238}Pu and ^{240}Pu relative to ^{239}Pu . These results strongly imply that the plutonium observed in the soils and bedrock actually reflects the migration of ^{242}Cm and ^{244}Cm and their subsequent decay to ^{238}Pu and ^{240}Pu respectively. A more detailed discussion of the plutonium mass ratios and migration is presented in the section on Chemical Forms of Migrating Nuclides.

Lithologic and radionuclide (^{137}Cs and ^{60}Co) profiles for a series of wells and soil borings (SB-1, SB-2, SB-4, SB-6, T7-27, and T7-28) recently drilled at the north end of ILW Trench 7 (Fig. 3) are illustrated in Fig. 9. The soil ^{137}Cs and ^{60}Co measurements were made for samples collected from the drill auger at identifiable lithologic boundaries. These profiles are difficult to interpret because the near-surface soils in this area were contaminated with ^{90}Sr and ^{137}Cs by a leak in the ILW transfer line which occurred near the location of Well T7-2 (Fig. 3). Liquid waste from the leak flowed along the surface between Well T7-2 and Well WT7-5 (Fig. 3) and is responsible for the ^{137}Cs contamination in the surface soils of Well T7-28 (Fig. 9). The surface-contaminated soils near the trench were covered with uncontaminated fill, as is reflected by the lack of ^{137}Cs contamination in the top 3 m of soil in Well T7-27 (Fig. 9). Although the surface soils were contaminated with ^{137}Cs from the pipeline leak, note the lack of significant trench

Table 14. Radionuclides in soils and weathered bedrock near ILW Trench 7

Nuclide	Sampling location ^a			
	Well T7-3	Well T7-9	Well T7-13	Seep soil
⁶⁰ Co (Bq/g)	4,700 ± 37	180 ± 1	320 ± 5	390 ± 4
^{108m} Ag (Bq/g)	37 ± 1	ND	ND	ND
¹²⁵ Sb (Bq/g)	ND ^b	ND	12 ± 1	4 ± 1
¹³⁷ Cs (Bq/g)	ND	ND	1 ± 1	ND
¹⁵⁴ Eu (Bq/g)	ND	ND	2 ± 1	ND
¹⁵⁵ Eu (Bq/g)	37 ± 1	ND	6 ± 1	ND
²²⁸ Th (Bq/kg)	—	—	150 ± 20	200 ± 30
²³⁰ Th (Bg/kg)	—	—	20 ± 5	10 ± 6
²³² U (Bq/kg)	9,180 ± 300	74 ± 1	110 ± 30	200 ± 50
²³³ U (Bq/kg)			930 ± 150	1,600 ± 300
²³⁸ U (Bq/kg)			48 ± 14	58 ± 20
²³⁸ Pu (Bq/kg)	3,580 ± 138	—	500 ± 70	140 ± 20
^{239,240} Pu (Bq/kg)	147 ± 6	—	14 ± 7	6 ± 1
²⁴¹ Am (Bq/kg)	—	—	1,900 ± 200	280 ± 30
²⁴⁴ Cm (Bq/kg)	—	—	3,100 ± 300	230 ± 20

^aSamples were taken from the wells and the seep soil on the following dates: T7-3, April 3, 1981; T7-9, February 20, 1981; T7-13, February 23, 1981; and Seep soil, December 9, 1980.

^bND indicates concentrations more than two orders of magnitude less than the ⁶⁰Co activity and therefore not detectable. Dashes (—) indicate not analyzed.

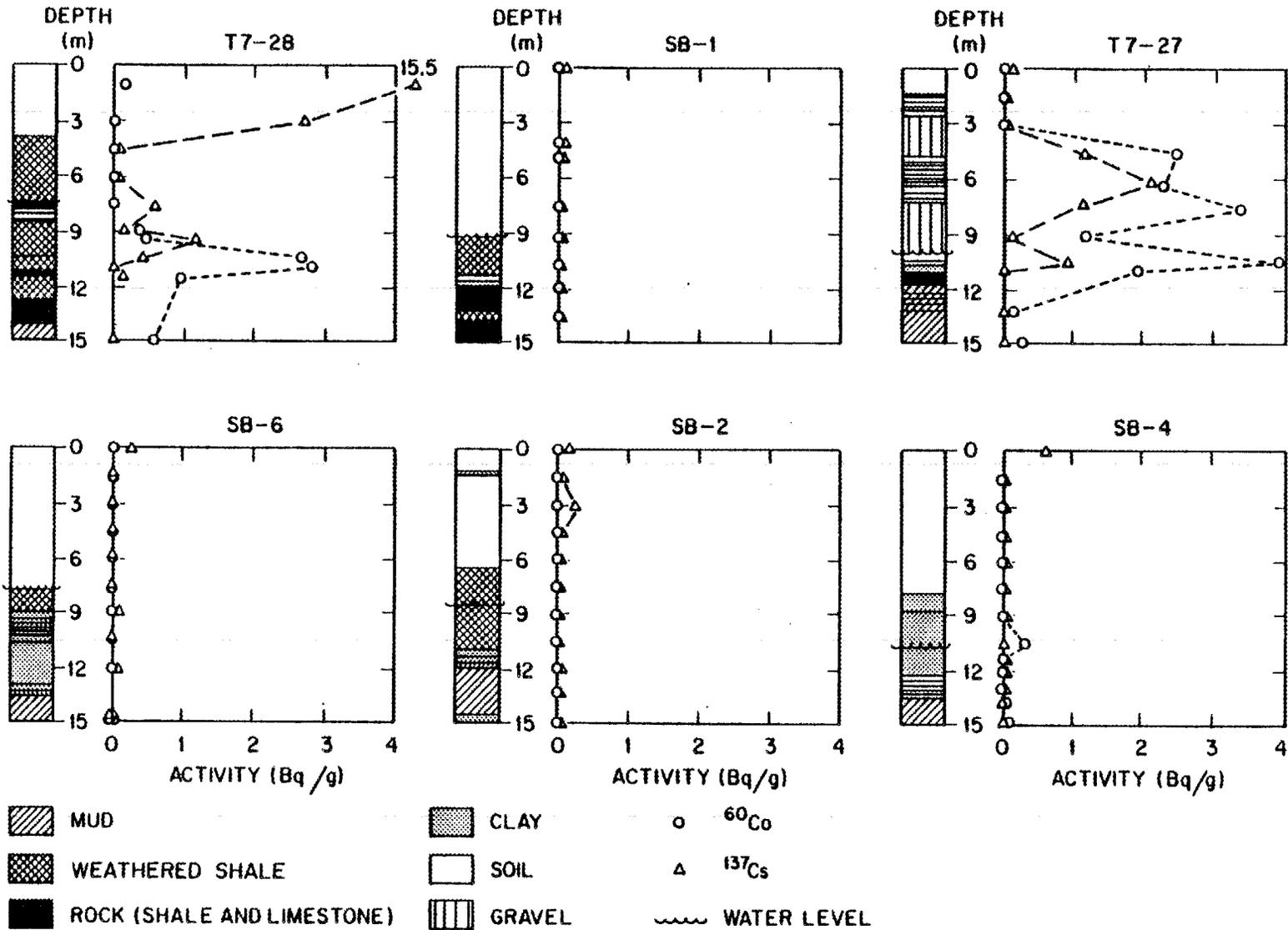


Fig. 9. Lithologic, ^{137}Cs and ^{60}Co profiles in soils at the north end of ILW Trench 7.

contamination (^{60}Co , ^{233}U , Na^+ , NO_3^- , etc.) in the groundwaters (see Appendix A and Table 6) and soils at the north end of the trench. This implies that the trench contamination migrates east-west along bedding planes, fold axes, and fault strikes but does not migrate to the north.

A soil and groundwater sample collected in June 1974 from Well T7-13 (near the seep) was found in storage during our investigation. This sample was radiochemically analyzed, decay-corrected, and compared with present (1981) activities measured in the sediment and water from the same well. These data are presented in Table 15. Radionuclide activities in the 1974 water and soil samples were similar to present day activities, indicating no major increase in radionuclide migration and soil contamination in the vicinity of ILW Trench 7 during the past decade. Although radionuclide migration from the trench may be occurring still, its effects on the extent of groundwater and soil contamination in the area are minor relative to the legacy of contamination resulting from past seepage operations. In fact, concentrations of the most mobile radionuclides, including ^3H , ^{60}Co , and ^{99}Tc , may actually be decreasing in the groundwaters around the trench as a result of seepage out of the system. Cobalt-60 activity in the 1981 groundwater samples (1700 Bq/L) is significantly lower than the value expected by decay-correcting the 1974 groundwater ^{60}Co data (4300 Bq/L). Although the activity of ^{60}Co in the groundwater fluctuates seasonally and with storm events, 1900 Bq/L is the highest ^{60}Co groundwater concentration measured in Well T7-13 during 1981 and 1982 (see data for August 2, 1982, in Appendix A). In addition, 1974 decay-corrected ^3H concentrations in Well T7-13 are significantly higher than ^3H concentrations measured in 1981 and 1982 (Appendix A).

Radionuclides in Vegetation

Samples of surface leaf litter collected in the vicinity of ILW Trench 7 contained appreciable amounts of radionuclide contamination, even in areas where the near-surface soils were relatively uncontaminated. One possible explanation is that roots of deciduous trees tap contaminated groundwater and transfer radioactivity to the surface. On October 27, 1982, green leaves were collected from deciduous trees grown near the seepage area

Table 15. Historical radionuclide data for the soils and groundwater of Well T7-13

Nuclide	Water (Bq/L)			Sediment (Bq/kg) ^a		
	June 1974	(Decay-corrected) ^b	May 1981	June 1974	(Decay-corrected)	February 1981
⁶⁰ Co	10,800 ± 259	(4,320)	1,700 ± 44	729,000 ± 3,700	(292,000)	357,000 ± 740
¹²⁵ Sb	ND ^c	- ^c	ND	132,000 ± 10,700	(23,300)	13,700 ± 1,000
¹³⁷ Cs	ND	-	ND	ND	-	ND
¹⁵⁴ Eu	ND	-	ND	8,000 ± 3,000	(4,600)	2,000 ± 1,000
¹⁵⁵ Eu	ND	-	ND	38,500 ± 4,400	(14,600)	7,070 ± 1,000
²²⁸ Th	-	-	-	280 ± 20	(22)	150 ± 19
²³⁰ Th	-	-	-	36 ± 4	(36)	19 ± 4
²³² U	1 ± 1	(0.9)	2 ± 1	130 ± 20	(120)	110 ± 30
²³³ U	13 ± 1	(13)	15 ± 1	1,000 ± 100	(1,000)	930 ± 150
²³⁸ U	-	-	0.05 ± 0.01	46 ± 10	(48)	48 ± 15
²³⁸ Pu	0.045 ± 0.002	(0.033)	0.027 ± 0.002	920 ± 140	(870)	500 ± 67
^{239,240} Pu	0.001 ± 0.004	-	0.003 ± 0.004	48 ± 15	(48)	15 ± 7
²⁴¹ Am	-	-	0.080 ± 0.005	2,400 ± 400	(2,370)	1,900 ± 200
²⁴² Cm	-	-	ND	9 ± 6	-	4 ± 3
²⁴⁴ Cm	-	-	0.172 ± 0.004	4,000 ± 800	(3,050)	3,100 ± 300

^aAlpha analyses by T. Scott (Analytical Chemistry Division).

^bThe June 1974 data corrected for the amount of decay after 7 years.

^cND indicates not detectable; dashes (-) indicate not analyzed.

of ILW Trench 7 (Well T7-13) and other contaminated areas near the ILW pits and trenches (wells WT5-7 and W-106) to evaluate the degree of radionuclide redistribution through plant uptake. Measured radionuclide concentrations in green leaves and respective groundwater samples are presented in Table 16.

The data in Table 16 make it apparent that radionuclide accumulation in green leaves does not correspond to the radionuclide content in the groundwater and that there is a preferential accumulation (uptake) of ^{90}Sr and ^{99}Tc relative to ^{60}Co and ^{233}U . The data indicate further that tree uptake may be a significant vector in transferring groundwater contamination to the surface soil.

CHEMICAL FORMS OF MIGRATING RADIONUCLIDES

A number of chemical, geological, and hydrological factors influence radionuclide mobility. In general, the chemical factors primarily affect radionuclide sorption and solubility, whereas the geological and hydrological factors primarily affect radionuclide transport. Most of the studies concerned with nuclide sorption and solubility have involved laboratory experiments designed to determine nuclide distributions between dissolved and sorbed phases under controlled conditions. Distribution coefficients (K_d) have been experimentally determined for a wide variety of radionuclides over a wide variety of environmental conditions (Sorathesn et al. 1960; Tamura 1965; Nishita and Essington 1967; Tamura 1972; Duursma 1973; Cleveland 1979; Bondietti and Francis 1980; Schell et al. 1980; Czyscinski and Weiss 1981; Kirby 1981; Onishi et al. 1981; Spalding and Hoffman 1982). The general findings of these studies are that (1) sorption, for most radionuclides, is sensitive to groundwater pH and soil organic and hydrous Fe-Mn oxide content; (2) sorption for multivalent nuclides, such as technetium, uranium, and plutonium depends on groundwater Eh and the oxidation state of the nuclide; (3) organic complexation may promote the solubilization and migration of otherwise immobile nuclides; (4) cesium and thorium should be relatively immobile in groundwater, each having a particle-to-water K_d of more than $>10^4$;

Table 16. Radionuclide content in tree leaves and groundwaters from contaminated areas

Well number	Sample	Radionuclide activity ^a			
		⁶⁰ Co	⁹⁰ Sr	⁹⁹ Tc	²³³ U
T7-13	Water	1,332	0.33	1,500	17.00
	Hickory	52	4,600	31,000	1.5
WT5-5	Water	15	0.06	470	0.44
	Maple	3	220	44,000	0.97
W-106	Water	4	0.19	250	3.10
	Maple	18	160	11,000	0.75

^aActivity units: Water measured in Bq/L; plants measured in Bq/kg (dry weight at 70°C).

(5) cobalt, europium, americium, curium, strontium, and antimony should be somewhat mobile with K_d s between 10^2 and 10^4 ; and (6) ruthenium, iodine, and tritium are highly mobile, with K_d s $<10^2$.

Cesium-137

Cesium occurs as a monovalent cation that may be associated with OH^- in groundwater (Baes and Mesmer 1976) but rarely forms solution complexes. Dissolved ^{137}Cs could be measured only in groundwater samples collected near the north end of ILW Trench 7 in an area contaminated by a leak in the ILW transfer pipeline (Fig. 3). The particle-to-water distribution of ^{137}Cs in these samples was 3×10^5 (Table 13), which is almost identical to the distribution coefficient for ^{137}Cs (10,000 mL/g) derived by laboratory experiments using Conasauga shale (Tamura 1972; Duguid 1977; Cerling and Turner 1982). The absence of detectable ^{137}Cs in the ILW Trench 7 groundwaters and its high apparent distribution coefficient arises from its strong affinity for being selectively and irreversibly adsorbed by illite, the dominant clay mineral in Conasauga bedrock and soils (Fig. 6). This irreversible sorption of ^{137}Cs results from its accommodation in interlayer sites of 1.0-nm (illitic) micaeous minerals (Tamura and Jacobs 1960). As a result, ^{137}Cs sorption is not strongly affected by the pH of the groundwater (Duguid 1977) but is affected by the concentration of other cations in solution (Tamura and Jacobs 1960; Olsen 1979). In addition, radiocesium sorption in freshwaters appears to be relatively unaffected by organics (Schell et al. 1980) or Fe-Mn hydroxides (Cerling and Turner 1982), and soluble organic complexes of cesium have little effect on its migration (Nishita and Essington 1967).

From the above discussion, we would not expect ^{137}Cs to migrate any appreciable distances from the disposal trench. This expectation is supported by the earlier work of Lomenick et al. (1967), which showed that about 85% of the ^{137}Cs discharged to ILW pits 2 and 3 was retained within the first few centimeters of weathered Conasauga bedrock. Lomenick et al. (1967) did point out, however, that narrow, irregular zones or channels exist within the Conasauga formation, where groundwater velocities and radionuclide migration may be much greater. The data presented

for Well T7-20 (see Table 13 and Fig. 7) indicate that such zones do exist near ILW Trench 7 and that ^{137}Cs migration may be occurring along these zones in association with particulate transport in the groundwater.

Well T7-20 is located about 10 m from the trench (Fig. 3). The gamma log for Well T7-20 (illustrated in Fig. 7) indicates three discrete layers of radionuclide migration from the trench to the well. Although these three contaminated layers probably represent relict migration pathways from past seepage operations, they may also serve as preferred flow pathways for runoff and seepage during periods of heavy rainfall. Particulate transport of ^{137}Cs along these pathways is indicated by the suspended matter and rainfall data presented in Table 17. The large peaks in suspended-matter- ^{137}Cs activity in Well T7-20 correlate with periods of pronounced rainfall and imply that ^{137}Cs , sorbed on suspended particles, has migrated over 10 m within 20 years. Particulate transport of ^{60}Co between the trench and Well T7-20 may also occur, as is evidenced by the higher particle-to-water distribution coefficient for ^{60}Co in Well T7-20 relative to other wells in the trench vicinity (Table 12). Although particulate transport is not a major concern for short-lived radionuclides such as ^{137}Cs and ^{60}Co , it may be a significant transport mechanism for longer-lived nuclides, such as Th, Pu, and Am isotopes, which have high distribution coefficients and are otherwise relatively immobile.

Strontium-90

Strontium-90 is a divalent alkaline-earth cation. It is one of the few radionuclides commonly transported in an uncomplexed ionic form and exhibits sorption by ion exchange. Consequently, ^{90}Sr sorption correlates with the cation-exchange capacity of the soil and is highly dependent on the concentration of competing cations in the groundwater and on pH. In highly alkaline environments, ^{90}Sr coprecipitates with CaCO_3 , and this solid phase controls its solubility. Laboratory-derived K_d s, using Conasauga bedrock, are on the order of 20 to 100 mL/g (Spalding and Cerling 1979). The low K_d values are primarily a result of the relatively high concentrations of calcium in the Conasauga bedrock and groundwaters and its competition with ^{90}Sr for exchange sites. Cerling and

Table 17. Rainfall and suspended-particulate ^{137}Cs activities for Well T7-20

Collection date	^{137}Cs Activity (Bq/g)	Rainfall (mm)
29 Apr 82	96	70 ^a
10 Jun 82	23	55 ^a
23 Jun 82	256	
09 Jul 82	145	178 ^a
19 Jul 82	97	
26 Jul 82	56	1
28 Jul 82		4
29 Jul 82		1
30 Jul 82		16
31 Jul 82		69
02 Aug 82	888 ^b	117 ^a
11 Aug 82	74	
25 Aug 82	158	
10 Sep 82	10	135 ^a
06 Oct 82	38	50 ^a
20 Oct 82	25	
22 Nov 82	132	198 ^a
07 Jan 83	265	37 ^a
20 Jan 83	714	
02 Feb 83	659	94 ^a
18 Feb 83	899 ^c	

^aMonthly total.

^bThe large increase in ^{137}Cs activity followed soon after a major rainfall event on July 31, 1982.

^c90 mm of the monthly total (94 mm) precipitated before February 18, 1983.

Turner (1982) have indicated that about 20% of the sorbed ^{90}Sr in stream sediments is nonexchangeable and is associated with hydrous manganese-oxide coatings.

Despite the low K_d of ^{90}Sr in Conasauga bedrock and soils, its concentration in groundwaters near ILW Trench 7 is extremely low (Appendix A). Apparently, chemical treatments of the ILW (discussed earlier) and the precautions taken to obtain and maintain an alkaline environment near the trench have worked effectively to precipitate or sorb ^{90}Sr in the trench sludge (Table 4), or on the CaCO_3 fill, and thus limit its migration. Now that the trench is abandoned and is no longer being continually fed with basic waste liquids, it will slowly begin to lose its alkalinity (and retaining capacity for ^{90}Sr) through interactions with groundwater and percolating "acidic" rain water. The high groundwater pH (as high as 9) in wells T7-13, T7-24, and T7-25 (Appendix A) suggests that the trench is indeed losing its alkalinity, but the rate of loss is uncertain. Simple calculations, assuming no ^{90}Sr migration until all the CaCO_3 in the trench is dissolved, suggest that the trench will retain ^{90}Sr from 10^3 to 10^6 years, depending on the volume and acidity of the interacting groundwater. If ^{90}Sr migration is initiated when the alkaline residues from the original ILW are dissolved, then calculations based on the removal rate of sodium suggest a retaining time of only a few (10 to 100) years.

Cobalt-60

Cobalt-60 is a transition metal, geochemically similar to iron, and can exist in two oxidation states, Co(II) and Co(III). The relative stabilities of Co(II) and Co(III) in solution are greatly affected by complexes with common anions (Onishi et al. 1981). Cobaltous ion (Co^{+2}) is the most soluble and stable form up to a pH of about 9.5, but complexing can stabilize trivalent cobalt in groundwater solutions. Laboratory-determined K_d values for ^{60}Co in weathered Conasauga bedrock are 70,000 and 1,200 mL/g at pH 6.7 and 12.0 respectively (Means et al. 1978a). Cobalt-60 sorption is primarily controlled by the manganese-oxide component of the soils and bedrock (Jenne and Wahlberg 1968; Means et al. 1978b; Cerling and Turner 1982).

Average ^{60}Co particle-to-water distribution data for field samples collected in the vicinity of ILW Trench 7 are listed in Table 12. These values ranged from 10,000 in Well T7-20 (near the trench) to 500 in wells T7-21 and T7-13 (near the seep) and are approximately an order of magnitude higher than the ^{60}Co distribution data reported by Means et al. (1978a) for field samples collected in the same area. This large increase in the apparent K_d of ^{60}Co during the past 10 years probably results from the escape of mobile ^{60}Co from the system, as reflected by the much higher dissolved ^{60}Co concentrations in the 1974 groundwater samples (see Table 15 and Appendix A).

The fact that the apparent K_d for ^{60}Co in the groundwaters near ILW Trench 7 is much lower than expected from laboratory experiments has elicited much interest and research. Means et al. (1976) noted that ^{60}Co in the ILW Trench 7 groundwater does not readily exchange on Na^+ -form cation resins, suggesting that it is tightly bound in a solution complex. Laboratory experiments passing 100 mL of filtered seep water with adjusted hydrogen ion concentrations through cation and anion exchange columns indicate that the ^{60}Co solution complex is anionic and is stable (or inert) at extremely low pH values (Table 18).

