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DATA RELATED TO CONTAMINANT DISTRIBUTION AT THE BEATTY, NEVADA AND RICHLAND, WASHINGTON LOW-LEVEL RADIOACTIVE WASTE DISPOSAL SITES

by

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Introduction

The Beatty, Nevada low-level radioactive waste (LLRW) site was utilized from 1962 to 1992; the Richland, Washington LLRW site was opened in 1965 and remains in use. Both sites accepted hazardous chemical wastes for disposal in separate trenches; disposal of such materials continues at the Beatty site, but not at the Richland site. This report provides a summary of data on the distribution of radioactive and chemical contaminants derived from these facilities. Most of the data are from various regulatory agency, operator, and consultant reports, which are generally of difficult access. More readily accessible newer data and some data not previously published by the authors are included for completeness.

Setting

Beatty Site. The Beatty site (Fig. 1), located 17 km south of the town of Beatty, Nevada in the Amargosa Desert, was used for disposal of LLRW from 1962 to 1992 (Conference of Radiation Control Program Directors 1996). A chemical waste disposal facility, opened in 1970 and currently still in use, occupies the eastern half of the site. The site is at the eastern edge of the Holocene flood plain of the Amargosa River, about 3 km east of the present main river channels, and close to Bare Mountain (Fig. 2). The main channels of the Amargosa River are entrenched about 4-5 m, but braids on the flood plain are likely active during large flood events (Fig. 3). Some larger distributaries of the Amargosa River are located ~0.5 km west of the site, and smaller ones are intersected by the site boundary (Fig. 2). Some time after early 1994, a large (~10 m) berm was constructed on the north side of the waste facility by excavating a ditch approximately parallel to the north fence line of the facility (Fig. 4); the ditch extends around the west side of the facility. Runoff from Bare Mountain is channeled east of the LLRW site in a drainage approximately parallel to the Amargosa River.

The eastern part of the LLRW site is located on the edge of a low ridge elongate parallel to U.S. Highway 95 on the east side of the waste facility. The ridge consists in part of upper Proterozoic metamorphic rocks in the lower plate of the Miocene Bare Mountain detachment fault (Hamilton, 1988), surrounded by river gravels that lie above the present flood plain. These alluvial deposits consist dominantly of angular to well-rounded clasts of intermediate and silicic volcanic rocks and lesser proportions of metasedimentary rocks, including minor metadolomite and quartzite. Undissected surfaces have a mature pavement with moderate desert varnish, and may represent abandoned flood plains of older river braids (Warren Hamilton, written comm., 1997). The pavement is underlain by a vesicular A (Av) soil horizon 3-5 cm thick.

The LLRW part of the facility is located on two alluvial units of the Amargosa River flood plain (Swadley and Parrish, 1988), both of which consist of fine-grained reworked eolian sand deposits capped by small pebble lag gravels that form an immature pavement over a 2-3 cm-thick Av soil horizon. The stratigraphy and lithology of sedimentary rocks in the unsaturated zone are known only in outline. Unconsolidated deposits are about 170 m thick at the site (Nichols, 1987), and the top of the saturated zone is at a depth of about 87 m in the northeast (Fischer, 1992) and 110 m in the southwest (Prudic and others, 1997). Johnson (1990), in a study of the chemical waste facility, refers to "upper and lower ground water units" separated by a silt-clay layer on the order of 24 m thick, but gives no further details or evidence of multiple aquifers. The unsaturated zone appears to consist largely or entirely of unconsolidated to weakly indurated deposits, including fluvial, alluvial fan, and marsh valley-fill deposits (Nichols, 1987; Fischer, 1992). Nichols (1987) also reported driller's logs showing "calcareous clay and limestone (?), clay with gravel, and clayey limestone (?)" at depths of about 100 to 120 m. "Clay lenses" were inferred from geophysical logs of monitoring wells 302 (at ~35 and ~45 m depth) and 303 (at ~8-10 m, ~22 m, and ~25 m). The only deposits (inferred from geophysical logs) that correlate among wells 301, 302, and 303 (see Fig. 5) are "marsh (?) deposits" at depths of about 70 to 90 m (Fischer, 1992). Little information is available on the hydrologic properties of disturbed and undisturbed deposits in the unsaturated zone below 13 m depth (Nichols, 1987; Fischer, 1992), which is >2 m shallower than the deepest disposal trenches (Table 1). Hydrologic properties were reported to depths of 5 m, on samples from which all clasts >2 mm across were removed (Andraski, 1996); that study concluded that disturbances from construction and backfilling of waste trenches significantly altered the hydrologic properties of near-surface materials.