Table 18. Cation and anion exchange characteristics of dissolved ^{60}Co in filtered seep water

pH	Percentage of Na^+ cation exchange		Percentage of Cl^- anion exchange	
	Resin	Effluent	Resin	Effluent
7.2 (natural)	ND ^a	100	45	55
5.0			30	70
3.0			10	90
1.0	Trace	100	Trace	100

^aNot detectable.

Cobalt-60 complexes having common inorganic anions, such as PO_4^{3-} , SO_4^{2-} , CO_3^{2-} , NO_3^- , Cl^- , or HCO_3^- , would be expected to dissociate at pH 1, allowing the ^{60}Co -cation to exchange for Na^+ on the cation resin. However, it is evident from the data in Table 18 that dissociation of the ^{60}Co complex does not occur at low pH, suggesting that the ^{60}Co complex is organic. Dissolved and colloidal organics have a strong capacity for binding radionuclides and thus exert considerable control over nuclide mobilization, transport, and sorption (Cleveland and Rees 1981). About 60 to 80% of these dissolved organics are generally composed of natural humic substances. Several synthetic organic chemicals and chelating agents used in laboratory experiments and cleanup or decontamination operations may also be present in the waste liquids and groundwaters near disposal areas (Means et al. 1978a; Czyscinski and Weiss 1981). Bondietti (Auerbach et al. 1974) originally suggested that ^{60}Co in the groundwaters near ILW Trench 7 was mobilized as an ethylenediaminetetraacetic acid (EDTA) complex, and the results described below are consistent with that hypothesis.

Dissolved organic carbon in ILW Trench 7 groundwaters ranges from 2 to 22 mg/L, with the highest concentrations occurring in the seep waters. Total phosphorous concentrations range from 0.1 to 3.1 mg/L, with the highest concentrations occurring in Well T7-20 near the trench (Appendix B). To help determine whether low molecular weight organics or higher molecular weight humic substances were complexing and mobilizing ^{60}Co near ILW Trench 7, a groundwater sample from Well T7-13 was ultra filtered, using pressure, through a 500-MW (AMICON) dialysis membrane. Approximately 80% of the ^{60}Co activity in the groundwater sample passed through the membrane, indicating that most of the ^{60}Co was bound to a low molecular weight complex. Means et al. (1978a), using Sephadex chromatographic gels, gas chromatography, and mass spectrometry, established that greater than 90% of the ^{60}Co was associated with an organic fraction smaller than 700 MW; identified the presence of 3.4×10^{-7} M EDTA in this fraction; and proposed that ^{60}Co is transported as an EDTA complex in the groundwaters near ILW Trench 7. EDTA, a synthetic low molecular weight organic chelating agent, has been used in cleanup and decontamination operations at ORNL and was therefore expected to be present in the waste liquids (Duquid 1977).

In an attempt to document and verify ^{60}Co chelation by EDTA in the ILW Trench 7 groundwaters, we collected a 40-L groundwater sample from Well T7-13 on April 16, 1982. The sample was filtered through 0.45- μm pore size millipore filters. The retained suspended matter was chemically and mineralogically analyzed (see Fig. 6), and the filtered water was evaporated by freeze drying to concentrate the dissolved radionuclides. The flaky white residues which remained in the freeze-drying pan were redissolved with about 80 mL of demineralized water. Carbonate and sulfate salts precipitated during residue dissolution, producing a white slurry. An aliquot of the slurry was placed in a tube and centrifuged to separate the aqueous phase from the solid phase. After collection of the aqueous phase, the precipitate was washed with a CaCO_3 -saturated water and then redissolved with a dilute acid (0.1 N HCl) solution. A small amount of an insoluble fraction remained in the tube after the acid dissolution. The distribution of ^{60}Co activity among the separated fractions is presented in Table 19.

Table 19. Distribution of ^{60}Co activity among experimental fractions

Fraction	Distribution of ^{60}Co activity (%)
Aqueous phase	72.5
CaCO_3 - washing solution	15.6
Dilute acid treatment	
Soluble solid phase ^a	5.4
Insoluble solid phase ^b	6.5

^aMore than 90% of the dilute acid (0.1 N HCl) soluble fraction was water soluble.

^bX-ray diffraction analysis of this insoluble phase indicated that it was amorphous organic matter.

The major portion of the ^{60}Co in the slurry was associated with the aqueous phase, which appeared to be saturated with highly soluble organic and inorganic complexes. The aqueous phase was acidified to pH 3 to decompose carbonate complexes and treated with a cation-exchange resin (this acidified and treated solution is designated as Solution-A). It was then injected into a strong anion-exchange column of a high-performance liquid chromatograph (HPLC), using orthophosphate eluting solutions of different pHs. The elution patterns were monitored by ultraviolet and gamma-ray spectrometry and are illustrated in Fig. 10.

The elution profiles in Fig. 10 are not easily interpreted and may indicate that Solution-A has more than one ^{60}Co complex. As the pH of the eluting solution decreased, elution of a pH-dependent fraction of ^{60}Co was delayed; however, the position of the other fraction remained unchanged. The position of the pH-independent fraction was similar to the peak position of acetone, which was used as a marker for nonabsorbing species. The peak positions of synthetic Co(III)-EDTA having eluting solutions at varying pHs matched with the positions of the pH-dependent fraction of Solution-A. On the other hand, the peak positions of Co(II)-EDTA and other divalent metal-EDTA compounds, which were more negatively charged at a given pH, were displaced to the left of the Co(III)-EDTA peak (i.e., greater transport time) at pHs below 7 (Fig. 10). As pH decreased, the orthophosphate ions in the eluting solution were less dissociated and less effective in replacing absorbed complex compounds having varying degrees of dissociation at given pHs. Consequently, a complex having fewer negative charges would be eluted first and would be less tolerant of pH changes in the eluting solution. At present, it is not possible to determine if the pH-independent fraction represents an unknown ^{60}Co complex or if it is $^{60}\text{Co(III)-EDTA}$ which has eluted improperly because of the interference of other components with the column. Although characterization of the specific ^{60}Co -organic complexes is not as yet complete, our HPLC results indicate that at least a fraction of the mobile ^{60}Co in the groundwaters near ILW Trench 7 is complexed with EDTA, as Bondietti suggests (Auerbach et al. 1974) and that the oxidation state of the complexed ^{60}Co is trivalent rather than divalent.

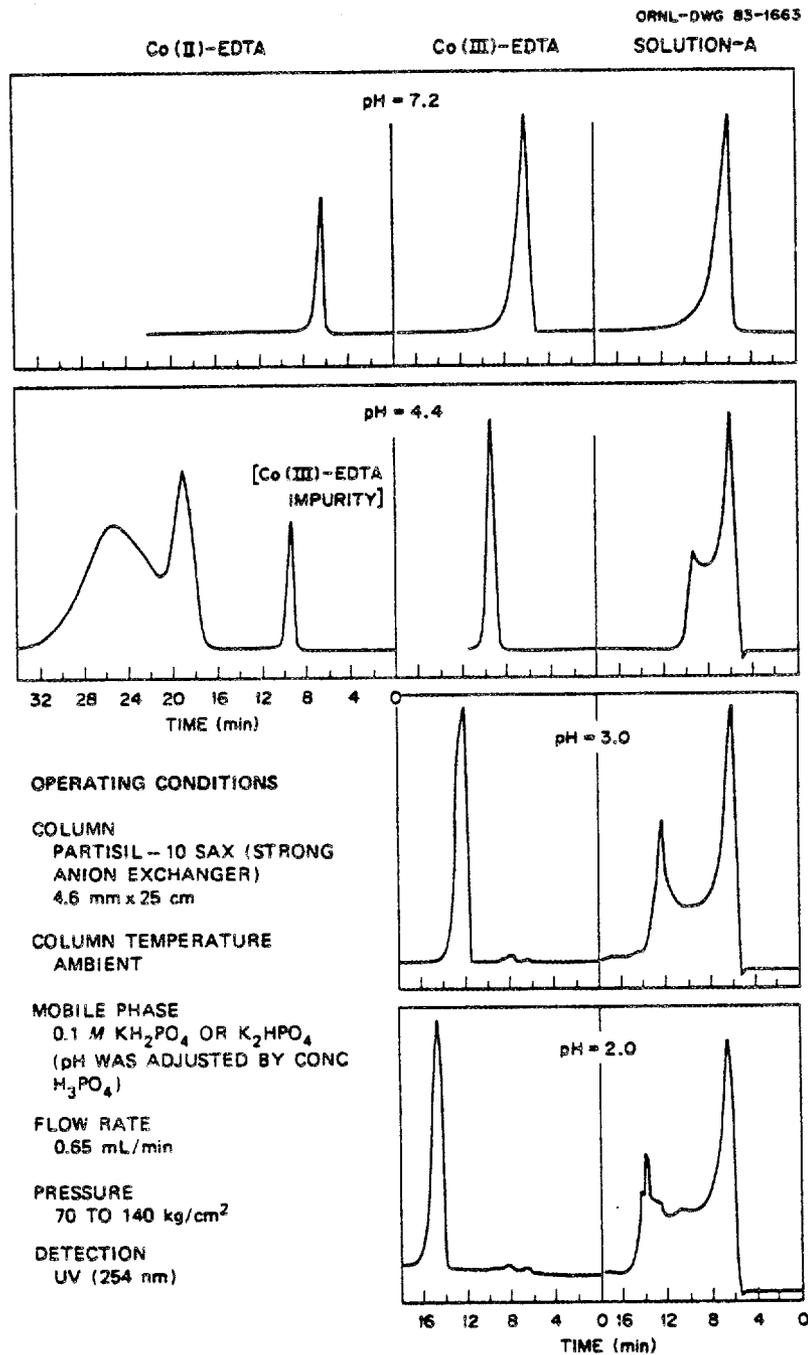


Fig. 10. Elution profiles for Well T7-13 water and synthetic $^{58}\text{Co(III)-EDTA}$ and $^{57}\text{Co(II)-EDTA}$ solutions.

This conclusion is also supported by a coprecipitation with iron hydroxides experiment using ^{60}Co . When an aliquot of T7-13 well water was treated with ferrous and ferric iron, marked differences in the removal rates of ^{60}Co were observed between the two treatments (Table 20). The ferric hydroxide and other well-known coprecipitators, such as aluminum hydroxide, were unable to remove significant amounts of complexed ^{60}Co from the water. Therefore, the redox states of the solutions imposed by the treatments were suspected to be a key controlling factor for the removal rates observed. In general, thermodynamic stability constants (K) of Co(III)-organo complexes are far greater than Co(II)-organo complexes. For example the K value of Co(III)-EDTA is $10^{40.6}$, whereas the K value of Co(II)-EDTA is only $10^{16.3}$ (Sillen and Martell 1964). The Co(II)-EDTA is also known to be kinetically more labile than the Co(III)-EDTA (Krishnan and Jervis 1967). If the complexed ^{60}Co is in a reduced state (II) in the groundwater, relatively high removal rates would be expected because both ferrous and ferric treatments would remove the labile $^{60}\text{Co(II)}$ through coprecipitation after metal-exchange processes. However, the higher removal rate after ferrous treatment and lower rate after ferric treatment suggest that the complexed ^{60}Co is in a trivalent rather than divalent state. Only ferrous iron can chemically reduce the $^{60}\text{Co(III)}$ -organo complex to a less stable $^{60}\text{Co(II)}$ -organo complex and thus allow the $^{60}\text{Co(II)}$ released from complexes to coprecipitate.

Technetium-99

Technetium may exist in aqueous solutions in valence states from (-I) to (VII), depending on the types of complexation. Tc(VII) is the most common and stable state under oxidizing conditions, forming a negatively charged pertechnetate oxyanion (TcO_4^-). The pertechnetate anion is highly soluble in water and is extremely mobile in soils having laboratory-derived K_d s of generally less than 1 mL/g (Wildung et al. 1979). Recent studies by Bondietti and Francis (1980) indicate that the pertechnetate anion (TcO_4^-) can be chemically reduced to Tc(IV), forming rather insoluble TcO_2 in anoxic environments or in soils which contain an appreciable amount of organic matter.

Table 20. Percentage of ^{60}Co removal from T7-13 groundwater by iron treatments^a

Treatment	Concentration ($\times 10^{-3}$ M)	Initial pH ^b	^{60}Co percentage removed
Ferrous iron	1	7.2	19
($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$)	2	6.8	38
	5	6.5	73
Ferric iron	1	7.5	8
($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$)	2	6.7	8
	5	3.2	21

^aIron compounds were added to solution in the form of a powder and the solutions were equilibrated for 19 h.

^bInitial pHs were measured after salt treatments and adjusted to 8.1 after 6 h of equilibration.

The lack of significant quantities of organic matter in the Conasauga weathered bedrock and the slightly oxidizing condition of the groundwaters in the vicinity of ILW Trench 7 (Table 7) allow ^{99}Tc to migrate from the trench as pertechnetate anion ($^{99}\text{TcO}_4^-$). Concentrations of ^{99}Tc are as high as 3,700 Bq/L in the groundwaters near ILW Trench 7 (Table 11). Pertechnetate is also readily taken up by vegetation (Wildung et al. 1979), which is consistent with the high ^{99}Tc concentrations ($\sim 31,000$ Bq/kg) measured in green leaves collected from deciduous trees in the ILW Trench 7 area (Table 16). Since $^{99}\text{TcO}_4^-$ may be reduced and immobilized in areas where the groundwater becomes anoxic or in soils with large organic concentrations, it is possible that ^{99}Tc may be accumulating in a concentration front or zone in soils some distance from the trench. This possibility should be investigated in the future.

Uranium Isotopes

Uranium may exist in four oxidation states: U(III), U(IV), U(V), and U(VI). In oxidizing environments, uranium is present as U(V) or U(VI), with U(VI) predominating when groundwater pH is greater than 5 (Langmuir 1978). Uranium(VI) is quite mobile because uranyl cations readily form soluble complexes with common groundwater anions such as carbonates [$(\text{UO}_2)_3(\text{CO}_3)_2^{2-}$ or $(\text{UO}_2)_3(\text{CO}_3)_3^{4-}$], phosphates [$\text{UO}_2(\text{HPO}_4)_2^{2-}$] or sulfates [UO_2SO_4]. Reduced U(III,IV), on the other hand, is very insoluble, precipitating as UO_2 or sorbing rapidly to the geologic media. Consequently, dissolved U(VI) can be removed from groundwaters by chemical reduction to U(IV). There is still uncertainty in the thermodynamic stability constant for U(VI) reduction, but constants commonly found in the literature predict that U(VI) would be reduced in the presence of measurable H_2S . Laboratory-derived K_d values range from 10^2 to 10^4 mL/g for U(IV) and from 10 to 10^3 mL/g for U(VI) (Onishi et al. 1981). Uranium K_d s are also highly dependent on pH (and, by inference, carbonate complexing). For example, using Conasauga shale, Bondietti (1982) showed that the particle-to-water distribution of U(VI) decreases by a factor of three as the groundwater pH increases from 5.8 to 7.9.

The most abundant uranium isotope in the groundwaters near ILW Trench 7 is ^{233}U . Concentrations of ^{233}U ranged as high as 18 Bq/L and activities in groundwater samples collected, prepared, and analyzed in an oxygen-free environment were identical to ^{233}U activities measured in duplicate samples exposed to oxygen (Table 9). Therefore, we conclude that the migrating uranium species is either already oxidized or is inert to oxidation.

Laboratory experiments involving ultrafiltration through a 500-MW dialysis membrane and passage through cation and anion exchange columns indicate that 100% of the mobile ^{233}U is in the form of a low molecular weight (<500 MW) anionic complex. To evaluate the nature of the anionic complex, exchange column experiments were conducted using filtered seep water and carbonate-saturated distilled water, spiked with $^{237}\text{U(VI)}$ and pH adjusted with HNO_3 . The column results are listed in Table 21 and indicate that the uranium species maintains its anionic nature in seep water acidified to a pH of 3, but at a pH of about 1, the apparent anionic complex is dissociated and the uranium is retained by the cation exchange resin. If carbonate were the only available anionic complexer (as in the case for distilled water, in Table 21) the uranium complex should have dissociated at a pH value between 5 and 3. Since the uranium complex maintained its anionic nature at a pH of about 3 in the seep water sample (Table 21), it appears that another anionic species (possibly PO_4^{3-}) may be an important complexing agent at low pH.

Total phosphorous concentrations in the groundwater near ILW Trench 7 are quite high (Table 6). Typically, uncontaminated groundwaters in the Conasauga bedrock contain total phosphorous concentrations between 0.01 to 0.05 mg/L. Total phosphorous concentrations in groundwater samples collected from wells which show the highest ^{233}U contamination (T7-3, T7-13, T7-20, T7-24, and T7-25) ranged from 0.2 to 2.7 mg/L (Table 6). Plots of the average groundwater ^{233}U activity in ILW Trench 7 wells, as a function of the average groundwater pH and total phosphorous concentration (Fig. 11), show that the ^{233}U concentration in the groundwaters is strongly correlated with the log of total dissolved phosphorous and pH. The dependence of the ^{233}U concentration on pH and phosphorous content is clearly evident in the groundwater data for Well T7-21 (see tables 6 and

Table 21. Cation and anion exchange characteristics of dissolved uranium

Water pH	Percentage of Na ⁺ cation exchange		Percentage of Cl ⁻ anion exchange	
	Resin	Effluent	Resin	Effluent
7.2 (seep)	ND ^a	100	100	ND ^a
5.0 (seep)			90	10
5.0 (distilled)			100	Trace
3.0 (seep)			90	10
3.0 (distilled)			5	95
1.0 (seep)	100	Trace	Trace	100

^aNot detectable.

^{233}U CONCENTRATION AS A FUNCTION OF TOTAL PHOSPHOROUS AND pH

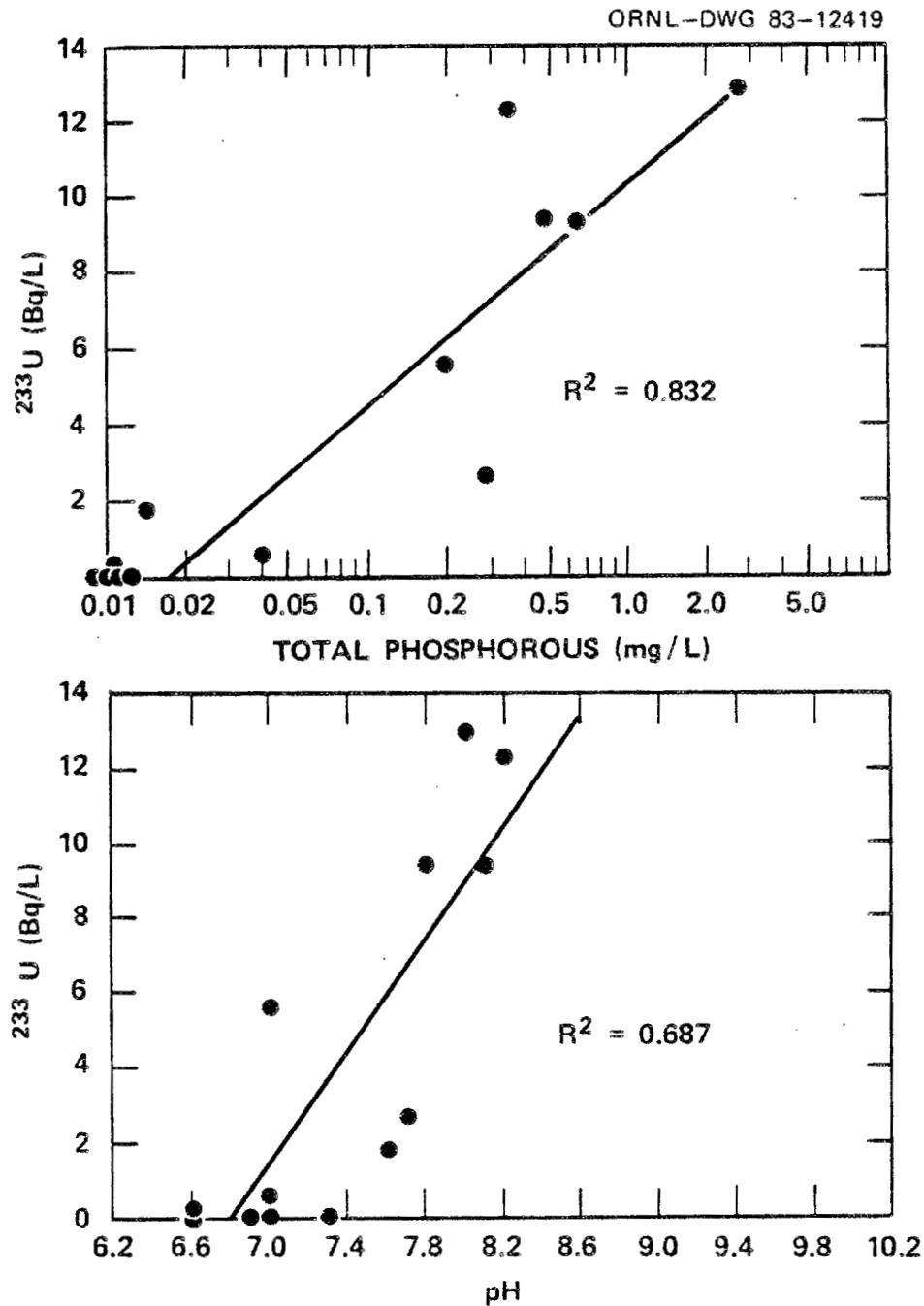


Fig. 11. ^{233}U activity as a function of groundwater pH and total phosphorous concentrations.

11, and Appendix A). Although the groundwater activities of ^{60}Co , ^{99}Tc , and ^3H in Well T7-21 are the highest of all wells in the vicinity of ILW Trench 7, the activities of ^{233}U are relatively low, probably reflecting the relatively low pH or phosphorous content of the groundwater in this location.

Multiple regression analytical techniques were applied to the ^{233}U , pH, and total phosphorous data in an attempt to identify specific interactions. The regression model used was

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_1^2 + B_4X_2^2 + B_5X_1X_2 + E$$

where Y represents the ^{233}U concentration, X_1 is the logarithm of the total phosphorous concentration, X_2 is the logarithm of the hydrogen ion concentration (pH), and the other terms represent the quadratic and cross product contributions. The results of this multiple regression analysis are given in Table 22. It is apparent from these data and from those illustrated in Fig. 11 that ^{233}U is better correlated with the log of the total phosphorous concentration ($R^2 = 0.832$) than with pH ($R^2 = 0.687$). The linear combination of pH and the log of total phosphorous produced a combined $R^2 = 0.866$ (Table 22), with the pH contribution being insignificant at the 5% confidence interval. The quadratic and cross product terms also contributed only insignificantly to the total multiple regression coefficient of $R^2 = 0.941$ (Table 22).

Table 22. Contributions of linear, quadratic, and cross product terms to the correlation of the full model

Regression	Degrees of freedom	Type I sum squares	R-Square	F-Ratio	Probability
Linear	2	264.6003	0.8663	51.13	0.0001
Quadratic	2	16.5761	0.0543	3.20	0.1029
Cross product	1	6.1417	0.0201	2.37	0.1673
Total regression	5	287.3181	0.9407	22.21	0.0004

The results given in Tables 21 and 22 and shown in Fig. 11 imply that the mobile ^{233}U species is a low molecular weight anionic complex, probably a phosphate complex, but the relative importance of carbonate complexing in the pH-carbonate regimes, which actually occur along transport pathways, is still being evaluated. The apparent K_d s of ^{233}U range from 10^3 in the groundwaters near the trench to 10^2 in the groundwaters near the seep. The $^{233}\text{U}/^{232}\text{U}$ activity ratio in the groundwaters is relatively constant, averaging about 10 near the trench and 9 near the seep, but is about a factor of 2 lower than the $^{233}\text{U}/^{232}\text{U}$ activity ratio (19) measured in the trench sludge (Table 4). At present, the fractionation process that decreased the groundwater $^{233}\text{U}/^{232}\text{U}$ activity ratio relative to that of the trench sludge is unknown, although one possibility is that the decay of ^{238}Pu to ^{234}U in the trench biases the trench samples, in that the alpha particles of ^{233}U and ^{234}U have similar energies.

The migration of uranium from the disposal trench is complicated by the fact that the Conasauga bedrock and soils are acidic from natural weathering, but the trench is alkaline due to the waste liquids and limestone fill. This creates a potential for the sorption of uranium to vary, depending on the degree of neutralization of the bedrock (Bondietti 1982). Uranium may be precipitated in acidic areas and redissolved as the area becomes alkaline as a result of interactions with contaminated groundwater. Consequently, the possibility of a uranium concentration front moving away from the trench should be investigated.

Transuranic Nuclides

Small quantities of Am, Cm, and Pu have been measured in the groundwaters (Table 10) and soils (Table 14) near ILW Trench 7. Although Am and Cm are expected to exist only as trivalent species, Pu can exhibit variable valencies, including Pu(III), Pu(IV), Pu(V), and Pu(VI) (Bondietti 1982). As is true of uranium, the higher valence states of Pu(V,VI) are more soluble in groundwaters (Bondietti and Trabalka 1980) and may be subject to carbonate complexing (Simpson et al. 1982). Laboratory-derived K_d s for plutonium in its oxidized (V,VI) states are

about 10^2 mL/g (Duguid 1977). Oxidized Pu is, however, easily reduced to less mobile Pu(III,IV), which forms relatively insoluble oxides and hydroxides having K_d s of about 10^5 mL/g. The trivalent and tetravalent states of Pu(III), Am(III), Cm(III), and Pu(IV) form stable organic complexes which may enhance their migration in groundwaters (Cleveland and Reese 1981). Carbonate interactions may also occur, especially in concentrated solutions in which hydrolysis is repressed (Bondiotti 1982; Simpson et al. 1982).

A groundwater sample collected from Well T7-13, located near the seep about 50 m downslope of ILW Trench 7 (Fig. 3), was filtered under pressure through a 500-MW membrane. The results from this experiment are given in Table 23. As mentioned previously, most of the ^{60}Co and all of the ^{233}U passed through the membrane filter. In addition, 50 to 60% of the Am, Cm, and Pu passed through the membrane filter, implying complexation with low molecular weight compounds, possibly carbonates, phosphates, or synthetic organics. However, a significant proportion of the dissolved ^{241}Am , ^{244}Cm , and ^{238}Pu , apparently is retained by the filter and may be associated with larger molecular weight materials, possibly natural organic substances (Bondiotti 1982).

Apparent K_d s for ^{241}Am , ^{244}Cm , and ^{238}Pu between the soils and groundwater in the vicinity of ILW Trench 7 are listed in Table 24 and range from 10^4 to 10^5 . Consequently, we would expect ^{241}Am , ^{244}Cm , and ^{238}Pu to be relatively immobile, which is consistent with our observations that the highest concentrations of these nuclides are in the soils and weathered bedrock near the trench (Table 14). Nevertheless, the occurrence of these nuclides in the groundwaters and soils near the seep, approximately 50 m downslope of the trench, is still an enigma and must reflect a preferred-flow pathway within the weathered bedrock (see the following section). The migration of plutonium and its distribution between soil and groundwater phases are particularly complicated, because both oxidized Pu(V,VI) and reduced Pu(III,IV) species are present (Table 10) and plutonium can be generated from curium decay. Although the data are limited, it appears that 70 to 80% of the dissolved plutonium in the groundwaters near the trench (Well T7-3) is in an oxidized (V,VI) state (see Table 10), whereas only 10 to 20% of the dissolved plutonium near

Table 23. Ultrafiltration behavior of nuclides in T7-13 groundwater

Nuclide	Total activity ^a (mBq/L)	>500 MW (mBq/L)	<500 MW (mBq/L)	Percentage of passage
⁶⁰ Co	1,690,000 ± 60,000	360,000 ± 11,000	1,320,000 ± 44,000	~80
^{233,232} U	17,200 ± 1,000	ND	17,000 ± 1,000	~100
²⁴⁴ Cm	172 ± 7	73 ± 3	108 ± 2	~60
²⁴¹ Am	103 ± 5	30 ± 2	57 ± 2	~55
²³⁸ Pu (III,VI) (V,VI)	22 ± 1 5 ± 1	{ 10 ± 1	{ 15 ± 1	{ ~55

^aThe sample, collected on May 7, 1981, was yellow in color. Most of the yellowish color was retained by the 500-MW membrane. The actinide analyses were made by J. N. Brantley and E. A. Bondietti.

Table 24. Field-determined apparent distribution coefficients (K_d) for Am, Cm, and Pu

Nuclide (Source)	Water activity (Bq/L)	Soil activity (Bq/kg)	K_d
^{238}Pu (Well T7-3)	0.011 ± 0.001	$3,580 \pm 140$	3.3×10^5
(Well T7-13)	0.027 ± 0.002	500 ± 70	1.8×10^4
^{241}Am (Well T7-13)	0.080 ± 0.005	$1,900 \pm 200$	2.4×10^4
^{244}Cm (Well T7-13)	0.172 ± 0.007	$3,100 \pm 300$	1.8×10^4

the seep (Well T7-13) is oxidized (Table 10). The results in Table 23 indicate that oxidized plutonium accounts for only a third of the total plutonium activity which passes through the 500-MW membrane, implying that a significant portion of the reduced Pu(III,IV) must also be complexed with low molecular weight materials.

Determining the chemical forms or complexes which promote plutonium migration is also complicated by its generation from curium decay. In May 1965, at which time the trench was actively being used for disposal operations, it was noted that ^{242}Cm was migrating from the trench and could be detected in the seep stream and White Oak Creek (Lasher 1965). Since ^{242}Cm has a relatively short half-life (162 d), decaying to ^{238}Pu , it is suspected that the ^{238}Pu contamination in the vicinity of ILW Trench 7 may actually reflect the movement of precursor ^{242}Cm at the original time of disposal rather than ^{238}Pu migration.

A Cm source for the Pu contamination is supported by the Pu isotopic ratio data presented in Table 25. Measured activities for $^{239,240}\text{Pu}$ are reported because the energy pulses from the alpha particles produced by the decay of ^{239}Pu cannot usually be resolved from those produced by the decay of ^{240}Pu . The large increase in the $^{238}\text{Pu}/^{239,240}\text{Pu}$ activity ratio measured in the soils (~ 40) and groundwater (~ 20) relative to the activity ratio in the trench sludge (~ 1) is consistent with ^{242}Cm decay as the primary source for the ^{238}Pu contamination. In addition, mass spectrometer analyses (Table 25) indicate that 60% of the total $^{239,240}\text{Pu}$ activity in the soil near ILW Trench 7 results from ^{240}Pu decay rather than ^{239}Pu decay and that the ^{240}Pu contribution is approximately twice that expected from the sludge analysis. The source of the extra ^{240}Pu in the soils and groundwater may also be a result of curium migration and decay (^{244}Cm decaying to ^{240}Pu) rather than preferential ^{240}Pu migration.

TRANSPORT PATHWAYS OF MIGRATING RADIONUCLIDES

Although geochemical factors and complexes influence nuclide solubility, nuclide migration from ILW Trench 7 is controlled primarily by local hydrological flow patterns, which are governed by local geological

Table 25. Plutonium isotopic activity and mass ratios in the trench sludge and surrounding geologic media

Sample	Measured activity ratio ^a (²³⁸ Pu/ ^{239,240} Pu)		Measured mass ratios ^b (²³⁸ Pu/ ²³⁹ Pu)(²⁴⁰ Pu/ ²³⁹ Pu)		Calculated activity ratios ^c (²³⁸ Pu/ ²³⁹ Pu)(²⁴⁰ Pu/ ²³⁹ Pu)	
Trench sludge	1		0.02	0.18	6	0.6
T7-13 water	20					
T7-3 soil	40		0.30	0.39	85	1.4

^aFrom Tables 4, 10, and 14.

^bFrom Table 5.

^cCalculated assuming the specific activity of ²³⁸Pu to be approximately 6.44×10^{11} Bq/g; ²³⁹Pu = 2.27×10^9 Bq/g, and ²⁴⁰Pu = 8.40×10^9 Bq/g.

features such as folds, faults, and zones of greater weathering. The well gamma-log profiles, illustrated in figs. 7 and 8, indicate that during past seepage operations the waste liquids migrated along discrete layers. Soil and groundwater analyses indicate that the migration was in an east-west direction, parallel to bedding planes, and along fold and fault strikes between the trench and seep area. The lack of trench contamination in the soils and groundwaters just north of the trench (Fig. 9 and Appendix A) implies little or no nuclide migration across bedding planes and against the groundwater gradient, which rises sharply to the north (Fig. 2).

To identify the geological and hydrological factors which may affect nuclide migration, a geologic cross section was exposed parallel to the trench by widening the banks of an already existing access road, located about halfway between the trench and seep area. A series of wells (T7-21, T7-22, T7-23, T7-24, and T7-25) was drilled along this cross section (Fig. 12). Average groundwater analyses from these wells are given in Table 26. Exposing this geologic cross section delineated a fault zone at T7-21, a large anticlinal fold at T7-23, and another fault zone at T7-25 (Fig. 12) all of which strike east-west, intersecting both the trench and the seep area.

Groundwater analyses indicated little or no contamination in the groundwaters of Well T7-23, which is capped by the limestone fold (see Fig. 12 and Table 26) and that the greatest contamination occurred in wells drilled through the fault zones (see tables 6 and 26). Well T7-21 is a 15-m well drilled adjacent to a 9-m well (T7-10) along a fault zone which is visible topographically as a result of surface drainage erosion (Fig. 12). In addition to Well T7-10, several other shallow 9-m wells (including T7-9 and T7-4) were drilled along or adjacent to this fault zone over a decade ago (Fig. 3). Because of the relatively low activities in the groundwaters of Well T7-10, it was previously concluded that the pathway delineated by these wells was not the major migration route for trench contamination to the seep area and that migration from the north end of the trench was more likely (Means et al. 1976). The soil gamma-ray log for Well T7-21 (Fig. 8) indicates, however, that the zone of contamination occurs at and below the 9-m level. Consequently, the

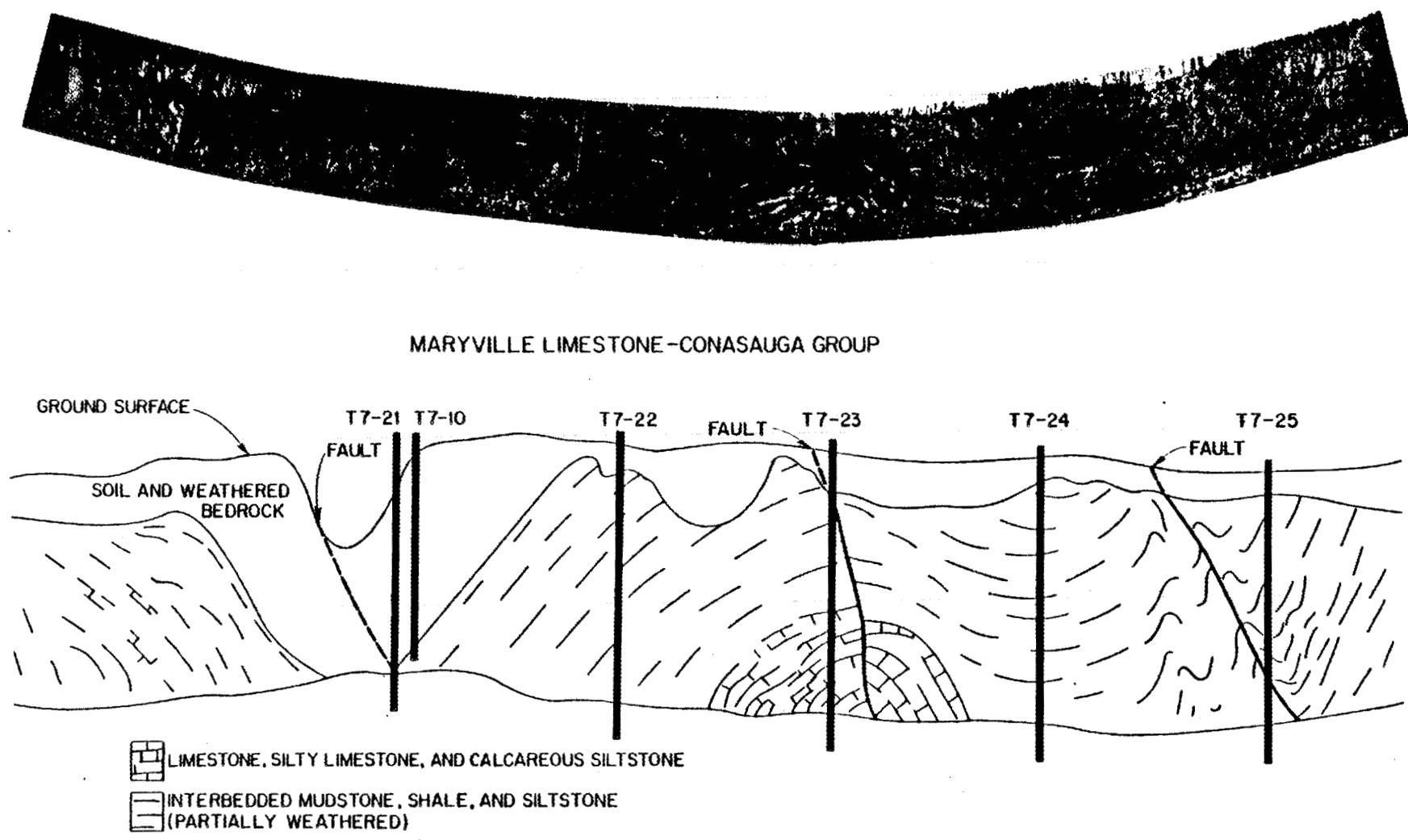


Fig. 12. Cross-sectional photo and map illustrating the geological structures and well locations.

Table 26. Average groundwater characteristics for the cross-sectional wells illustrated in Fig. 12

Well number	pH	SO ₄ ⁼ (mg/L)	Na ⁺ (mg/L)	Total P (mg/L)	³ H (Bq/L)	⁹⁹ Tc (Bq/L)	⁶⁰ Co (Bq/L)	²³³ U (Bq/L)	⁹⁰ Sr (Bq/L)
T7-21 (fault)	7.0	678	271	0.04	27,300	3,450	2,040	0.6	0.7
T7-10 (shallow)	6.6	23	18	0.02	3,170	— ^a	275	0.1	2.6
T7-22	7.7	218	241	0.28	14,000	500	1,040	2.7	0.3
T7-23 (fold)	7.3	82	14	0.02	10,700	ND ^a	ND	ND	0.8
T7-24	8.1	170	213	0.48	8,490	450	1,315	9.4	0.4
T7-25 (fault)	8.2	129	188	0.34	5,960	250	1,030	12.3	2.1

^aDash (—) indicates not analyzed; ND indicates not detected.

lack of contamination in Well T7-10 relative to Well T7-21 (Table 26) and the well gamma-log data (Fig. 8) imply that the shallow, older wells did not penetrate deep enough to tap the contamination migration layers and that this fault zone may have indeed served as a transport pathway.

Although concentrations of ^3H , ^{60}Co , ^{99}Tc , and ILW chemical constituents (Na^+ , Ca^{++} , Mg^{++} , Cl^- , NO_3^- , and SO_4^{--}) are extremely high in the groundwaters of T7-21 (Table 26), the alkalinity, pH, and ^{233}U concentrations are relatively low compared to those in wells (T7-20, T7-3, T7-24, T7-25, and T7-13) located to the north of the limestone fold (Fig. 12). Data collected monthly during 1981 and 1982 indicated a possible migration pathway between wells T7-3 (near the north end of the trench) and T7-13 (near the seep). The groundwaters in both wells were characterized by relatively high ^{60}Co and ^{233}U activities; high Na^+ , NO_3^- , SO_4^{--} , and total P concentrations; and high pH and carbonate alkalinity (Table 6). In addition, temporal variations in the groundwater characteristics are highly correlated in wells T7-3 and T7-13 (Fig. 13). Groundwater ^{233}U and ^{60}Co concentrations in both wells undergo seasonal variations, with the lowest activities occurring in the fall and winter and the highest activities occurring in the spring and after prolonged rainstorm events. The rise in nuclide activities also correlates with a rise in groundwater level and pH.

The possibility of a transport pathway between the north end of ILW Trench 7 and the seep area is also indicated by an inflection in the groundwater level in this area (Fig. 2). As noted earlier, the groundwater level remains fairly horizontal and does not undergo any appreciable seasonal fluctuations under the trench or in wells to the south of the limestone fold, shown in Fig. 12. To the north of the limestone fold the water table gradually rises and the range of fluctuation increases. The recorded changes in groundwater level during one week for wells T7-21 (south of the fold), T7-24 (north of the fold), and T7-26 (north of the trench) are illustrated in Fig. 14. Groundwater level fluctuations as high as 6 m have also been recorded for Well T7-2 (Fig. 15), located about 50 m north of the trench. These results imply that a transport pathway occurs near the inflection point in the groundwater table and that this pathway is responsible for the damping effect

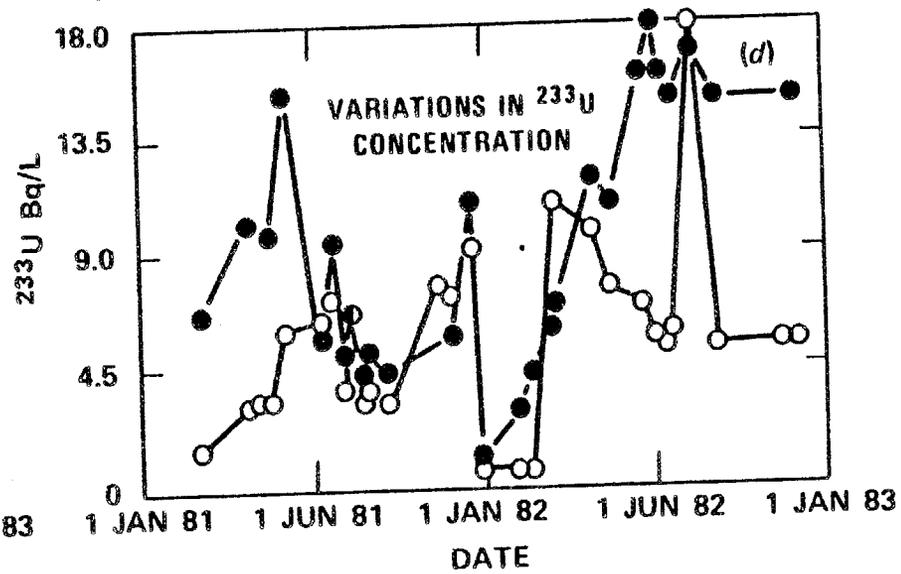
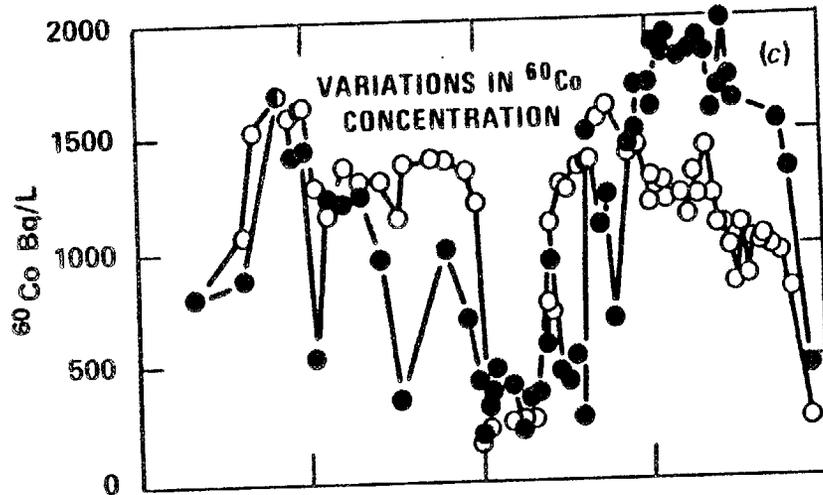
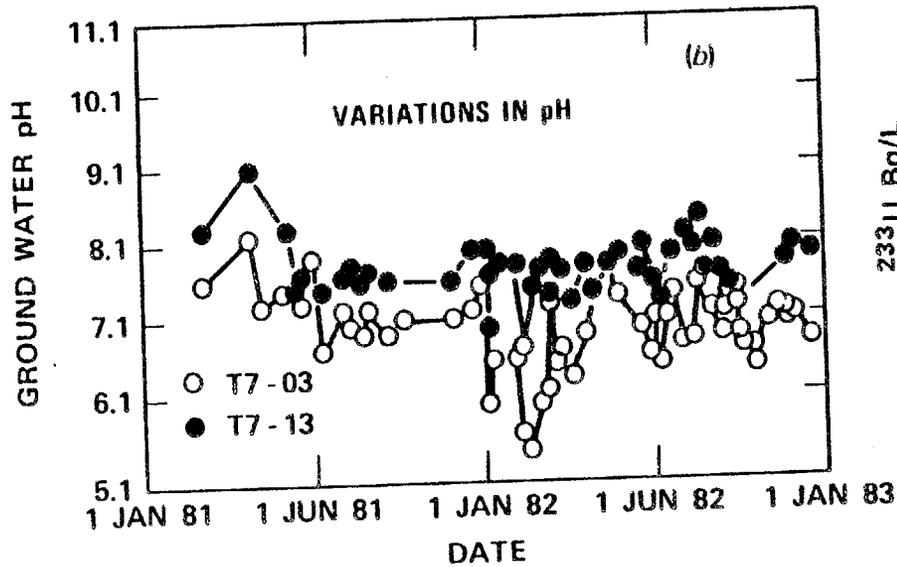
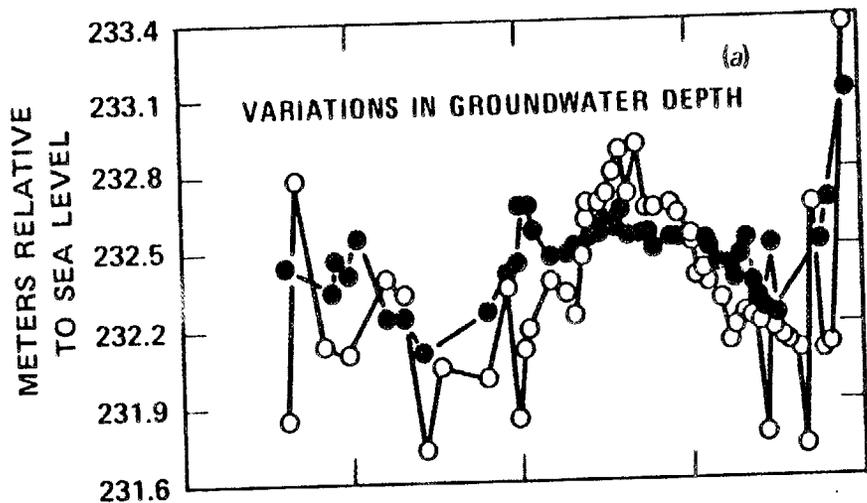


Fig. 13. Temporal variations in groundwater depth, pH, and ²³³U and ⁶⁰Co concentrations in Wells T7-3 and T7-13.