The vegetation community is creosote (*Larrea tridentata*) scrub and white bursage (*Ambrosia dumosa*) as codominants, and lesser abundances of spiny hopsage (*Grayia spinosa*), desert holly (*Atriplex hymenelytra*), Mormon tea (*Ephedra nevadensis*), and desert thorn (*Lycium andersonii*). Creosote shrubs are of small stature, mostly <1 m height, and spaced between 1 and 8 m apart; creosote individuals and other shrubs tend to cluster on older geomorphic surfaces. Annual precipitation at the site, dominantly winter rain, averaged 108 mm in the period 1981-1992 (Andraski, 1996) but was highly variable (range from 136 mm in 1987 to 14 mm in 1989). Longer term records indicate an average annual precipitation of 114 mm at Beatty (158 m higher elevation than the LLRW site), and 74 mm at Amargosa Farms, 30 km southeast of the site and 30 m lower in elevation (Nichols, 1987).

Richland Site. The Richland LLRW site is in the Pasco Basin on the Columbia River Plateau, and lies within the U. S. Department of Energy's Hanford Reservation in southeastern Washington (Fig. 5). The site opened for low-level radioactive waste in 1965. The disposal site is on an essentially undissected surface, which has a veneer of stabilized (where undisturbed) sand sheets and small dunes (Fig. 6). Regrading of the site and its location near the crest of a gentle rise makes it subject to stormwater runon from the east (U. S. Environmental Protection Agency [USEPA], 1992). Beneath the eolian sand deposits, the section at the Hanford Reservation comprises in descending order: (1) flood deposits of gravel, sand, and silt of the Pleistocene Hanford formation (informally named; ~65 m thick); (2) gravels that contain less basalt clasts than underlying Ringold gravels and have a quartzo-feldspathic sand matrix (~25 m thick); and (3) lacustrine clay with thin silt and sand interbeds, overbank laminated to massive silt and silty fine sands with paleosols containing variable amounts of pedogenic carbonate, fluvial quartzo-feldspathic sands and gravels of varied lithologies, and alluvial fan deposits of crudely stratified basaltic detritus of the Miocene-Pliocene Ringold Formation (~185 m thick) (Lindsey, 1991; Reidel and others, 1992; Lindsey and others, 1994). Sedimentary rocks of the Ringold Formation lie on basalts of the Columbia River Group.

LLRW site-specific stratigraphic information based on trench exposures (to ~14 m depth) and boreholes (to ~110 m depth) indicates surficial colluvium, alluvium, dune sands, and interbedded volcanic ash deposits to a depth of ~3-6 m, ~15-18 m of well-bedded silt and fine to coarse sand slackwater deposits ("Touchet Beds"), and gravels of the Hanford formation (?) and Ringold Formation to the bottom of the boreholes (USEPA, 1992). Sedimentary rocks of the Hanford formation contain numerous mostly steep dipping clastic dikes from a few centimeters to over a meter thick (Connelly and others, 1992).

An unconfined aquifer in the Ringold Formation is at a depth of ~100 m (Fig. 5) (Lindsey and others, 1994). Ground water flow paths are toward the Columbia River, some 16 km distant (Fig. 5). Natural recharge of the aquifer is from rainfall and runoff from surrounding hills, infiltration from small ephemeral streams, and subsurface infiltration from fractures in underlying basalts. Artificial recharge of contaminated liquids has occurred at the 200 West and 200 East sites (Fig. 5) (Connelly and others, 1992; Trent, 1992; Lindsey and others, 1994).

The LLRW site is on the north flank of the Cold Creek syncline in the Yakima fold belt; interbedded basalts and gravels comprising the north flank of the syncline dip gently (~5°) southward (Lindsey and others, 1994); the lower part of the Ringold Formation was folded with the underlying basalts, whereas overlying sedimentary materials are undeformed and fill structural lows in the older rocks (USEPA, 1992). Vegetation is a shrub-steppe community of sagebrush (*Artemisia* spp), rabbitbrush (*Chrysothamnus* spp), and antelope bitterbrush (*Purshia tridentata*), with bluebunch wheatgrass (*Agropyron spicatum*) and mixtures of non-native cheatgrass (*Bromus tectorum*) and native grasses (The Nature Conservancy of Washington, 1996). Average annual precipitation in the period 1951-1980 was 160 mm, 52% of which fell from November through February. Annual precipitation in this period ranged from 76 to 246 mm (Kearney, 1989).