WEEKLY FLUCTUATION IN GROUNDWATER LEVELS

ORNL DWG 83-12418

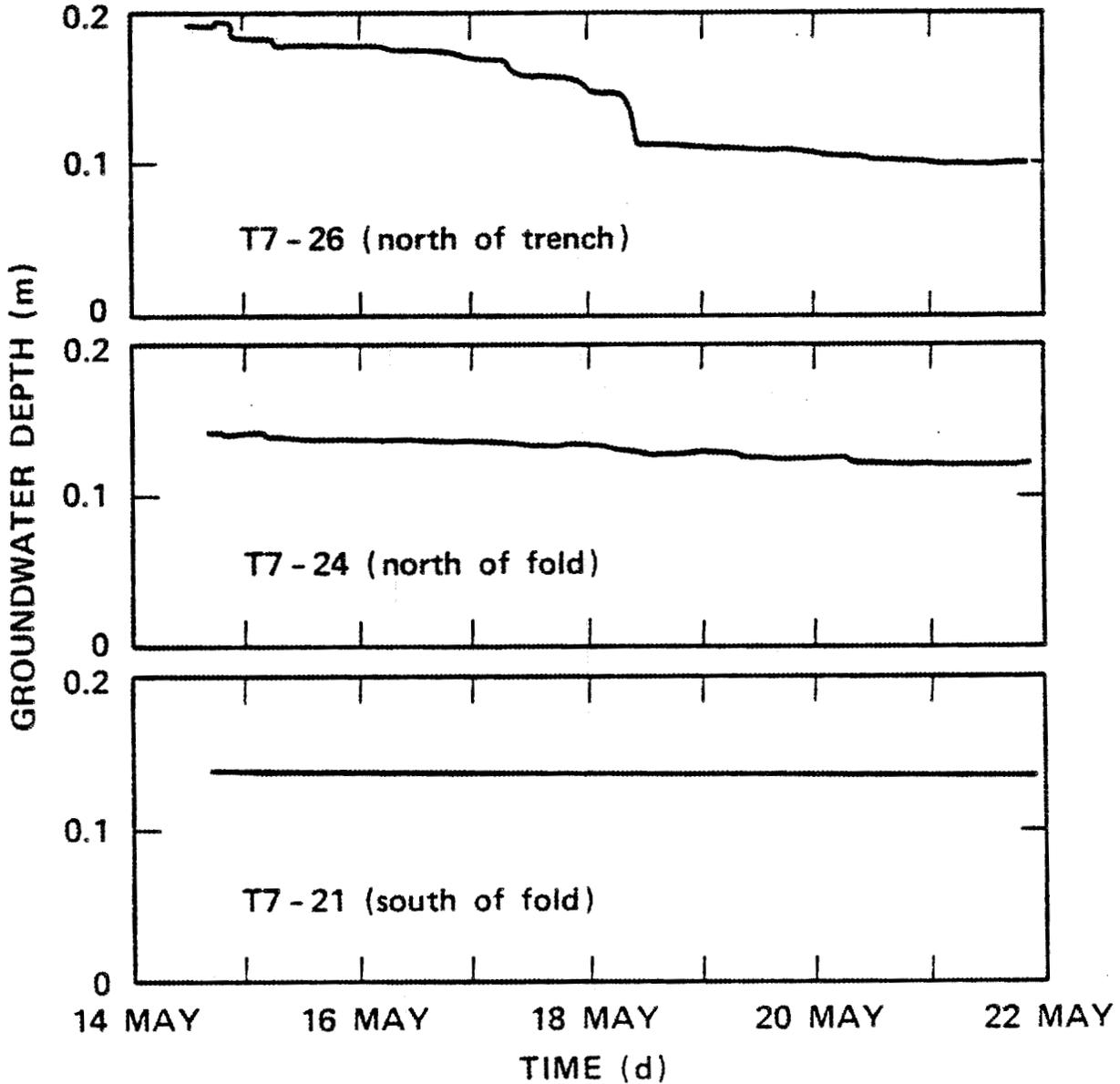


Fig. 14. Fluctuations in the groundwater level in Wells T7-26, T7-24, and T7-21 during one week.

YEARLY FLUCTUATION IN GROUNDWATER LEVELS

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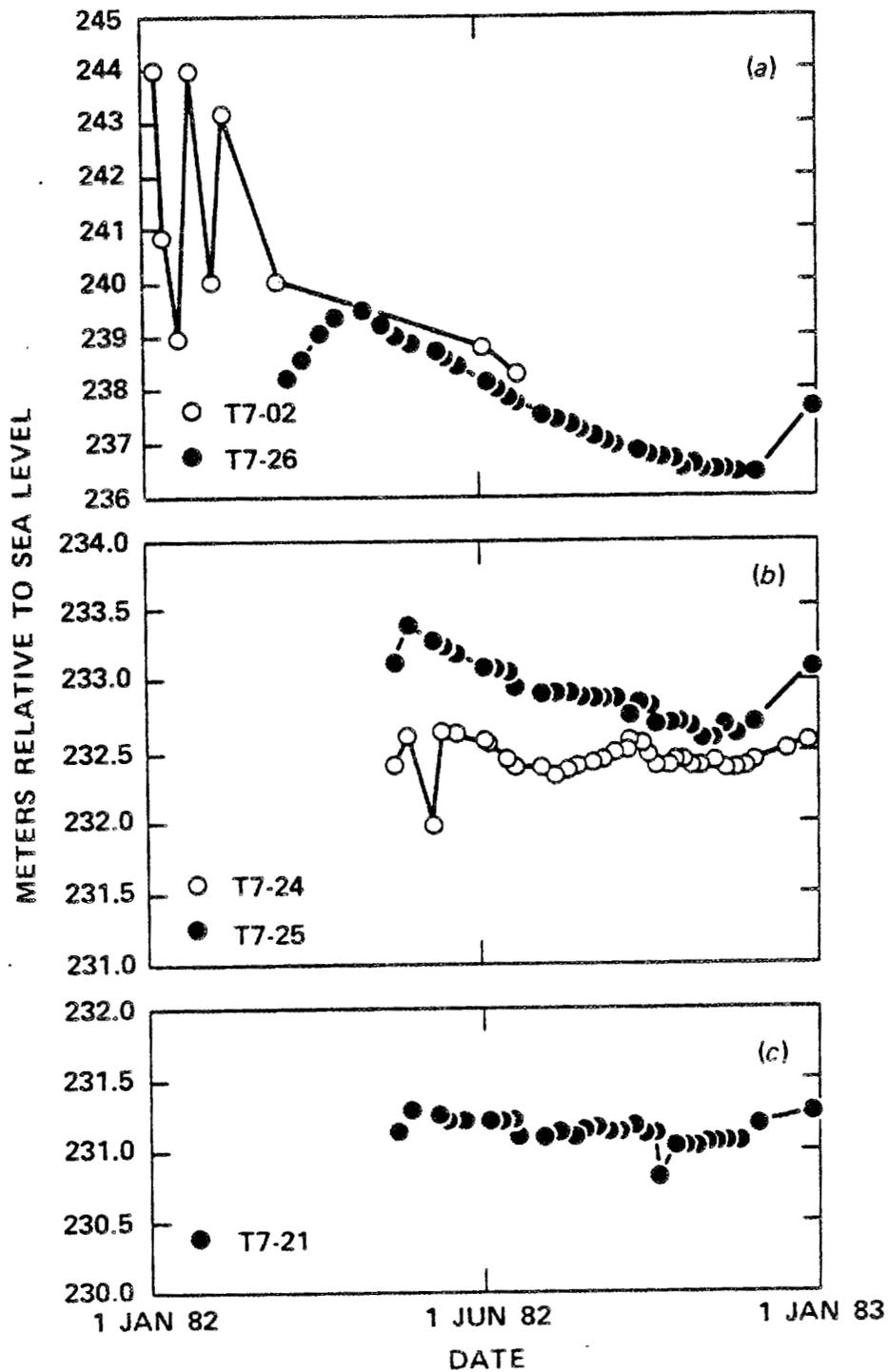


Fig. 15. Fluctuations in the groundwater levels in Wells T7-2, T7-21, T7-24, and T7-26 during one year.

on the groundwater level fluctuations to the south. More extensive hydrological modeling in the vicinity of ILW Trench 7, however, will be required to document this pathway with more certainty.

The high alkalinity and pH of the groundwaters in wells T7-20 and T7-3 (near the trench), T7-24 and T7-25 (north of the fold between the trench and seep), and T7-13 (near the seep) imply a present-day leaching of the alkaline fill in the trench or contaminated soils near the trench. The rise in radionuclide activity in these wells, in association with a rise in the groundwater level, suggests that the contamination is leached during the spring and after periods of prolonged rain when either (1) the groundwater level rises and intersects the relict migration layers illustrated in figs. 7 and 8, or (2) perched groundwater, resulting from precipitation drainage and seepage, percolates through or along contaminated geologic strata before penetrating the groundwater table. At present, we cannot distinguish between these two processes, but both may occur and will have to be addressed by remedial actions.

A new series of wells and soil borings (SB-1, SB-2, SB-4, SB-6, T7-27, and T7-28) have recently been drilled at the north end of ILW Trench 7 (Fig. 3) to document these environmental mechanisms and pathways for nuclide mobilization. Dye tracer tests are currently being conducted to identify transport pathways more accurately and to determine transport rates. Once the migration pathways are established, field experiments can be conducted to determine what reactions are occurring between the contaminated groundwater and soils and to determine the nuclide migration rates and retardation factors along the flow pathway.

The lack of any significant seasonal fluctuations in the groundwater table in Well T7-21 and its low pH and ^{233}U concentrations suggest that the pathway along this fault zone (Fig. 12) is not transporting recent contamination derived from the alkaline trench or nearby soils but is transporting contamination derived from the relict migration layers which occur below the groundwater table in this area (Fig. 8). Although transport along this pathway may be contaminating the seep area, it does not appear to be leaching alkalinity from the trench or affecting its retention capacity for ^{90}Sr .

CONCLUSIONS AND RECOMMENDATIONS

A number of chemical, hydrological, and geological variables influence radionuclide mobility. In general, the chemical variables affect nuclide sorption and solubility and the hydrological and geological variables affect nuclide transport. The interaction of these variables is complicated, and field investigations are therefore difficult to conduct, difficult to interpret, and difficult to document by repeated measurements. Consequently, scientists interested in nuclide sorption, solubility, and migration have resorted to laboratory experiments and transport models designed to reduce or control these environmental variables. In doing so, however, the complexity does not disappear but takes on a new form as scientists attempt to translate laboratory data and computational models to actual field situations. In this report, we summarize our findings concerning (1) the operational history and nuclide inventory for ILW Trench 7; (2) the chemical forms for several of the radionuclides migrating from the trench; and (3) the geochemical, geological, and hydrological processes which promote their migration. Our conclusions are as follows:

1. A total of 3.2×10^7 L of ILW containing about 10^7 GBq of fission nuclides, activation products, actinides, and transuranics were disposed in ILW Trench 7 between 1962 and 1966. Analyses of the trench sludge indicate that ^{90}Sr , ^{137}Cs , ^{60}Co , and ^{241}Pu - ^{241}Am contribute most of the radioactivity in the trench.
2. Groundwater characteristics in the vicinity of ILW Trench 7 are still greatly influenced by the constituents of the waste liquids disposed over two decades ago. Most of the radioactivity in the groundwaters consisted of ^3H , ^{60}Co , and ^{99}Tc and their concentrations are strongly correlated with other soluble constituents of the ILW, including Na^+ , Cl^- , NO_3^- , and $\text{SO}_4^{=}$. The most abundant transuranic radionuclide in the groundwaters is ^{233}U and only minor amounts of Pu, Am, and Cm were detected. Concentrations of ^{90}Sr and ^{137}Cs in the groundwaters were extremely low, despite the fact

that these two nuclides accounted for most of the activity disposed in the trench. The lack of ^{90}Sr mobility is attributed to the chemical treatments and precautions taken to obtain and maintain an alkaline environment near the trench, and the lack of ^{137}Cs mobility is attributed to its strong affinity for irreversible sorption by illite, which is the dominant clay mineral in Conasauga bedrock and soils.

3. The mobility of ^{233}U , ^{60}Co , and ^{99}Tc in the groundwaters around ILW Trench 7 has been attributed to low molecular weight anionic complexing. The mobile ^{233}U species appears to be phosphate complexed, but the relative importance of carbonate complexing in the pH-carbonate regimes which actually occur in the Conasauga bedrock are still being evaluated. Bondietti (Auerbach et al. 1974) reported that complexation of ^{60}Co with a soluble chelating agent (EDTA) caused its high mobility. Our results indicate that more than one ^{60}Co -organo complex may occur, and the mobile ^{60}Co complexed with EDTA is in a trivalent oxidation state. The high concentrations of long-lived ^{99}Tc in these slightly oxidizing groundwaters reflect its mobility as negatively charged pertechnetate ions (TcO_4^-).
4. Plutonium isotopic ratios measured in the trench sludge are very different from ratios measured in the groundwaters and soils near the trench, which are highly enriched in ^{238}Pu and ^{240}Pu relative to ^{239}Pu . These results strongly imply that the plutonium contamination observed in the vicinity of ILW Trench 7 primarily results from the migration of ^{242}Cm and ^{244}Cm and their subsequent decay to ^{238}Pu and ^{240}Pu respectively, rather than reflects actual migration of plutonium itself.
5. A comparison of radionuclide activities in a groundwater and soil sample collected from Well T7-13 in 1974 with present activities measured in samples collected from the same well indicate that (1) there has been no major increase in radionuclide migration and soil contamination in the vicinity of ILW Trench 7 during the past decade; (2) the effects of present-day migration on the extent of

groundwater and soil contamination in the area are minor relative to the legacy of contamination from past seepage operations; and (3) concentrations of the most mobile radionuclides (^3H and ^{60}Co) and waste constituents (Na^+ , NO_3^- , etc.) are rapidly decreasing in the groundwaters, implying seepage out of the system.

6. Well gamma-log profiles indicate that the waste liquids migrated along discrete layers during past seepage operations. These relict migration paths may also serve as preferred flow pathways for runoff and seepage during periods of heavy rainfall. Radionuclide transport in association with particles appears to occur as perched groundwater percolates along these relict migration layers. High groundwater radionuclide concentrations occur in areas where the water table intersects these relict layers.
7. Radionuclide concentrations in the groundwaters near the north end of ILW Trench 7 undergo seasonal variations, with the lowest activities occurring in the fall and winter and the highest activities occurring in the spring and after prolonged rainstorm events. The rise in nuclide activity in these wells correlates with a rise in the groundwater level and a concurrent increase in groundwater pH. This suggests that the water table may rise to saturate either the alkaline fill at the north end of the trench or relict contaminated soils, thus promoting migration.
8. Two suspected transport pathways from the trench to the nearby seep have been identified based on groundwater compositions and nuclide concentrations, inflections in the groundwater table, field seismic surveys, and local geologic structures. Both pathways appear to be associated with fault zones which strike between the trench and seep area. However, only the pathway at the north end of the trench appears to be leaching alkalinity and thus affecting the retention capacity for ^{90}Sr .

Recommended Remedial Actions

Trench contamination is being leached and transported by two mechanisms: the percolation of perched groundwater along relict contamination layers during drainage and seepage after periods of prolonged rainfall, and a seasonal rise in the groundwater table and its saturation of either relict migration layers or the contaminated alkaline zone at the northern end of the trench. At present, we cannot distinguish between these two mechanisms, and the ideal corrective measures for each may not be identical. A French drain groundwater interceptor has been proposed to eliminate the transport of perched groundwater into the north end of the trench and reduce fluctuations in the groundwater level (Cutshall 1983). Although the success of such a drain in suppressing radionuclide migration in areas where the relict layers of contamination are already below the groundwater table is not as certain as the success in intersecting perched flow into the trench, it will nevertheless help maintain a dry alkaline environment for the trench and ensure its integrity for nuclide retention.

In addition to the French drain, the asphalt trench cover should be extended to include the ridge top alongside the trench and the recharge area between the French drain and the trench itself. This will hinder the infiltration and percolation of water along the relict contamination layers which are currently above the water table. To work effectively, the runoff from the extended asphalt cover must be collected and directed away from the areas in which the soils are highly contaminated.

Recommended Research

Investigations should be continued in the design and effectiveness of a French drain to intercept groundwater at the north end of ILW Trench 7. These investigations will require more extensive hydrological modeling of the area which, in turn, will require a better understanding of the geological structures governing groundwater transport.

Radionuclide migration from ILW Trench 7 is complicated because the Conasauga bedrock and soils are acidic from natural weathering, but the trench is alkaline due to the waste liquids and limestone fill. Consequently, it is possible that a soil concentration front, for radionuclides

whose solubilities are pH dependent (such as uranium), will move away from the trench. In addition, for radionuclides whose solubilities depend on their oxidation state (such as technetium), a concentration front may also exist where the groundwaters become anoxic. Future research in the vicinity of ILW Trench 7 should examine these possibilities.

The high groundwater pH suggests that the trench may be losing its alkalinity and thus its retention capacity for ^{90}Sr . The rate of alkalinity loss and its effects on ^{90}Sr retention need to be examined. Accurate rate estimates require more detailed information concerning the volume of water interacting with contaminated strata and the rate of groundwater flow in the immediate vicinity. Since the research summarized here implies that specific transport pathways exist around ILW Trench 7, any characterization of groundwater flow must consider these pathways. Calculations concerning the rate of alkalinity loss may also be made using historical records of sodium input with the waste and its loss to the groundwaters.

The total quantities and potential mobilization of transuranics, ^{232}Th , and daughter radionuclides in the ILW Trench 7 area and in the vicinity of the other formerly used seepage pits and trenches should be defined more accurately. Such information will be crucial for the ultimate closure of these pit and trench areas. Field experiments should be conducted to determine nuclide migration rates and retardation factors along the transport pathways and to examine the types of reactions occurring between the contaminated groundwater and weathered bedrock. Data concerning the chemical properties of the water and groundwater transport should be modeled to help characterize the geochemical and hydrological factors which influence nuclide migration. In addition, these data provide an opportunity for field evaluating geochemical and transport models, thus eliminating some of the uncertainty associated with extrapolating laboratory data to natural environments.

APPENDIXES

APPENDIX A
 CHRONOLOGICAL RADIONUCLIDE DATA FOR WELLS IN THE VICINITY OF ILW TRENCH 7
 ACTIVITY IN (Bq/L)

NUM=T7-02

OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
25	T7-02	03APR81	237.568	7.20	.	.	.	2.000E-02	2.000E-03	6.660E+01
26	T7-02	29MAY81	.	6.40	.	.	0.000E+00	.	.	5.513E+00
27	T7-02	21AUG81	237.698	.	.	.	.	.	.	.
28	T7-02	31AUG81	237.538	6.80	.	.	0.000E+00	2.600E-02	.	6.290E+00
29	T7-02	12DEC81	237.488	.	.	.	.	.	.	.
30	T7-02	17DEC81	237.468	.	.	.	.	.	.	.
31	T7-02	26DEC81	240.748	7.50	6.700E+01	2.900E+03	6.140E+00	.	.	.
32	T7-02	29DEC81	238.248	.	.	.	.	.	.	.
33	T7-02	04JAN82	244.058	.	.	.	.	.	.	.
34	T7-02	07JAN82	240.836	.	.	.	.	.	.	.
35	T7-02	14JAN82	238.958	.	.	.	.	.	.	.
36	T7-02	20JAN82	244.048	.	.	.	.	.	.	.
37	T7-02	29JAN82	240.048	6.60	3.100E+02	8.700E+02	.	.	.	.
38	T7-02	04FEB82	243.198	.	.	.	.	.	.	.
39	T7-02	26FEB82	240.058	.	7.200E+01	5.600E+03	.	.	.	.
40	T7-02	01JUN82	238.798	6.44	8.200E+01	1.300E+03	7.400E+00	.	.	9.620E+00
41	T7-02	23JUN82	236.278	7.20	3.200E+02	1.100E+03	3.700E+00	.	.	5.402E+00

NUM=T7-03

OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
42	T7-03	12JUL74	.	.	4.850E+04	.	6.991E+03	.	.	.
43	T7-03	23JUL74	.	.	6.500E+04	.	9.990E+03	.	.	.
44	T7-03	15AUG74	.	.	3.900E+04	.	1.126E+04	.	.	.
45	T7-03	20JUN75	.	.	9.567E+04	3.000E+00	6.806E+03	.	.	.
46	T7-03	20FEB81	.	7.60	.	.	7.659E+02	1.380E+00	1.200E-01	.
47	T7-03	03APR81	231.848	8.20	.	.	1.069E+03	3.130E+00	2.700E-01	.
48	T7-03	14APR81	232.788	7.30	.	.	1.520E+03	3.290E+00	3.600E-01	.
49	T7-03	22APR81	.	.	.	.	.	3.200E+00	.	.
50	T7-03	07MAY81	232.128	7.50	7.990E+03	.	1.683E+03	6.000E+00	5.100E-01	.
51	T7-03	15MAY81	232.088	7.50	.	.	1.569E+03	.	.	.
52	T7-03	19MAY81	232.278	7.30	.	.	1.606E+03	.	.	.
53	T7-03	29MAY81	232.098	7.90	.	.	1.624E+03	.	.	.
54	T7-03	09JUN81	.	6.70	.	.	1.280E+03	6.350E+00	5.400E-01	.
55	T7-03	26JUN81	.	.	.	.	1.154E+03	7.250E+00	6.100E-01	.
56	T7-03	07JUL81	.	7.20	.	.	.	3.700E+00	.	.
57	T7-03	17JUL81	232.398	7.00	.	.	1.365E+03	4.770E+00	.	.
58	T7-03	31JUL81	.	6.90	.	.	.	3.100E+00	.	.
59	T7-03	07AUG81	232.338	7.20	.	.	1.288E+03	3.670E+00	.	.
60	T7-03	21AUG81	232.228	.	.	.	.	.	.	.
61	T7-03	31AUG81	231.708	6.90	.	.	1.299E+03	3.140E+00	.	.
62	T7-03	21SEP81	232.048	7.09	.	.	1.140E+03	.	.	.
63	T7-03	30SEP81	.	.	.	.	1.373E+03	.	.	.
64	T7-03	07OCT81	231.978	.	.	.	.	.	.	.

APPENDIX A (continued)

CONCENTRATIONS IN BQ/L
DEPTH CORRECTED TO MEAN SEA LEVEL IN METERS

11:10 FRIDAY, JUNE 24, 1983 13

NUM=17-03

Obs	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
65	17-03	14OCT81	231.928	.	.	.	.	.	.	.
66	17-03	02NOV81	.	.	.	.	1.391E+03	7.700E+00	1.000E+00	.
67	17-03	13NOV81	231.958	.	.	.	.	.	.	.
68	17-03	19NOV81	231.998	7.11	.	.	1.391E+03	7.300E+00	8.000E-01	.
69	17-03	25NOV81	232.008	.	.	.	.	.	.	.
70	17-03	03DEC81	232.008	.	.	.	.	.	.	.
71	17-03	10DEC81	232.008	.	.	.	.	.	.	.
72	17-03	16DEC81	232.358	7.20	.	.	1.339E+03	9.200E+00	1.100E+00	.
73	17-03	17DEC81	232.028	.	.	.	.	.	.	.
74	17-03	28DEC81	231.838	7.54	7.500E+03	3.000E-01	1.200E+03	4.500E-01	1.700E-01	.
75	17-03	03JAN82	232.188	.	.	.	.	.	.	.
76	17-03	04JAN82	232.108	6.00	.	.	1.424E+02	.	.	.
77	17-03	08JAN82	232.188	6.55	.	.	2.142E+02	.	.	.
78	17-03	14JAN82	232.138	.	.	.	.	.	.	.
79	17-03	20JAN82	232.228	.	.	.	.	.	.	.
80	17-03	21JAN82	.	.	.	.	2.085E+02	.	.	.
81	17-03	28JAN82	232.378	6.60	.	.	2.386E+02	.	.	.
82	17-03	29JAN82	232.378	.	9.500E+02	1.400E+00	2.390E+02	5.200E-01	7.000E-02	.
83	17-03	04FEB82	232.218	5.60	.	.	2.516E+02	.	.	.
84	17-03	11FEB82	232.328	5.40	.	.	2.394E+02	3.500E-01	2.300E-02	.
85	17-03	19FEB82	232.228	6.00	.	.	2.627E+02	.	.	.
86	17-03	25FEB82	232.478	6.17	.	.	7.992E+02	.	.	.
87	17-03	28FEB82	232.618	7.40	6.500E+03	2.800E-01	7.770E+02	.	.	.
88	17-03	04MAR82	232.678	6.50	.	.	1.106E+03	1.100E+01	1.100E+00	.
89	17-03	11MAR82	232.678	6.71	.	.	1.280E+03	.	.	.
90	17-03	19MAR82	232.708	6.37	.	.	1.254E+03	.	.	.
91	17-03	26MAR82	232.798	.	.	.	1.354E+03	.	.	.
92	17-03	01APR82	232.868	6.92	.	.	1.365E+03	.	.	.
93	17-03	07APR82	232.708	7.35	7.500E+03	2.000E-02	1.384E+03	9.900E+00	1.100E+00	.
94	17-03	08APR82	232.708	.	.	.	.	.	.	.
95	17-03	16APR82	232.918	.	.	.	1.558E+03	.	.	.
96	17-03	23APR82	232.648	7.80	9.200E+03	6.000E-02	1.621E+03	7.600E+00	9.700E-01	.
97	17-03	29APR82	232.648	7.40	.	.	.	.	.	.
98	17-03	14MAY82	232.678	7.21	.	.	1.413E+03	.	.	.
99	17-03	21MAY82	232.648	7.02	.	.	1.450E+03	7.000E+00	6.900E-01	.
100	17-03	01JUN82	232.518	6.64	.	.	1.191E+03	5.700E+00	5.000E-01	.
101	17-03	04JUN82	232.548	7.14	.	.	1.299E+03	.	.	.
102	17-03	10JUN82	232.388	6.54	.	.	1.247E+03	5.400E+00	3.300E-01	.
103	17-03	17JUN82	232.408	7.14	.	.	1.265E+03	.	.	.
104	17-03	23JUN82	232.368	7.50	9.200E+03	2.200E+00	1.206E+03	5.800E+00	3.200E-01	.
105	17-03	09JUL82	232.298	6.81	.	.	1.225E+03	.	.	.
106	17-03	19JUL82	232.128	6.85	8.600E+03	8.100E-01	1.136E+03	1.800E+01	.	.
107	17-03	26JUL82	232.188	7.55	.	.	1.313E+03	.	.	.
108	17-03	02AUG82	232.258	7.26	.	.	1.221E+03	.	.	.
109	17-03	11AUG82	232.258	7.17	.	.	1.432E+03	.	.	.
110	17-03	18AUG82	232.228	7.18	8.300E+03	2.000E-01	1.228E+03	5.300E+00	7.000E-01	.
111	17-03	25AUG82	232.198	6.08	.	.	1.091E+03	.	.	.
112	17-03	02SEP82	231.758	7.40	.	.	1.088E+03	.	.	.
113	17-03	10SEP82	232.208	7.40	.	.	9.916E+02	.	.	.
114	17-03	15SEP82	232.168	6.91	.	.	8.436E+02	.	.	.
115	17-03	21SEP82	232.148	6.77	1.100E+04	1.500E-01	1.066E+03	.	.	.
116	17-03	30SEP82	232.128	6.80	.	.	8.695E+02	.	.	.
117	17-03	06OCT82	232.108	6.45	.	.	1.025E+03	.	.	.

APPENDIX A (continued)

CONCENTRATIONS IN BU/L
DEPTH CORRECTED TO MEAN SEA LEVEL IN METERS

11:10 FRIDAY, JUNE 24, 1983 14

NUM=T7-03

OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
118	T7-03	14OCT82	232.088	7.00	.	.	1.021E+03	.	.	.
119	T7-03	20OCT82	231.708	7.06	.	.	1.043E+03	.	.	.
120	T7-03	27OCT82	232.038	6.99	.	.	9.509E+02	.	.	.
121	T7-03	27OCT82	232.038	6.99	.	.	3.518E+04	.	.	.
122	T7-03	03NOV82	232.658	7.25	7.600E+03	1.100E-01	9.805E+02	5.500E+00	7.000E-01	.
123	T7-03	10NOV82	232.078	7.09	.	.	9.731E+02	.	.	.
124	T7-03	22NOV82	232.108	7.18	7.300E+03	9.600E-01	8.029E+02	5.400E+00	6.700E-01	.
125	T7-03	04DEC82	232.188	.	.	.	.	.	.	.
126	T7-03	14DEC82	233.368	6.82	.	.	2.405E+02	.	.	.
127	T7-03	28DEC82	232.428	.	.	.	.	.	.	.
128	T7-03	07JAN83	232.518	7.13	.	.	8.066E+02	.	.	.
129	T7-03	13JAN83	232.518	.	.	.	.	.	.	.
130	T7-03	20JAN83	232.628	7.00	.	.	9.546E+02	.	.	.
131	T7-03	18FEB83	232.618	7.02	.	.	6.364E+02	.	.	.
132	T7-03	11MAR83	232.608	7.49	.	.	8.140E+02	.	.	.
133	T7-03	21MAR83	232.588	7.33	.	.	9.546E+02	.	.	.

NUM=T7-04

OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
134	T7-04	23JUL74	.	.	6.570E+04	7.000E-01	1.866E+04	.	.	.
135	T7-04	15AUG74	.	.	5.380E+04	.	1.609E+04	.	.	.
136	T7-04	20JUN75	.	.	1.245E+05	3.000E+00	1.702E+04	.	.	.
137	T7-04	07AUG81	.	5.5	.	.	5.254E+03	3.500E-02	.	.

NUM=T7-05

OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
138	T7-05	23JUL74	.	.	7.750E+04	1.000E+00	1.732E+04	.	.	.
139	T7-05	15AUG74	.	.	4.970E+04	.	1.561E+04	.	.	.
140	T7-05	20JUN75	.	.	1.165E+05	.	5.883E+03	.	.	.
141	T7-05	28DEC81	232.024	6.43	3.000E+02	5.600E-01	1.735E+03	.	.	.
142	T7-05	29JAN82	232.394	6.80	1.800E+02	5.000E-01	.	.	.	.
143	T7-05	28FEB82	232.664	6.30	1.500E+02	2.500E+01	.	.	.	.
144	T7-05	07APR82	233.014	6.70	1.400E+03	2.700E-01	.	.	.	.
145	T7-05	01JUN82	233.134	6.67	2.900E+03	1.200E-01	2.638E+03	.	.	.
146	T7-05	23JUN82	233.064	6.90	3.300E+03	1.400E+00	2.760E+03	1.400E-01	2.000E-01	.
147	T7-05	09JUL82	232.974	6.84	.	.	1.162E+03	.	.	.
148	T7-05	19JUL82	232.964	7.10	3.200E+03	5.600E-01	2.205E+03	.	.	.
149	T7-05	02AUG82	232.864	6.50	.	.	1.406E+03	.	.	.
150	T7-05	11AUG82	232.834	6.68	.	.	9.546E+02	.	.	.
151	T7-05	18AUG82	232.824	7.70	4.400E+02	1.200E-01	3.404E+02	1.000E-01	1.100E-02	.
152	T7-05	25AUG82	232.814	6.51	.	.	1.384E+03	.	.	.
153	T7-05	02SEP82	232.944	6.69	.	.	7.992E+02	.	.	.
154	T7-05	10SEP82	232.764	6.59	.	.	1.184E+03	.	.	.
155	T7-05	15SEP82	232.694	6.71	.	.	1.471E+03	.	.	.
156	T7-05	21SEP82	232.664	6.38	1.100E+03	2.200E-01	1.351E+03	2.800E-01	1.700E-01	.
157	T7-05	30SEP82	232.614	7.00	.	.	1.284E+03	.	.	.
158	T7-05	06OCT82	232.614	6.25	.	.	1.480E+03	.	.	.

APPENDIX A (continued)

11:10 FRIDAY, JUNE 24, 1983 15

CONCENTRATIONS IN BU/L
DEPTH CORRECTED TO MEAN SEA LEVEL IN METERS

NUM=T7-05

UBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
159	T7-05	14OCT82	232.584	6.26	.	.	8.177E+02	.	.	.
160	T7-05	20OCT82	232.594	6.20	.	.	1.476E+03	.	.	.
161	T7-05	27OCT82	232.564	6.00	.	.	1.343E+03	.	.	.
162	T7-05	27OCT82	232.564	6.00	.	.	4.969E+04	.	.	.
163	T7-05	03NOV82	232.574	5.95	2.300E+02	3.500E-01	1.295E+02	9.700E-02	1.400E-02	.
164	T7-05	10NOV82	232.534	6.22	.	.	1.169E+03	.	.	.
165	T7-05	22NOV82	232.634	6.50	4.900E+02	5.000E-01	2.442E+02	1.000E-01	5.500E-02	.
166	T7-05	14DEC82	232.834	6.20	.	.	4.070E+02	.	.	.
167	T7-05	28DEC82	232.834	.	.	.	.	.	.	.
168	T7-05	07JAN83	232.854	6.31	.	.	7.622E+02	.	.	.
169	T7-05	13JAN83	232.814	.	.	.	.	.	.	.
170	T7-05	20JAN83	232.834	6.40	.	.	1.313E+03	.	.	.
171	T7-05	02FEB83	236.014	6.86	.	.	6.253E+01	.	.	.
172	T7-05	18FEB83	233.044	6.40	.	.	1.406E+03	.	.	.
173	T7-05	11MAR83	233.104	6.55	.	.	1.965E+03	.	.	.
174	T7-05	21MAR83	233.084	6.59	.	.	6.475E+02	.	.	.

NUM=T7-06

UBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
175	T7-06	28DEC81	233.01	6.15	5.600E+01	1.100E+00	3.219E+01	.	.	.
176	T7-06	29JAN82	233.29	6.50	7.900E+01	6.000E-01	.	.	.	.
177	T7-06	28FEB82	233.69	6.60	5.600E+01	5.000E+01	.	.	.	.
178	T7-06	07APR82	233.91	7.00	6.500E+01	4.900E-01	.	.	.	.
179	T7-06	23JUN82	233.21	7.15	1.400E+02	1.200E+00	4.810E+00	.	.	.
180	T7-06	19JUL82	233.10	7.00	3.300E+01	2.800E-01	3.700E+00	.	.	.
181	T7-06	21SEP82	232.91	6.25	1.000E+02	2.600E-01	5.550E+00	1.600E-01	6.600E-02	.
182	T7-06	03NOV82	233.89	6.31	7.300E+01	3.600E-01	0.000E+00	6.400E-02	1.100E-02	.
183	T7-06	22NOV82	233.87	5.48	9.600E+01	4.200E-01	0.000E+00	4.500E-02	3.000E-02	.
184	T7-06	07JAN83	233.64	.	.	.	.	.	.	.
185	T7-06	13JAN83	233.73	.	.	.	.	.	.	.
186	T7-06	20JAN83	233.51	.	.	.	.	.	.	.

NUM=T7-09

UBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
187	T7-09	26JUN74	.	6.6	1.050E+04	2.000E+00	9.694E+03	.	.	.
188	T7-09	12JUL74	.	6.6	1.210E+04	.	1.091E+04	.	.	.
189	T7-09	23JUL74	.	6.5	1.200E+04	.	1.121E+04	.	.	.
190	T7-09	15AUG74	.	.	1.130E+04	.	1.251E+04	.	.	.
191	T7-09	20JUN75	.	.	3.800E+04	.	9.250E+02	.	.	.
192	T7-09	20FEB81	.	.	.	.	8.880E+01	4.000E-03	5.000E-04	.

APPENDIX A (continued)

CONCENTRATIONS IN BU/L
DEPTH CORRECTED TO MEAN SEA LEVEL IN METERS

11:10 FRIDAY, JUNE 24, 1983 16

NUM=T7-10

Obs	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
193	T7-10	26JUN74	.	7.30	1.053E+04	.	2.257E+02	.	.	.
194	T7-10	12JUL74	.	7.10	6.900E+02	.	1.850E+02	.	.	.
195	T7-10	23JUL74	.	6.70	.	.	2.405E+02	.	.	.
196	T7-10	15AUG74	.	.	1.862E+04	.	2.886E+02	.	.	.
197	T7-10	20JUN75	.	.	1.200E+04	2.000E+00	3.626E+03	.	.	.
198	T7-10	07AUG81	232.063	6.80	.	.	1.369E+02	3.000E-03	.	.
199	T7-10	31AUG81	232.213	6.50	.	.	1.439E+02	1.200E-02	.	.
200	T7-10	28DEC81	232.243	6.33	2.500E+03	1.700E+00	.	.	.	.
201	T7-10	29JAN82	232.303	6.50	3.400E+03	1.600E+00	4.070E+01	.	.	.
202	T7-10	28FEB82	232.473	6.40	2.600E+03	1.000E+00	.	.	.	.
203	T7-10	07APR82	231.713	6.90	1.700E+03	9.000E-01	.	.	.	.
204	T7-10	23APR82	232.363	6.53	1.800E+03	1.100E+00	9.065E+01	1.800E-01	1.000E-02	.
205	T7-10	29APR82	231.963	6.75	.	.	1.857E+02	.	.	.
206	T7-10	01JUN82	232.403	6.13	4.000E+03	1.600E+01	1.843E+03	.	.	.
207	T7-10	23JUN82	232.343	6.30	5.400E+03	1.700E+00	2.379E+02	.	.	.
208	T7-10	19JUL82	232.343	7.00	4.000E+03	4.200E-01	1.676E+02	.	.	.
209	T7-10	18AUG82	232.303	7.20	5.200E+03	5.700E-01	1.221E+02	5.200E-01	8.600E-02	.
210	T7-10	21SEP82	231.963	6.33	7.000E+03	6.200E-01	1.426E+02	1.000E-01	4.200E-02	.
211	T7-10	03NOV82	232.193	6.47	1.900E+02	2.800E+00	1.961E+01	4.300E-02	9.000E-03	.
212	T7-10	22NOV82	232.263	6.75	2.100E+02	2.600E+00	0.000E+00	3.000E-02	3.000E-02	.
213	T7-10	20JAN83	232.383	.	.	.	.	.	.	.

NUM=T7-13

Obs	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
214	T7-13	15AUG74	.	.	6.850E+04	.	1.066E+04	.	.	.
215	T7-13	20JUN75	.	.	4.767E+04	1.000E+00	1.014E+04	.	.	.
216	T7-13	22FEB80	.	8.20	.	.	.	3.530E+00	4.000E-01	.
217	T7-13	16DEC80	.	7.60	.	.	1.295E+03	6.500E+00	7.600E-01	.
218	T7-13	20FEB81	.	8.30	.	.	7.918E+02	6.620E+00	7.800E-01	.
219	T7-13	03APR81	232.454	9.10	.	.	8.606E+02	1.023E+01	1.270E+00	.
220	T7-13	03APR81	232.454	9.10	.	.	3.258E+04	1.023E+01	1.270E+00	.
221	T7-13	22APR81	.	.	.	.	.	9.600E+00	.	.
222	T7-13	07MAY81	.	8.30	7.420E+03	.	1.687E+03	1.539E+01	1.610E+00	.
223	T7-13	15MAY81	232.344	7.60	.	.	1.569E+03	.	.	.
224	T7-13	19MAY81	232.474	7.70	.	.	1.421E+03	.	.	.
225	T7-13	29MAY81	232.424	7.80	.	.	1.443E+03	.	.	.
226	T7-13	09JUN81	232.564	7.50	.	.	5.402E+02	5.640E+00	6.600E-01	.
227	T7-13	26JUN81	.	.	.	.	1.225E+03	9.440E+00	1.110E+00	.
228	T7-13	07JUL81	.	7.70	.	.	.	5.100E+00	.	.
229	T7-13	17JUL81	232.244	7.80	.	.	1.202E+03	6.600E+00	.	.
230	T7-13	31JUL81	.	7.60	.	.	.	4.300E+00	.	.
231	T7-13	07AUG81	232.244	7.70	.	.	1.243E+03	5.130E+00	.	.
232	T7-13	31AUG81	232.104	7.60	.	.	9.583E+02	4.330E+00	.	.
233	T7-13	21SEP81	.	.	.	.	3.404E+02	.	.	.
234	T7-13	19NOV81	232.254	7.60	8.200E+03	5.100E-01	1.006E+03	5.700E+00	7.000E-01	.
235	T7-13	16DEC81	232.404	8.00	.	.	6.919E+02	1.100E+01	1.300E+00	.
236	T7-13	28DEC81	232.444	8.01	1.000E+03	2.600E-01	4.299E+02	9.100E-01	1.500E-01	.
237	T7-13	04JAN82	232.674	7.00	.	.	1.891E+02	.	.	.
238	T7-13	07JAN82	232.674	7.60	.	.	3.315E+02	.	.	.
239	T7-13	08JAN82	232.674	7.71	.	.	3.737E+02	.	.	.

APPENDIX A (continued)

CONCENTRATIONS IN BO/L
DEPTH CORRECTED TO MEAN SEA LEVEL IN METERS

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NUM=T7-13

OBS	NUM	DATE	DEPTH	PH	M3	SR90	CD60	U233	U232	CS137
240	T7-13	13JAN82	232.574	7.87	.	.	4.810E+02	.	.	.
241	T7-13	21JAN82	.	.	.	.	1.580E+02	.	.	.
242	T7-13	28JAN82	232.474	7.63	.	.	3.996E+02	.	.	.
243	T7-13	29JAN82	232.474	7.83	1.400E+03	3.000E-01	4.000E+02	2.800E+00	3.400E-01	.
244	T7-13	04FEB82	.	6.70	.	.	2.146E+02	.	.	.
245	T7-13	11FEB82	232.484	7.50	8.800E+02	1.000E-02	3.548E+02	4.300E+00	3.600E-01	.
246	T7-13	19FEB82	232.504	7.74	.	.	3.663E+02	.	.	.
247	T7-13	25FEB82	232.474	7.31	.	.	5.809E+02	.	.	.
248	T7-13	28FEB82	232.544	7.88	1.900E+03	3.700E-01	5.809E+02	6.000E+00	6.200E-01	.
249	T7-13	04MAR82	232.544	7.77	.	.	9.435E+02	7.000E+00	6.800E-01	.
250	T7-13	11MAR82	232.554	7.71	.	.	4.477E+02	.	.	.
251	T7-13	19MAR82	232.604	7.31	.	.	4.292E+02	.	.	.
252	T7-13	26MAR82	232.574	.	.	.	5.180E+02	.	.	.
253	T7-13	01APR82	232.654	7.81	.	.	2.597E+02	.	.	.
254	T7-13	07APR82	232.554	7.47	1.800E+03	1.600E-01	1.506E+03	1.200E+01	1.100E+00	.
255	T7-13	16APR82	232.554	.	.	.	1.099E+03	.	.	.
256	T7-13	23APR82	232.564	7.90	7.800E+03	1.300E-01	1.239E+03	1.100E+01	1.200E+00	.
257	T7-13	29APR82	232.494	7.94	.	.	6.845E+02	.	.	.
258	T7-13	14MAY82	232.534	7.71	.	.	1.447E+03	.	.	.
259	T7-13	20MAY82	232.524	7.70	.	.	1.510E+03	1.600E+01	1.800E+00	.
260	T7-13	21MAY82	232.534	6.07	.	.	1.702E+03	1.600E+01	1.900E+00	.
261	T7-13	01JUN82	232.544	7.61	.	.	1.709E+03	1.800E+01	2.100E+00	.
262	T7-13	04JUN82	232.544	7.14	.	.	1.609E+03	.	.	.
263	T7-13	10JUN82	232.514	7.37	.	.	1.880E+03	1.600E+01	2.300E+00	.
264	T7-13	17JUN82	232.524	7.95	.	.	1.839E+03	.	.	.
265	T7-13	23JUN82	232.514	7.90	1.100E+04	4.000E-01	1.920E+03	1.500E+01	1.600E+00	.
266	T7-13	09JUL82	232.424	8.26	.	.	1.828E+03	.	.	.
267	T7-13	19JUL82	232.424	8.06	1.500E+04	3.000E-01	1.828E+03	1.700E+01	.	.
268	T7-13	26JUL82	232.374	8.40	.	.	1.854E+03	.	.	.
269	T7-13	02AUG82	232.454	7.67	.	.	1.902E+03	.	.	.
270	T7-13	11AUG82	232.524	8.06	.	.	1.846E+03	.	.	.
271	T7-13	18AUG82	232.354	7.70	1.600E+04	1.600E-01	1.595E+03	1.500E+01	1.700E+00	.
272	T7-13	25AUG82	232.304	7.16	.	.	1.702E+03	.	.	.
273	T7-13	02SEP82	232.254	7.54	.	.	1.991E+03	.	.	.
274	T7-13	10SEP82	232.504	7.47	.	.	1.735E+03	.	.	.
275	T7-13	15SEP82	232.234	7.29	.	.	1.643E+03	.	.	.
276	T7-13	21SEP82	232.104	.	.	.	.	.	.	.
277	T7-13	10NOV82	232.514	7.86	.	.	1.543E+03	.	.	.
278	T7-13	22NOV82	232.674	8.06	9.300E+03	1.100E-01	1.332E+03	1.500E+01	1.800E+00	.
279	T7-13	18DEC82	233.104	7.95	.	.	4.773E+02	.	.	.
280	T7-13	07JAN83	.	8.04	.	.	7.770E+02	.	.	.
281	T7-13	13JAN83	232.624	.	.	.	.	.	.	.
282	T7-13	20JAN83	232.554	.	.	.	.	.	.	.
283	T7-13	02FEB83	232.704	7.79	.	.	1.073E+03	.	.	.
284	T7-13	18FEB83	232.584	8.14	.	.	1.251E+03	.	.	.
285	T7-13	11MAR83	232.564	8.31	.	.	1.051E+03	.	.	.

APPENDIX A (continued)

CONCENTRATIONS IN BG/L
DEPTH CORRECTED TO MEAN SEA LEVEL IN METERS

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NUM=T7-15										
OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
286	T7-15	15AUG74	.	.	3.930E+04	.	3.034E+03	.	.	.
287	T7-15	20JUN75	.	.	4.830E+03	1.000E+00	9.990E+01	.	.	.
288	T7-15	20FEB81	.	7	.	.	2.220E+01	1.000E-02	1.000E-03	.
NUM=T7-20										
OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
289	T7-20	23APR82	231.001	9.08	6.100E+03	4.700E-01	8.325E+02	6.500E+00	1.000E+00	.
290	T7-20	29APR82	232.611	8.90	.	.	7.696E+02	.	.	.
291	T7-20	11MAY82	232.691	.	.	.	.	.	.	.
292	T7-20	14MAY82	232.571	.	.	.	.	.	.	.
293	T7-20	21MAY82	232.501	.	.	.	.	.	.	.
294	T7-20	04JUN82	232.421	.	.	.	.	.	.	.
295	T7-20	10JUN82	232.311	8.73	.	.	8.140E+02	8.500E+00	9.000E-01	.
296	T7-20	17JUN82	232.361	8.95	.	.	9.435E+02	.	.	.
297	T7-20	23JUN82	232.231	9.10	3.500E+03	3.400E+00	9.916E+02	1.500E+01	2.000E+00	.
298	T7-20	09JUL82	231.911	9.10	.	.	1.029E+03	.	.	.
299	T7-20	19JUL82	231.831	8.86	2.400E+03	8.100E-01	9.435E+02	5.900E+00	.	.
300	T7-20	26JUL82	231.811	9.30	.	.	1.006E+03	.	.	.
301	T7-20	02AUG82	231.801	8.51	.	.	8.954E+02	.	.	.
302	T7-20	11AUG82	231.811	8.60	.	.	8.251E+02	.	.	.
303	T7-20	18AUG82	231.731	7.81	4.300E+03	6.300E-01	7.696E+02	1.600E+01	2.500E+00	.
304	T7-20	25AUG82	231.731	7.04	.	.	7.511E+02	.	.	.
305	T7-20	02SEP82	231.731	7.52	.	.	6.253E+02	.	.	.
306	T7-20	10SEP82	231.731	6.82	.	.	6.216E+02	.	.	.
307	T7-20	15SEP82	231.731	6.85	.	.	6.949E+02	.	.	.
308	T7-20	21SEP82	231.691	7.56	7.000E+03	4.500E-01	1.873E+03	1.600E+01	2.300E+00	.
309	T7-20	30SEP82	231.661	7.40	.	.	5.476E+02	.	.	.
310	T7-20	06OCT82	231.621	7.00	.	.	7.881E+02	.	.	.
311	T7-20	14OCT82	231.711	7.01	.	.	6.512E+02	.	.	.
312	T7-20	20OCT82	231.611	7.56	.	.	6.623E+02	.	.	.
313	T7-20	27OCT82	231.611	7.40	.	.	4.033E+02	.	.	.
314	T7-20	27OCT82	231.611	7.40	.	.	1.492E+04	.	.	.
315	T7-20	03NOV82	231.631	7.58	7.500E+03	2.400E-01	5.454E+02	.	.	.
316	T7-20	10NOV82	231.611	7.59	.	.	5.661E+02	.	.	.
317	T7-20	22NOV82	231.631	7.68	5.900E+03	3.600E-01	5.994E+02	1.600E+01	1.400E-01	.
318	T7-20	14DEC82	232.001	7.46	.	.	3.959E+02	.	.	.
319	T7-20	28DEC82	232.251	.	.	.	.	.	.	.
320	T7-20	07JAN83	232.361	8.54	.	.	.	.	.	.
321	T7-20	13JAN83	232.321	.	.	.	5.513E+02	.	.	.
322	T7-20	20JAN83	232.341	8.80	.	.	.	.	.	.
323	T7-20	02FEB83	232.431	8.30	.	.	6.512E+02	.	.	.
324	T7-20	18FEB83	232.521	9.40	.	.	6.512E+02	.	.	.
325	T7-20	11MAR83	232.501	9.57	.	.	8.658E+02	.	.	.
326	T7-20	21MAR83	232.541	9.58	.	.	8.473E+02	.	.	.
							9.546E+02	.	.	.

APPENDIX A (continued)

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CONCENTRATIONS IN BQ/L
DEPTH CORRECTED TO MEAN SEA LEVEL IN METERS

NUM=17-21

OBS	NUM	DATE	DEPTH	PH	M3	SR90	CO60	U233	U232	CS137
327	17-21	23APR82	231.148	6.90	2.200E+04	2.300E-01	2.676E+03	1.600E+00	2.700E-01	.
328	17-21	29APR82	231.298	6.90	.	.	.	.	.	.
329	17-21	10MAY82	231.268	.	.	.	.	.	.	.
330	17-21	14MAY82	231.218	.	.	.	.	.	.	.
331	17-21	21MAY82	231.228	.	.	.	.	.	.	.
332	17-21	04JUN82	231.228	.	.	.	.	.	.	.
333	17-21	10JUN82	231.208	.	.	.	.	.	.	.
334	17-21	17JUN82	231.218	.	.	.	.	.	.	.
335	17-21	23JUN82	231.118	7.00	3.100E+04	2.100E+00	2.475E+03	.	.	.
336	17-21	09JUL82	231.108	.	.	.	.	.	.	.
337	17-21	19JUL82	231.148	7.08	2.900E+04	1.400E-01	2.338E+03	6.600E-01	.	.
338	17-21	28JUL82	231.118	.	.	.	.	.	.	.
339	17-21	02AUG82	231.148	.	.	.	.	.	.	.
340	17-21	11AUG82	231.178	.	.	.	.	.	.	.
341	17-21	18AUG82	231.148	6.10	2.600E+04	2.500E-01	1.757E+03	2.000E-01	1.100E-02	.
342	17-21	25AUG82	231.148	.	.	.	.	.	.	.
343	17-21	03SEP82	231.178	.	.	.	.	.	.	.
344	17-21	10SEP82	231.128	.	.	.	.	.	.	.
345	17-21	16SEP82	231.128	.	.	.	.	.	.	.
346	17-21	21SEP82	230.828	6.74	2.600E+04	5.900E-01	1.584E+03	4.900E-01	1.200E-01	.
347	17-21	30SEP82	231.048	.	.	.	.	.	.	.
348	17-21	06OCT82	231.048	.	.	.	.	.	.	.
349	17-21	14OCT82	231.048	.	.	.	.	.	.	.
350	17-21	20OCT82	231.068	6.76	.	.	1.991E+03	.	.	.
351	17-21	27OCT82	231.068	6.87	.	.	1.920E+03	.	.	.
352	17-21	27OCT82	231.068	6.87	.	.	7.105E+04	.	.	.
353	17-21	03NOV82	231.078	6.86	2.700E+04	2.200E-01	1.720E+03	3.400E-01	4.400E-02	1.110E+01
354	17-21	10NOV82	231.078	6.87	.	.	1.043E+03	.	.	.
355	17-21	22NOV82	231.198	6.87	3.000E+04	1.100E+00	1.857E+03	4.300E-01	4.500E-02	3.700E+01
356	17-21	26DEC82	231.278	.	.	.	.	.	.	.
357	17-21	07JAN83	231.218	6.51	.	.	6.177E+02	.	.	.
358	17-21	13JAN83	231.248	.	.	.	.	.	.	.
359	17-21	20JAN83	231.218	.	.	.	.	.	.	.
360	17-21	02FEB83	231.448	6.77	.	.	1.439E+03	.	.	.
361	17-21	18FEB83	231.308	6.61	.	.	1.339E+03	.	.	.
362	17-21	11MAR83	231.328	6.92	.	.	1.495E+03	.	.	.

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NUM=17-22

OBS	NUM	DATE	DEPTH	PH	M3	SR90	CO60	U233	U232	CS137
363	17-22	23APR82	231.516	7.63	3.200E+04	4.000E-02	1.088E+03	3.000E-01	1.000E-02	.
364	17-22	29APR82	231.626	7.40	.	.	1.017E+03	.	.	.
365	17-22	23JUN82	231.556	7.70	1.200E+04	1.000E+00	1.165E+03	.	.	.
366	17-22	19JUL82	231.566	7.25	1.000E+04	1.800E-01	1.206E+03	.	.	.
367	17-22	18AUG82	231.456	8.00	1.000E+04	3.000E-02	1.095E+03	3.600E+00	5.200E-01	.
368	17-22	21SEP82	231.476	7.72	1.100E+04	2.100E-01	1.077E+03	3.700E+00	5.800E-01	.
369	17-22	03NOV82	231.516	7.77	1.100E+04	3.500E-01	8.880E+02	3.100E+00	4.000E-01	.
370	17-22	22NOV82	231.536	7.79	1.200E+04	8.000E-02	8.325E+02	2.600E+00	3.300E-01	0.000E+00
371	17-22	07JAN83	231.656	.	.	.	.	.	.	.
372	17-22	13JAN83	231.616	.	.	.	.	.	.	.
373	17-22	20JAN83	231.606	.	.	.	.	.	.	.

APPENDIX A (continued)

CONCENTRATIONS IN BU/L
DEPTH CORRECTED TO MEAN SEA LEVEL IN METERS

11:10 FRIDAY, JUNE 24, 1983 20

NUM=T7-23

UBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
374	T7-23	23APR82	230.33	7.13	7.900E+03	4.600E-01	3.700E+00	1.400E-01	5.000E-03	.
375	T7-23	29APR82	232.27	7.23	.	.	3.700E+00	.	.	.
376	T7-23	03MAY82	232.31	.	.	.	.	.	.	.
377	T7-23	16MAY82	232.28	.	.	.	.	.	.	.
378	T7-23	14MAY82	232.27	.	.	.	.	.	.	.
379	T7-23	21MAY82	232.24	.	.	.	.	.	.	.
380	T7-23	04JUN82	232.19	.	.	.	.	.	.	.
381	T7-23	10JUN82	232.16	.	.	.	.	.	.	.
382	T7-23	17JUN82	232.10	.	.	.	.	.	.	.
383	T7-23	23JUN82	232.03	7.40	1.100E+04	1.400E+00	6.290E+00	.	.	.
384	T7-23	09JUL82	231.84	.	.	.	.	.	.	4.070E+00
385	T7-23	19JUL82	231.88	7.03	1.000E+04	8.800E-01	3.700E+00	.	.	.
386	T7-23	28JUL82	231.88	.	.	.	.	.	.	.
387	T7-23	02AUG82	231.96	.	.	.	.	.	.	.
388	T7-23	11AUG82	231.96	.	.	.	.	.	.	.
389	T7-23	16AUG82	231.96	.	1.000E+04	5.200E-01	0.000E+00	1.400E-01	5.500E-02	.
390	T7-23	25AUG82	231.96	.	.	.	.	.	.	.
391	T7-23	03SEP82	231.97	.	.	.	.	.	.	.
392	T7-23	10SEP82	231.96	.	.	.	.	.	.	.
393	T7-23	16SEP82	231.96	.	.	.	.	.	.	.
394	T7-23	21SEP82	231.16	7.75	1.200E+04	9.800E-01	0.000E+00	1.000E-01	1.000E-01	.
395	T7-23	30SEP82	231.62	.	.	.	.	.	.	.
396	T7-23	06OCT82	231.69	.	.	.	.	.	.	.
397	T7-23	14OCT82	231.85	.	.	.	.	.	.	.
398	T7-23	20OCT82	231.91	.	.	.	.	.	.	.
399	T7-23	27OCT82	231.66	.	.	.	.	.	.	.
400	T7-23	03NOV82	231.93	7.24	1.100E+04	9.600E-01	0.000E+00	1.100E-01	2.400E-02	.
401	T7-23	10NOV82	231.94	.	.	.	.	.	.	.
402	T7-23	22NOV82	231.99	7.26	1.300E+04	5.800E-01	0.000E+00	1.600E-01	1.100E-01	.
403	T7-23	28DEC82	232.26	.	.	.	.	.	.	.
404	T7-23	07JAN83	232.22	.	.	.	.	.	.	.
405	T7-23	13JAN83	232.18	.	.	.	.	.	.	.
406	T7-23	20JAN83	232.16	.	.	.	.	.	.	.

NUM=T7-24

UBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
407	T7-24	23APR82	232.40	7.30	1.200E+04	4.200E-01	2.176E+03	2.300E+00	2.860E-01	.
408	T7-24	29APR82	232.61	7.48	.	.	1.017E+03	.	.	.
409	T7-24	10MAY82	232.00	.	.	.	.	.	.	.
410	T7-24	14MAY82	232.64	.	.	.	.	.	.	.
411	T7-24	21MAY82	232.61	.	.	.	.	.	.	.
412	T7-24	01JUN82	232.56	.	.	.	.	.	.	.
413	T7-24	04JUN82	232.56	.	.	.	1.413E+03	.	.	.
414	T7-24	10JUN82	232.51	8.28	.	.	.	.	.	.
415	T7-24	17JUN82	232.44	8.36	.	.	1.450E+03	6.300E+00	7.200E-01	.
416	T7-24	23JUN82	232.41	7.80	1.200E+04	5.400E-01	1.158E+03	.	.	.
417	T7-24	09JUL82	232.37	8.11	.	.	1.402E+03	6.700E+00	8.200E-01	.
418	T7-24	19JUL82	232.33	8.11	6.700E+03	3.300E-01	1.402E+03	.	.	.
419	T7-24	26JUL82	232.36	9.30	.	.	1.454E+03	1.100E+01	.	.
420	T7-24	02AUG82	232.39	8.79	.	.	1.572E+03	.	.	.
							1.495E+03	.	.	.

APPENDIX A (continued)

CONCENTRATIONS IN 80/L
DEPTH CORRECTED TO MEAN SEA LEVEL IN METERS

11:10 FRIDAY, JUNE 24, 1983 21

NUM=T7-24

UDS	NUM	DATE	DEPTH	PH	H3	SR90	CD60	U233	U232	CS137
421	T7-24	11AUG82	232.42	8.79	.	.	1.140E+03	.	.	.
422	T7-24	18AUG82	232.46	7.21	7.700E+03	1.900E-01	1.421E+03	1.100E+01	1.700E+00	.
423	T7-24	25AUG82	232.49	7.09	.	.	1.402E+03	.	.	.
424	T7-24	02SEP82	232.51	8.02	.	.	1.225E+03	.	.	.
425	T7-24	03SEP82	232.56	.	.	.	.	.	.	.
426	T7-24	10SEP82	232.54	7.16	.	.	1.132E+03	.	.	.
427	T7-24	16SEP82	232.47	.	.	.	1.214E+03	.	.	.
428	T7-24	21SEP82	232.41	8.72	6.100E+03	6.600E-01	1.195E+03	1.200E+01	1.700E-01	.
429	T7-24	30SEP82	232.41	8.58	.	.	1.214E+03	.	.	.
430	T7-24	02OCT82	232.43	.	.	.	.	.	.	.
431	T7-24	06OCT82	232.43	8.45	.	.	1.291E+03	.	.	.
432	T7-24	14OCT82	232.41	7.32	.	.	1.247E+03	.	.	.
433	T7-24	20OCT82	232.41	.	.	.	.	.	.	.
434	T7-24	27OCT82	232.43	.	.	.	.	.	.	.
435	T7-24	03NOV82	232.39	8.74	6.000E+03	1.600E-01	9.798E+02	1.200E+01	1.700E+00	.
436	T7-24	10NOV82	232.40	.	.	.	.	.	.	.
437	T7-24	22NOV82	232.42	8.54	8.900E+03	2.000E-01	1.095E+03	1.040E+01	1.500E+00	.
438	T7-24	14DEC82	232.52	8.14	.	.	6.734E+02	.	.	.
439	T7-24	28DEC82	232.57	.	.	.	.	.	.	.
440	T7-24	07JAN83	232.62	8.29	.	.	7.844E+02	.	.	.
441	T7-24	13JAN83	232.73	.	.	.	.	.	.	.
442	T7-24	20JAN83	232.73	8.74	.	.	8.251E+02	.	.	.
443	T7-24	02FEB83	232.74	7.49	.	.	7.992E+02	.	.	.
444	T7-24	16FEB83	232.83	8.76	.	.	8.695E+02	.	.	.
445	T7-24	11MAR83	232.80	6.99	.	.	9.509E+02	.	.	.

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NUM=T7-25

UDS	NUM	DATE	DEPTH	PH	H3	SR90	CD60	U233	U232	CS137
446	T7-25	23APR82	233.119	8.88	1.200E+04	5.000E+00	1.817E+03	1.500E+01	2.000E+00	.
447	T7-25	29APR82	233.369	8.70	.	.	1.861E+03	.	.	.
448	T7-25	11MAY82	233.279	.	.	.	.	.	.	.
449	T7-25	14MAY82	233.249	.	.	.	.	.	.	.
450	T7-25	21MAY82	233.189	.	.	.	.	.	.	.
451	T7-25	04JUN82	233.069	.	.	.	.	.	.	.
452	T7-25	10JUN82	233.069	.	.	.	.	.	.	.
453	T7-25	17JUN82	233.059	.	.	.	.	.	.	.
454	T7-25	23JUN82	232.959	8.30	6.300E+03	1.300E+00	1.332E+03	.	.	.
455	T7-25	09JUL82	232.849	.	.	.	.	.	.	.
456	T7-25	19JUL82	232.899	7.98	5.600E+03	1.600E+00	9.398E+02	.	.	.
457	T7-25	28JUL82	232.899	.	.	.	.	.	.	.
458	T7-25	02AUG82	232.879	.	.	.	.	.	.	.
459	T7-25	11AUG82	232.869	.	.	.	.	.	.	.
460	T7-25	18AUG82	232.849	.	5.200E+03	1.400E+00	9.398E+02	1.600E+01	2.400E+00	.
461	T7-25	25AUG82	232.849	.	.	.	.	.	.	.
462	T7-25	03SEP82	232.749	.	.	.	.	.	.	.
463	T7-25	10SEP82	232.829	.	.	.	.	.	.	.
464	T7-25	16SEP82	232.799	.	.	.	.	.	.	.
465	T7-25	21SEP82	232.709	8.49	6.200E+03	2.200E+00	1.009E+03	1.500E+01	2.300E+00	.
466	T7-25	30SEP82	232.699	.	.	.	.	.	.	.
467	T7-25	06OCT82	232.699	.	.	.	.	.	.	.

APPENDIX A (continued)

CONCENTRATIONS IN BG/L
DEPTH CORRECTED TO MEAN SEA LEVEL IN METERS

11:10 FRIDAY, JUNE 24, 1983 22

NUM=T7-25

OBS	NUM	DATE	DEPTH	PH	M3	SR90	CO60	U233	U232	CS137
468	T7-25	14OCT82	232.669	.	.	.	.	.	.	.
469	T7-25	20OCT82	232.599	8.40	.	.	1.021E+03	.	.	.
470	T7-25	27OCT82	232.599	8.48	.	.	1.054E+03	.	.	.
471	T7-25	27OCT82	232.599	8.48	.	.	3.902E+04	.	.	.
472	T7-25	03NOV82	232.669	8.41	4.300E+03	1.100E+00	6.808E+02	1.100E+01	1.600E+00	.
473	T7-25	10NOV82	232.619	7.40	.	.	3.034E+02	.	.	.
474	T7-25	22NOV82	232.699	7.43	2.100E+03	2.200E+00	3.071E+02	4.600E+00	6.900E-01	.
475	T7-25	26DEC82	233.069	.	.	.	.	.	.	.
476	T7-25	07JAN83	233.129	.	.	.	.	.	.	.
477	T7-25	13JAN83	233.119	.	.	.	.	.	.	.
478	T7-25	20JAN83	233.149	.	.	.	.	.	.	.

NUM=T7-26

OBS	NUM	DATE	DEPTH	PH	M3	SR90	CO60	U233	U232	CS137
479	T7-26	04MAR82	238.201	.	.	.	.	.	.	.
480	T7-26	11MAR82	238.551	.	.	.	.	.	.	.
481	T7-26	19MAR82	239.031	.	.	.	.	.	.	.
482	T7-26	26MAR82	239.341	.	.	.	.	.	.	.
483	T7-26	08APR82	239.491	.	.	.	.	.	.	.
484	T7-26	16APR82	239.211	.	.	.	.	.	.	.
485	T7-26	23APR82	238.941	7.42	8.100E+01	7.100E+01	3.700E+00	1.200E-01	2.100E-02	.
486	T7-26	29APR82	238.891	.	.	.	.	.	.	.
487	T7-26	11MAY82	238.721	.	.	.	.	.	.	.
488	T7-26	14MAY82	238.621	.	.	.	.	.	.	.
489	T7-26	21MAY82	238.451	.	.	.	.	.	.	.
490	T7-26	04JUN82	238.161	.	.	.	.	.	.	.
491	T7-26	10JUN82	238.051	.	.	.	.	.	.	.
492	T7-26	17JUN82	237.911	.	.	.	.	.	.	.
493	T7-26	23JUN82	237.771	6.70	1.200E+02	7.600E+01	3.700E+00	.	.	9.990E+00
494	T7-26	09JUL82	237.521	.	.	.	.	.	.	.
495	T7-26	19JUL82	237.421	7.24	7.300E+01	6.500E+01	3.700E+00	.	.	.
496	T7-26	26JUL82	237.311	.	.	.	.	.	.	.
497	T7-26	02AUG82	237.251	.	.	.	.	.	.	.
498	T7-26	11AUG82	237.161	.	.	.	.	.	.	.
499	T7-26	18AUG82	237.041	7.20	1.100E+02	6.200E+01	0.000E+00	1.000E-01	4.400E-02	.
500	T7-26	25AUG82	236.961	.	.	.	.	.	.	.
501	T7-26	09SEP82	236.821	.	.	.	.	.	.	.
502	T7-26	10SEP82	236.841	.	.	.	.	.	.	.
503	T7-26	15SEP82	236.761	.	.	.	.	.	.	.
504	T7-26	21SEP82	236.721	6.84	8.100E+01	7.400E+01	7.548E+01	8.000E-03	9.200E-02	.
505	T7-26	30SEP82	236.661	.	.	.	.	.	.	.
506	T7-26	06OCT82	236.501	.	.	.	.	.	.	.
507	T7-26	14OCT82	236.531	.	.	.	.	.	.	.
508	T7-26	20OCT82	236.461	.	.	.	.	.	.	.
509	T7-26	27OCT82	236.461	.	.	.	.	.	.	.
510	T7-26	03NOV82	236.421	6.85	5.300E+01	6.600E+01	0.000E+00	1.200E-01	1.500E-02	.
511	T7-26	10NOV82	236.431	.	.	.	.	.	.	.
512	T7-26	22NOV82	236.341	7.07	7.700E+01	5.900E+01	0.000E+00	1.500E-01	3.300E-02	.
513	T7-26	28DEC82	237.631	.	.	.	.	.	.	.
514	T7-26	07JAN83	237.941	.	.	.	.	.	.	.

APPENDIX A (continued)

11:10 FRIDAY, JUNE 24, 1983 23

CONCENTRATIONS IN BQ/L
DEPTH CORRECTED TO MEAN SEA LEVEL IN METERS

NUM=T7-26

OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
515	T7-26	13JAN83	237.961	:	:	:	:	:	:	:
516	T7-26	20JAN83	238.001	:	:	:	:	:	:	:

NUM=T7-27

OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
517	T7-27	22NOV82	229.666	6.56	2.100E+03	3.200E-01	0.000E+00	4.800E-01	5.800E-02	.
518	T7-27	28DEC82	233.346	.	.	.	.	.	.	.
519	T7-27	07JAN83	233.066	.	.	.	.	.	.	.
520	T7-27	13JAN83	233.126	.	.	.	.	.	.	.
521	T7-27	20JAN83	233.046	.	.	.	.	.	.	.

NUM=T7-29

OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
522	T7-29	22NOV82	234.486	6.76	1.400E+02	8.400E-01	0.000E+00	7.000E-02	1.000E-02	.
523	T7-29	28DEC82	235.308	.	.	.	.	.	.	.
524	T7-29	07JAN83	235.508	.	.	.	.	.	.	.
525	T7-29	13JAN83	235.588	.	.	.	.	.	.	.
526	T7-29	20JAN83	235.598	.	.	.	.	.	.	.

NUM=T7-3N

OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
527	T7-3N	17JUL81	.	7	.	.	1.362E+03	4.200E+00	.	.

NUM=WT7-5

OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
528	WT7-5	07AUG81	231.02	6.90	.	.	2.775E+00	1.500E-02	.	2.590E-01
529	WT7-5	26DEC81	231.13	6.65	1.300E+02	9.000E+01	9.250E+00	.	.	.
530	WT7-5	29JAN82	231.20	6.95	1.600E+02	1.100E+01	.	.	.	.
531	WT7-5	28FEB82	231.20	6.95	1.900E+02	1.400E+00	.	.	.	.
532	WT7-5	07APR82	231.17	7.01	2.400E+02	1.400E+00	.	.	.	.
533	WT7-5	01JUN82	231.18	6.99	1.200E+03	1.300E+00	6.290E+00	.	.	.
534	WT7-5	23JUN82	231.10	7.00	1.300E+03	2.200E+00	1.073E+01	.	.	.
535	WT7-5	19JUL82	231.14	6.60	9.200E+02	1.500E+00	7.400E+00	9.000E-01	1.300E-02	.
536	WT7-5	18AUG82	231.15	7.20	5.800E+02	1.200E+00	.	.	.	.
537	WT7-5	21SEP82	230.18	6.68	8.100E+03	4.000E-02	0.000E+00	.	.	.
538	WT7-5	03NOV82	231.65	6.50	2.700E+02	9.000E-01	0.000E+00	.	.	.

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APPENDIX A (continued)

CUNCENTRATIONS IN BU/L
DEPTH CORRECTED TO MEAN SEA LEVEL IN METERS

11:10 FRIDAY, JUNE 24, 1983 11

NUM=SB-01										
OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
1	SB-01	22NOV82	235.072	6.79	2.100E+02	3.900E+00	0.000E+00	4.400E-02	1.300E-02	.
2	SB-01	20JAN83	235.972	.	.	.	.	.	.	.

NUM=SB-02										
OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
3	SB-02	22NOV82	234.837	6.52	4.100E+02	1.200E+00	0.000E+00	6.300E-02	1.500E-02	.
4	SB-02	20JAN83	235.917	.	.	.	.	.	.	.

NUM=SB-04										
OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
5	SB-04	22NOV82	233.788	6.73	2.100E+02	5.200E-01	0.000E+00	6.000E-02	4.000E-03	.
6	SB-04	28DEC82	235.088	.	.	.	.	.	.	.
7	SB-04	13JAN83	235.198	.	.	.	.	.	.	.
8	SB-04	20JAN83	235.188	.	.	.	.	.	.	.

NUM=SB-06										
OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
9	SB-06	22NOV82	231.506	7.35	5.700E+01	3.600E-01	0.000E+00	4.400E-02	4.200E-02	.
10	SB-06	20JAN83	236.376	.	.	.	.	.	.	.

NUM=SEEP										
OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
11	SEEP	05MAR73	.	.	.	.	3.996E+03	.	.	.
12	SEEP	11MAY73	.	.	.	.	6.806E+03	.	.	.
13	SEEP	04JUN73	.	.	.	.	1.010E+04	.	.	.
14	SEEP	26JUN74	.	.	.	.	1.121E+04	.	.	.
15	SEEP	12JUL74	.	.	5.080E+04	2.000E+00	6.584E+03	.	.	.
16	SEEP	23JUL74	.	.	5.420E+04	.	7.696E+03	.	.	.
17	SEEP	15AUG74	.	.	5.470E+04	.	6.917E+03	.	.	.
18	SEEP	20JUN75	.	.	5.120E+04	.	7.030E+03	.	.	.
19	SEEP	22FEB80	.	7.2	1.038E+05	1.000E+00	.	.	.	.
20	SEEP	09DEC80	.	6.2	.	.	6.290E+02	3.480E+00	1.000E+00	.
21	SEEP	20FEB81	.	7.0	.	.	1.021E+03	1.100E+00	1.400E-01	.
22	SEEP	03APR81	.	6.0	.	.	9.605E+02	7.800E-01	9.000E-02	.
			.	6.5	.	.	.	.	.	.

NUM=STREM										
OBS	NUM	DATE	DEPTH	PH	H3	SR90	CO60	U233	U232	CS137
23	STREM	07AUG81	.	7.1	.	.	9.694E+02	1.200E-01	.	.
24	STREM	31AUG81	.	6.9	.	.	9.361E+02	3.000E-01	.	.

APPENDIX B
GROUNDWATER CHEMICAL CHARACTERISTICS

Well number	Date	Conductivity mhos @ 25°	pH	Total Alk CaCO ₃ ug/ml	MCO ₃ ug/ml	CO ₃ ug/ml	SO ₄ ug/ml	NO ₃ ug/ml	NO ₂ ug/ml	Cl ug/ml	Na ug/ml	K ug/ml	Hg ug/ml	Ca ug/ml	Mn ug/ml	Fa ug/ml	Co ug/ml	Zn ug/ml	Al ug/ml	Si ug/ml	PO ₄ ug/ml	Inorg C ug/ml	Org C ug/ml	Organic acid meg/ml	Total P ug/ml
Seep water	Aug 74	2.77 x 10 ⁻³	7.86	288	283	5	501	156	0.23	30	500	3.8	10.9	68	<1	<1	<1	—	<0.2	6.2	0.170	73	9.9	—	—
	Dec 80	—	7.26	120	120	<0.1	100	65	—	5.6	110	—	2.2	20	1.30	0.40	—	—	—	—	—	29	22.0	—	—
	Feb 81	—	7.95	150	150	—	124	31	—	5.6	132	1.7	3.0	27	<0.01	0.20	—	—	—	—	0.023	—	—	—	0.03
	Aug 81	—	—	—	—	—	613	168	—	—	271	3.4	41.0	213	0.63	0.02	—	0.02	—	—	0.023	—	15.0	—	0.04
T7-02	Aug 81	—	—	—	—	16	0.05	—	—	4.3	1.6	5.7	85	0.28	0.016	—	0.26	—	—	0.014	—	19.0	—	0.014	
T7-3	Aug 74	2.8 x 10 ⁻³	7.45	217	217	—	435	118	J.006	18	390	2.7	5.0	57	<1	<0.1	<0.1	—	<0.2	3.8	0.050	49	6.5	—	—
	Feb 81	—	7.55	230	230	—	124	15	—	5.4	132	1.7	3.0	27	<0.01	0.20	—	—	—	—	0.045	—	—	—	0.05
	Aug 81	—	—	—	—	—	185	38	—	—	222	1.9	6.8	51	0.02	0.08	—	0.33	—	—	0.098	—	0.7	—	0.12
	Apr 82	—	8.42	295	287	8	215	41	—	7.2	338	1.9	3.3	28	0.02	<0.002	—	—	0.006	4.1	—	66	3.1	—	0.22
Nov 82	—	7.18	—	—	—	85	—	<10	<5	200	4.1	3.0	35	0.03	0.03	<0.013	0.3	<0.058	3.5	<25	—	—	—	0.40	
T7-5	Aug 74	3.35 x 10 ⁻³	6.56	38	38	—	1047	183	0.12	23	423	3.3	54	34	3.30	0.40	0.15	—	0.2	8.7	0.047	9	2.3	0.012	—
	Nov 82	—	6.50	—	—	—	<25	—	<10	<5	17	3.3	2.9	27	0.08	0.10	<0.013	0.72	<0.058	1.1	<25	—	—	—	0.38
T7-10	Aug 74	6.1 x 10 ⁻³	7.04	100	100	—	32	45	1.8	6	36	1.4	13.2	48	<1	<0.1	<0.1	—	<0.2	9.1	0.026	24	21.9	0.010	—
	Aug 81	—	—	—	—	—	21	3	—	—	35	2.1	10.0	21	0.64	0.02	—	0.56	—	—	0.008	—	18.0	—	0.01
	Apr 82	—	8.00	177	177	<1	24	5	—	2.6	16	1.8	5.8	55	0.38	<0.002	—	—	0.002	5.7	—	37	2.3	—	0.03
	Nov 82	—	6.75	—	—	—	<25	<10	—	6	4	4.7	5.7	32	0.21	0.08	<0.013	4.5	<0.058	1.4	<25	—	—	—	<0.33
T7-13	Aug 74	3.56 x 10 ⁻³	8.33	310	300	—	495	233	0.01	16	800	4.4	0.9	8	<1	<0.1	<0.1	—	<0.1	2.2	0.310	84	19.5	0.017	—
	Feb 81	—	8.28	229	229	—	43	15	—	2.3	13	1.8	0.5	2	<0.01	0.40	—	—	—	—	0.700	60	4.6	—	0.71
	Apr 82	—	8.44	486	476	10	121	143	—	4.7	433	2.7	0.9	8	0.03	0.01	—	—	0.080	3.6	—	112	7.0	—	0.58
	Nov 82	—	8.06	—	—	—	129	—	<10	11	460	6.3	0.7	6	0.05	0.06	0.026	<0.01	<0.058	3.9	<25	—	—	—	0.65
T7-15	Aug 74	1.60 x 10 ⁻³	7.68	102	102	—	520	94	1.3	22	327	3.9	12.2	109	<1	<0.1	<0.1	—	<0.1	2.6	0.016	26	4.0	0.014	—
	Feb 81	—	7.70	37	37	—	42	2	—	2.5	30	0.7	1.7	14	0.02	<0.1	—	—	—	—	0.003	12	1.9	—	0.01
T7-20	Apr 82	—	8.70	292	252	40	155	19	—	5	155	1.9	4.9	28	0.01	0.003	—	—	0.220	2.5	—	66	6.6	—	2.30
	Nov 82	—	7.68	—	—	—	122	—	<10	7	310	5.8	4.7	27	0.04	0.029	<0.013	0.05	<0.058	2.0	<25	—	—	—	3.10
T7-21	Apr 82	—	7.92	251	251	—	813	135	—	24	301	6.8	38.0	214	0.10	0.01	—	—	0.904	8.8	—	82	4.1	—	0.04
	Nov 82	—	6.87	—	—	—	342	—	<10	30	340	5.5	26.0	200	0.43	0.04	0.047	0.23	<0.058	4.4	<25	—	—	—	<0.33
T7-22	Apr 82	—	8.13	289	289	—	294	67	—	20.6	332	4.5	14.1	82	0.14	0.01	—	—	0.028	5.0	—	67	5.9	—	0.05
	Nov 82	—	7.79	—	—	—	141	—	<10	10.0	350	5.8	4.5	31	0.03	0.03	0.017	0.04	<0.058	3.6	<25	—	—	—	0.51
T7-23	Apr 82	—	7.93	134	134	—	103	0.5	—	46	13	5.7	12.2	70	0.03	0.02	—	—	0.009	3.8	—	29	8.6	—	0.02
	Nov 82	—	7.27	—	—	—	62	—	<10	27	14	5.8	11	73	0.07	0.07	<0.013	<0.02	<0.058	3.8	<25	—	—	—	<0.33
T7-24	Apr 82	—	7.96	288	288	—	217	63	—	13.8	326	3.3	10.7	52	0.26	0.07	—	—	0.004	3.3	—	70	7.5	—	0.04
	Nov 82	—	8.54	—	—	—	172	—	<10	8.0	200	4.0	2.7	14	0.02	0.04	0.023	<0.02	<0.058	2.9	<25	—	—	—	0.92
T7-25	Apr 82	—	8.33	284	282	2	207	58	—	11.2	266	3.2	2.1	9	0.004	0.03	—	—	0.184	3.9	—	63	5.5	—	0.26
	Nov 82	—	7.43	—	—	—	50	—	<10	7	110	4.2	5.6	42	0.11	0.04	<0.013	0.22	<0.058	3.0	<25	—	—	—	0.42
T7-26	Apr 82	—	8.01	200	200	—	13	—	—	2.6	6	1.6	6.7	64	0.26	0.01	—	—	0.001	8.8	—	47	4.5	—	0.11
	Nov 82	—	7.07	—	—	—	<25	—	<10	<5	44	3.5	6.5	55	0.35	0.04	<0.013	0.40	<0.058	5.7	<25	—	—	—	<0.33
T7-27	Nov 82	—	6.56	—	—	—	<25	—	<10	<5	13	3.5	7.3	120	0.18	0.04	<0.013	0.02	<0.058	7.0	<25	—	—	—	<0.33
T7-29	Nov 82	—	6.76	—	—	—	<25	—	<10	<5	5	3.3	7.7	120	0.08	0.04	<0.013	0.04	<0.058	7.4	<25	—	—	—	<0.33
SB-1	Nov 82	—	6.79	—	—	—	<25	—	<10	<5	6	3.9	7.3	99	0.22	0.04	<0.013	<0.02	<0.058	7.7	<25	—	—	—	<0.33
SB-2	Nov 82	—	6.52	—	—	—	<25	—	<10	<5	4	3.3	6.1	71	0.05	0.03	<0.013	<0.02	<0.058	5.4	<25	—	—	—	<0.33
SB-6	Nov 82	—	6.73	—	—	—	<25	—	<10	<5	3	3.3	7.0	77	0.1	0.03	<0.013	<0.02	<0.058	8.8	<25	—	—	—	<0.33
SB-6	Nov 82	—	7.35	—	—	—	<25	—	<10	<5	46	3.3	5.6	63	0.04	0.03	<0.013	<0.02	<0.058	6.9	<25	—	—	—	<0.33

⁶⁰Co and ¹³⁷Cs CONCENTRATIONS ON SUSPENDED MATTER

----- NUM=T7-03 -----						
UBS	NUM	DATE	CO60 (Bq/L)	PCU60 (Bq/kg)	CO_KU	PCS137
1	T7-03	12JUL74	8.991E+03	.	.	.
2	T7-03	23JUL74	9.990E+03	.	.	.
3	T7-03	15AUG74	1.128E+04	.	.	.
4	T7-03	20JUN75	6.808E+03	.	.	.
5	T7-03	20FEB81	7.659E+02	7.030E+06	9178.74	.
6	T7-03	04APR81	1.069E+03	1.232E+06	1152.25	.
7	T7-03	14APR81	1.520E+03	5.180E+06	3407.98	.
8	T7-03	07MAY81	1.083E+03	3.537E+06	2101.10	.
9	T7-03	15MAY81	1.569E+03	.	.	.
10	T7-03	19MAY81	1.606E+03	.	.	.
11	T7-03	29MAY81	1.624E+03	.	.	.
12	T7-03	09JUN81	1.280E+03	1.328E+06	1037.57	.
13	T7-03	26JUN81	1.154E+03	.	.	.
14	T7-03	07JUL81	.	.	.	.
15	T7-03	17JUL81	1.365E+03	3.171E+06	2322.49	.
16	T7-03	31JUL81	.	.	.	.
17	T7-03	07AUG81	1.288E+03	2.701E+06	2097.70	.
18	T7-03	31AUG81	1.299E+03	1.950E+06	1501.42	1450
19	T7-03	21SEP81	1.140E+03	7.733E+05	678.57	.
20	T7-03	30SEP81	1.373E+03	.	.	.
21	T7-03	02NOV81	1.391E+03	.	.	.
22	T7-03	19NOV81	1.391E+03	2.216E+05	159.31	.
23	T7-03	10DEC81	1.339E+03	.	.	.
24	T7-03	26DEC81	1.200E+03	.	.	.
25	T7-03	04JAN82	1.424E+02	6.882E+05	4831.17	.
26	T7-03	08JAN82	2.142E+02	1.709E+06	7979.27	.
27	T7-03	21JAN82	2.083E+02	1.162E+05	557.73	.
28	T7-03	28JAN82	2.380E+02	1.243E+06	5209.30	.
29	T7-03	29JAN82	2.390E+02	.	.	.
30	T7-03	04FEB82	2.510E+02	6.364E+05	2529.41	.
31	T7-03	11FEB82	2.394E+02	3.715E+05	1551.78	.
32	T7-03	19FEB82	2.627E+02	2.723E+05	1036.62	.
33	T7-03	25FEB82	7.992E+02	4.440E+05	555.56	.
34	T7-03	28FEB82	7.770E+02	.	.	.
35	T7-03	04MAR82	1.106E+03	1.349E+06	1219.40	.
36	T7-03	11MAR82	1.280E+03	3.778E+06	2950.87	.
37	T7-03	19MAR82	1.254E+03	5.772E+05	460.18	.
38	T7-03	20MAR82	1.354E+03	.	.	.
39	T7-03	01APR82	1.365E+03	.	.	.
40	T7-03	07APR82	1.384E+03	.	.	.
41	T7-03	16APR82	1.558E+03	.	.	.
42	T7-03	23APR82	1.621E+03	6.327E+05	390.41	.
43	T7-03	29APR82	.	.	.	.
44	T7-03	14MAY82	1.413E+03	1.465E+06	1036.63	.
45	T7-03	21MAY82	1.450E+03	9.657E+06	6658.16	.
46	T7-03	01JUN82	1.191E+03	1.165E+06	978.26	.
47	T7-03	04JUN82	1.299E+03	1.913E+06	1472.93	.
48	T7-03	10JUN82	1.247E+03	3.885E+06	3115.73	7780
49	T7-03	17JUN82	1.265E+03	2.324E+06	1836.26	.
50	T7-03	23JUN82	1.205E+03	1.162E+06	963.19	.
51	T7-03	09JUL82	1.226E+03	2.468E+06	2015.11	.
52	T7-03	19JUL82	1.136E+03	2.213E+06	1947.88	.
53	T7-03	26JUL82	1.313E+03	1.760E+06	1354.93	.
54	T7-03	02AUG82	1.221E+03	1.228E+06	1006.06	.
55	T7-03	11AUG82	1.432E+03	8.769E+05	612.4	.
56	T7-03	18AUG82	1.228E+03	.	.	.
57	T7-03	25AUG82	1.091E+03	1.724E+06	1579.7	.
58	T7-03	02SEP82	1.088E+03	1.234E+07	11530.6	.
59	T7-03	10SEP82	9.910E+02	1.854E+06	1869.4	.
60	T7-03	15SEP82	6.436E+02	1.498E+06	1776.3	.
61	T7-03	21SEP82	1.086E+03	4.958E+06	4564.0	.
62	T7-03	30SEP82	8.895E+02	5.217E+06	5000.0	.
63	T7-03	06OCT82	1.025E+03	1.924E+06	1877.3	.
64	T7-03	14OCT82	1.021E+03	3.293E+06	3224.6	.
65	T7-03	20OCT82	1.043E+03	6.882E+05	659.6	.
66	T7-03	27OCT82	.	1.691E+06	.	.
67	T7-03	03NOV82	9.805E+02	.	.	.
68	T7-03	10NOV82	9.731E+02	3.197E+06	3285.2	.
69	T7-03	22NOV82	8.029E+02	9.953E+05	1239.6	2530
70	T7-03	10DEC82	2.405E+02	2.560E+06	10646.2	.
71	T7-03	07JAN83	8.066E+02	1.395E+06	1729.4	.
72	T7-03	20JAN83	9.546E+02	1.458E+06	1527.1	.
73	T7-03	16FEB83	6.364E+02	5.254E+06	8255.8	.
74	T7-03	11MAR83	8.140E+02	9.916E+05	1218.2	.
75	T7-03	21MAR83	9.546E+02	.	.	.

APPENDIX C (continued)

NUM=T7-05						
OBS	NUM	DATE	CO60 (Bq/L)	PCO60 (Bq/kg)	CO_KD	PCS137
76	T7-05	23JUL74	1.732E+04	.	.	.
77	T7-05	15AUG74	1.561E+04	.	.	.
78	T7-05	20JUN75	5.663E+03	.	.	.
79	T7-05	28DEC81	1.735E+03	.	.	.
80	T7-05	01JUN82	2.038E+03	.	.	.
81	T7-05	23JUN82	2.760E+03	7.215E+05	261.39	15100
82	T7-05	09JUL82	1.162E+03	3.419E+05	294.27	.
83	T7-05	19JUL82	2.205E+03	8.732E+05	395.97	.
84	T7-05	02AUG82	7.400E+03	4.625E+05	328.95	.
85	T7-05	11AUG82	9.546E+02	6.882E+05	720.93	.
86	T7-05	18AUG82	3.404E+02	.	.	.
87	T7-05	25AUG82	1.384E+03	9.509E+05	687.17	.
88	T7-05	02SEP82	7.992E+02	1.086E+06	1361.11	.
89	T7-05	10SEP82	1.184E+03	6.290E+04	53.13	.
90	T7-05	15SEP82	1.471E+03	2.109E+06	1433.24	.
91	T7-05	21SEP82	1.351E+03	1.099E+06	813.25	.
92	T7-05	30SEP82	1.284E+03	5.697E+06	5216.14	7290
93	T7-05	06OCT82	1.480E+03	1.920E+06	1297.50	.
94	T7-05	14OCT82	8.177E+02	1.676E+06	2049.77	.
95	T7-05	20OCT82	1.476E+03	8.991E+05	609.02	.
96	T7-05	27OCT82	1.343E+03	6.549E+05	487.60	.
97	T7-05	03NOV82	1.295E+02	.	.	.
98	T7-05	10NOV82	1.169E+03	1.099E+06	939.87	.
99	T7-05	22NOV82	2.442E+02	2.205E+05	903.03	.
100	T7-05	14DEC82	4.070E+02	1.702E+06	4181.82	.
101	T7-05	07JAN83	7.622E+02	3.641E+05	477.67	.
102	T7-05	20JAN83	1.313E+03	6.993E+05	532.39	.
103	T7-05	02FEB83	6.253E+01	5.624E+03	89.94	.
104	T7-05	18FEB83	1.406E+03	5.106E+06	3631.58	.
105	T7-05	11MAR83	1.965E+03	4.884E+05	248.59	.
106	T7-05	21MAR83	6.475E+02	.	.	.

NUM=T7-10						
OBS	NUM	DATE	CO60	PCO60	CO_KD	PCS137
107	T7-10	26JUN74	2.257E+02	.	.	.
108	T7-10	12JUL74	1.850E+02	.	.	.
109	T7-10	23JUL74	2.405E+02	.	.	.
110	T7-10	15AUG74	2.886E+02	.	.	.
111	T7-10	20JUN75	3.626E+03	.	.	.
112	T7-10	07AUG81	1.369E+02	4.884E+04	356.757	.
113	T7-10	31AUG81	1.439E+02	6.845E+04	475.578	.
114	T7-10	28DEC81	4.070E+01	.	.	.
115	T7-10	23APR82	9.065E+01	2.423E+04	267.347	.
116	T7-10	29APR82	1.857E+02	3.249E+04	174.900	.
117	T7-10	01JUN82	1.643E+03	.	.	.
118	T7-10	23JUN82	2.379E+02	.	.	.
119	T7-10	19JUL82	1.676E+02	.	.	.
120	T7-10	18AUG82	.	.	.	.
121	T7-10	21SEP82	1.428E+02	1.424E+05	997.409	630
122	T7-10	03NOV82	1.961E+01	.	.	.
123	T7-10	22NOV82	0.000E+00	0.000E+00	.	0

APPENDIX C (continued)

----- NUM=T7-13 -----						
UBS	NUM	DATE	CO60 (Bq/L)	PCU60 (Bq/kg)	CO_KD	PCS137
124	T7-13	15AUG74	1.066E+04	.	.	.
125	T7-13	20JUN75	1.014E+04	.	.	.
126	T7-13	22FEB80	.	.	.	.
127	T7-13	16DEC80	1.295E+03	2.657E+06	2051.43	.
128	T7-13	20FEB81	7.918E+02	5.160E+05	654.21	.
129	T7-13	01APR81	.	2.194E+05	.	.
130	T7-13	03APR81	8.103E+02	.	.	.
131	T7-13	04APR81	8.606E+02	2.183E+05	247.90	.
132	T7-13	07MAY81	1.667E+03	6.401E+05	379.39	.
133	T7-13	15MAY81	1.569E+03	5.180E+05	330.19	.
134	T7-13	19MAY81	1.421E+03	.	.	.
135	T7-13	29MAY81	1.443E+03	3.593E+05	248.97	.
136	T7-13	09JUN81	5.402E+02	6.401E+04	118.49	.
137	T7-13	26JUN81	1.225E+03	.	.	.
138	T7-13	07JUL81	.	.	.	.
139	T7-13	17JUL81	1.202E+03	2.971E+05	247.08	.
140	T7-13	31JUL81	.	.	.	.
141	T7-13	07AUG81	1.245E+03	4.218E+05	339.29	.
142	T7-13	31AUG81	9.583E+02	4.551E+05	474.90	.
143	T7-13	21SEP81	3.404E+02	.	.	.
144	T7-13	02NOV81	.	2.509E+05	.	.
145	T7-13	19NOV81	1.006E+03	2.375E+05	236.0	.
146	T7-13	16DEC81	6.919E+02	.	.	.
147	T7-13	28DEC81	4.299E+02	.	.	.
148	T7-13	04JAN82	1.891E+02	2.642E+05	1397.3	.
149	T7-13	07JAN82	3.315E+02	2.960E+05	892.9	.
150	T7-13	06JAN82	3.737E+02	1.347E+05	360.4	.
151	T7-13	13JAN82	4.810E+02	1.595E+05	331.5	.
152	T7-13	21JAN82	1.580E+02	1.217E+05	770.5	.
153	T7-13	28JAN82	3.996E+02	1.839E+05	460.2	.
154	T7-13	29JAN82	4.000E+02	.	.	.
155	T7-13	04FEB82	2.146E+02	2.220E+05	1034.5	.
156	T7-13	11FEB82	3.548E+02	2.013E+05	567.3	.
157	T7-13	19FEB82	3.663E+02	2.405E+05	656.6	.
158	T7-13	25FEB82	5.809E+02	2.871E+05	494.3	.
159	T7-13	28FEB82	5.809E+02	.	.	.
160	T7-13	04MAR82	9.435E+02	2.261E+05	239.8	.
161	T7-13	11MAR82	4.477E+02	3.300E+05	737.2	.
162	T7-13	19MAR82	4.292E+02	4.351E+05	1013.8	.
163	T7-13	26MAR82	5.180E+02	.	.	.
164	T7-13	01APR82	2.597E+02	.	.	.
165	T7-13	07APR82	1.506E+03	.	.	.
166	T7-13	16APR82	1.099E+03	.	.	.
167	T7-13	23APR82	1.239E+03	1.110E+05	69.6	.
168	T7-13	29APR82	6.845E+02	4.884E+04	71.4	.
169	T7-13	14MAY82	1.447E+03	3.929E+05	271.6	.
170	T7-13	20MAY82	1.510E+03	5.994E+05	397.1	.
171	T7-13	21MAY82	1.702E+03	2.597E+04	15.3	.
172	T7-13	01JUN82	1.709E+03	9.546E+06	5584.4	.
173	T7-13	04JUN82	1.609E+03	5.735E+05	356.3	.
174	T7-13	10JUN82	1.680E+03	1.613E+06	964.6	.
175	T7-13	17JUN82	1.839E+03	4.810E+05	261.6	.
176	T7-13	23JUN82	1.920E+03	7.733E+05	402.7	.
177	T7-13	09JUL82	1.628E+03	8.995E+05	492.1	.
178	T7-13	19JUL82	1.828E+03	8.584E+05	469.6	.
179	T7-13	26JUL82	1.854E+03	2.986E+05	161.1	.
180	T7-13	02AUG82	1.902E+03	6.253E+05	328.8	.
181	T7-13	11AUG82	1.846E+03	5.439E+05	294.6	.
182	T7-13	18AUG82	1.595E+03	.	.	.
183	T7-13	25AUG82	1.702E+03	6.105E+06	3587.0	.
184	T7-13	02SEP82	1.991E+03	1.188E+06	596.7	.
185	T7-13	10SEP82	1.735E+03	2.316E+05	133.5	.
186	T7-13	15SEP82	1.643E+03	6.734E+07	40991.0	.
187	T7-13	10NOV82	1.543E+03	3.737E+06	2422.1	.
188	T7-13	22NOV82	1.332E+03	5.365E+05	402.8	.
189	T7-13	14DEC82	4.773E+02	2.275E+05	476.7	.
190	T7-13	07JAN83	7.770E+02	2.098E+05	270.0	.
191	T7-13	02FEB83	1.073E+03	2.087E+05	194.5	.
192	T7-13	16FEB83	1.251E+03	3.489E+05	279.0	.
193	T7-13	11MAR83	1.051E+03	3.345E+05	318.3	.

APPENDIX C (continued)

NUM=T7-20						
Obs	NUM	DATE	CO60 (Bq/L)	PC060 (Bq/kg)	CO_KD	PCS137
194	T7-20	23APR82	8.325E+02	4.181E+04	50.2	.
195	T7-20	29APR82	7.696E+02	4.847E+05	629.8	2600
196	T7-20	10JUN82	8.140E+02	5.402E+05	663.6	633
197	T7-20	17JUN82	9.435E+02	1.754E+06	1856.8	.
198	T7-20	23JUN82	9.916E+02	2.294E+06	2313.4	6910
199	T7-20	09JUL82	1.029E+03	2.538E+06	2467.6	3920
200	T7-20	19JUL82	9.435E+02	2.723E+06	2886.3	2610
201	T7-20	26JUL82	1.006E+03	1.513E+06	1503.7	1520
202	T7-20	02AUG82	6.954E+02	7.252E+07	80991.7	24000
203	T7-20	11AUG82	8.251E+02	3.781E+07	45829.6	2010
204	T7-20	18AUG82	7.696E+02	.	.	.
205	T7-20	25AUG82	7.511E+02	5.624E+06	7487.7	4260
206	T7-20	02SEP82	6.253E+02	1.909E+06	3053.3	.
207	T7-20	10SEP82	6.216E+02	5.772E+05	926.6	267
208	T7-20	15SEP82	6.949E+02	2.453E+06	3530.4	.
209	T7-20	21SEP82	1.873E+03	1.791E+06	956.3	.
210	T7-20	30SEP82	5.476E+02	5.217E+06	9527.0	.
211	T7-20	06OCT82	7.881E+02	2.564E+06	3253.5	1040
212	T7-20	14OCT82	6.512E+02	1.077E+07	16534.1	.
213	T7-20	20OCT82	6.623E+02	7.696E+05	1162.0	683
214	T7-20	27OCT82	4.033E+02	1.095E+06	2715.6	.
215	T7-20	03NOV82	5.454E+02	.	.	.
216	T7-20	10NOV82	5.661E+02	1.206E+06	2130.7	.
217	T7-20	22NOV82	5.994E+02	1.517E+06	2530.9	3590
218	T7-20	14DEC82	3.959E+02	9.953E+05	2514.0	.
219	T7-20	07JAN83	5.513E+02	1.661E+06	3013.4	7160
220	T7-20	26JAN83	6.512E+02	2.135E+06	3278.4	19300
221	T7-20	02FEB83	6.512E+02	5.587E+06	8579.5	17800
222	T7-20	16FEB83	8.658E+02	7.511E+06	8675.2	24300
223	T7-20	11MAR83	8.473E+02	6.771E+07	79912.7	.
224	T7-20	21MAR83	9.546E+02	.	.	.

NUM=T7-21						
Obs	NUM	DATE	CO60	PC060	CO_KD	PCS137
225	T7-21	23APR82	2.676E+03	3.015E+04	11.27	.
226	T7-21	29APR82	.	.	.	.
227	T7-21	23JUN82	2.475E+03	.	.	.
228	T7-21	19JUL82	2.338E+03	.	.	.
229	T7-21	18AUG82	.	.	.	.
230	T7-21	21SEP82	1.584E+03	2.127E+06	1343.46	.
231	T7-21	20OCT82	1.991E+03	4.995E+05	250.93	.
232	T7-21	27OCT82	1.920E+03	6.956E+05	362.24	.
233	T7-21	03NOV82	1.720E+03	.	.	.
234	T7-21	10NOV82	1.643E+03	8.362E+05	509.01	.
235	T7-21	22NOV82	1.657E+03	2.657E+05	143.03	.
236	T7-21	07JAN83	8.177E+02	2.501E+05	305.88	.
237	T7-21	02FEB83	1.439E+03	1.698E+05	117.99	.
238	T7-21	18FEB83	1.339E+03	0.364E+05	475.14	.
239	T7-21	11MAR83	1.495E+03	1.639E+06	1096.53	.

NUM=T7-22						
Obs	NUM	DATE	CO60	PC060	CO_KD	PCS137
240	T7-22	25APR82	1.088E+03	3.360E+04	30.88	.
241	T7-22	29APR82	1.017E+03	.	.	.
242	T7-22	23JUN82	1.165E+03	.	.	.
243	T7-22	19JUL82	1.206E+03	.	.	.
244	T7-22	18AUG82	.	.	.	.
245	T7-22	21SEP82	1.077E+03	9.509E+06	8825.55	.
246	T7-22	03NOV82	8.880E+02	.	.	.
247	T7-22	22NOV82	8.325E+02	7.437E+06	8933.33	.

NUM=T7-23						
Obs	NUM	DATE	CO60	PC060	CO_KD	PCS137
248	T7-23	23APR82	3.700E+00	4.403E+03	1190	.
249	T7-23	29APR82	3.700E+00	0.000E+00	.	.
250	T7-23	23JUN82	6.240E+00	.	.	.
251	T7-23	19JUL82	3.700E+00	.	.	.
252	T7-23	18AUG82	.	.	.	.
253	T7-23	21SEP82	0.000E+00	0.000E+00	.	.
254	T7-23	03NOV82	0.000E+00	.	.	.
255	T7-23	22NOV82	0.000E+00	0.000E+00	.	.

APPENDIX C (continued)

NUM=T7-24						
OBS	NUM	DATE	CO60 (Bq/L)	PCO60 (Bq/kg)	CO_KD	PCS137
256	T7-24	23APR82	2.176E+03	4.440E+04	20.4	.
257	T7-24	29APR82	1.017E+03	1.769E+06	1738.2	.
258	T7-24	01JUN82	1.413E+03	.	.	.
259	T7-24	10JUN82	1.450E+03	7.807E+05	538.3	.
260	T7-24	17JUN82	1.156E+03	3.178E+05	274.4	.
261	T7-24	23JUN82	1.402E+03	9.324E+05	664.9	.
262	T7-24	09JUL82	1.402E+03	6.732E+05	622.7	.
263	T7-24	19JUL82	1.454E+03	1.891E+06	1300.3	.
264	T7-24	26JUL82	1.572E+03	6.697E+05	425.9	.
265	T7-24	02AUG82	1.495E+03	1.629E+07	6881.2	.
266	T7-24	11AUG82	1.146E+03	2.853E+06	2503.2	.
267	T7-24	18AUG82	1.421E+03	.	.	.
268	T7-24	25AUG82	1.402E+03	5.698E+06	4063.3	.
269	T7-24	02SEP82	1.225E+03	8.917E+05	728.1	.
270	T7-24	10SEP82	1.132E+03	1.942E+07	17156.9	.
271	T7-24	18SEP82	1.214E+03	6.845E+06	5640.2	.
272	T7-24	21SEP82	1.195E+03	7.363E+06	6161.0	.
273	T7-24	30SEP82	1.214E+03	3.811E+06	3140.2	.
274	T7-24	06OCT82	1.291E+03	1.110E+06	859.6	.
275	T7-24	14OCT82	1.247E+03	2.320E+06	1860.5	.
276	T7-24	03NOV82	9.798E+02	.	.	.
277	T7-24	22NOV82	1.095E+03	1.284E+07	11723.0	.
278	T7-24	14DEC82	6.734E+02	2.164E+06	3214.3	.
279	T7-24	07JAN83	7.644E+02	2.742E+06	3495.3	.
280	T7-24	20JAN83	8.251E+02	2.398E+06	2905.8	.
281	T7-24	02FEB83	7.992E+02	2.601E+06	3254.6	.

NUM=T7-24						
OBS	NUM	DATE	CO60	PCO60	CO_KD	PCS137
282	T7-24	18FEB83	8.695E+02	2.520E+07	28978.7	.
283	T7-24	11MAR83	9.509E+02	2.335E+06	2455.3	.

NUM=T7-25						
OBS	NUM	DATE	CO60	PCO60	CO_KD	PCS137
284	T7-25	23APR82	1.617E+03	1.954E+05	107.54	.
285	T7-25	29APR82	1.661E+03	1.724E+06	926.44	.
286	T7-25	23JUN82	1.332E+03	.	.	.
287	T7-25	19JUL82	9.398E+02	.	.	.
288	T7-25	21SEP82	1.009E+03	4.736E+06	4692.08	.
289	T7-25	20OCT82	1.021E+03	2.209E+06	2163.04	.
290	T7-25	27OCT82	1.054E+03	6.031E+05	571.93	.
291	T7-25	03NOV82	6.808E+02	.	.	.
292	T7-25	10NOV82	3.034E+02	9.287E+05	3060.98	.
293	T7-25	22NOV82	3.071E+02	2.897E+06	9433.73	.

NUM=T7-26						
OBS	NUM	DATE	CO60	PCO60	CO_KD	PCS137
294	T7-26	23APR82	3.700E+00	3.774E+05	102000	.
295	T7-26	23JUN82	3.700E+00	.	.	.
296	T7-26	19JUL82	3.700E+00	.	.	.
297	T7-26	18AUG82	.	.	.	.
298	T7-26	21SEP82	7.548E+01	0.000E+00	0	.
299	T7-26	03NOV82	0.000E+00	.	.	.
300	T7-26	22NOV82	0.000E+00	0.000E+00	.	1700

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