Disposal Practices

<u>Beatty Site</u>. Figure 7 shows the distribution of 22 disposal trenches at the Beatty site. Dimensions and dates of opening and closure are given in Table 1. The Nuclear Regulatory Commission (NRC) (1976) reported that liquid wastes had been disposed directly into trenches from at least June 1966 until Spring 1975 when means for solidification of wastes first became operational (US Ecology, 1990a). NRC (1976, p. 63) cited records of receipt at the facility of approximately 770 m^3 of liquid radioactive waste between 1966 and 1975. Site records reported by Striegl and others (1996) indicate disposal of at least 2,270 m^3 of liquid radioactive waste from the date of opening of the facility (1962); estimates range as high as ~2,650 m^3.

Individual trenches remained open for periods of 3 to 141 months (Table 1). The average measured annual precipitation at the site, 108 mm (Andraski, 1996), combined with dimensions and dates of opening and closing of the trenches (Table 1), indicates that the amount of rainfall incident on open trenches totaled ~40,000 m^3, and the amount incident on open and closed trenches totaled ~135,000 m^3 during the life of the facility (Table 2). An unknown additional amount of rainwater entered the trenches from runoff (photographs in Nevada State archives of a 34 mm rainstorm on August 15, 1984 show runoff entering over the lip of one trench), and, until 1994, runoff from the Amargosa River flood plain was intercepted by the disposal site.

<u>Richland Site</u>. Figure 8 shows the location of 21 disposal trenches and 5 underground resin tanks at the Richland site. Dimensions and dates of opening and closure of the trenches are given in Table 3. Approximately 480 m^3 of poorly documented chemical wastes were disposed in the chemical trench. Staff interviews (NRC, 1976) indicated that past disposal practices for this trench may have included disposal of uncontainerized bulk liquid waste; however, a report prepared for the Washington Department of Ecology (Kearney, 1987) concluded that "[a]ccording to the available information, disposal of free liquid at the site appears to have been very limited; thus the direct movement of nonaqueous waste liquids does not appear to be a release mechanism of concern at this site."

Wastes were disposed in randomly placed metal drums, fiberboard drums, and cardboard boxes in trenches 1-11A. Mixed radioactive and hazardous wastes, including scintillation fluids comprising toluene, benzene, and xylene, resin wastes, and shielding were disposed in these trenches (USEPA, 1992). Mixed wastes were not disposed at this site after November 1985, so trenches 11B and younger ones contain only radioactive waste, which was disposed in randomly placed steel drums and boxes (USEPA, 1992).

In the late 1960s five underground steel tanks ranging from ~3,800 to 75,700 m^3 capacity were installed (see Fig. 8) for the purpose of evaporative solidification of resin sludges. This procedure proved unsatisfactory, and resins were not stored in these tanks after the early 1970s. In early 1985, leaks were discovered in one tank resulting in contamination of adjacent soils by loss of 450 m^3 of liquids. Pumpable wastes were removed from all tanks, two tanks were removed, and three were filled with concrete. Analyses indicated that both radioactive (^{60}Co, ^{137}Cs, ^{3}H, ^{14}C) and organic wastes had been stored in the tanks (Kearney, 1987, USEPA, 1992).

Contaminant Distribution

Beatty Site. Tables 4-6 show the distribution of radioactive contaminants found in ground water beneath and near the Beatty facility. Monitoring of ground water at depths of ~90-110 m was begun in 1962, and of the unsaturated zone in 1963 (Conference of Radiation Control Program Directors, 1996). Gross alpha and gross beta above action levels[1] (30 pCi/L and 90 pCi/L, respectively) were first discovered in ground water in 1970; tritium (^{3}H) above detection levels in ground water was first observed in 1970, and levels exceeding action levels (2,000 pCi/L) were first documented in 1979 (Table 4). An internal Nuclear Regulatory Commission memorandum dated April 22, 1985, noted, in addition to high 1983 ^{3}H in ground water in wells 301 and 302, "[h]igh coliform bacteria counts in site ground water, ...[r]adium-225 up to 18 pCi/l, [c]hromium and [b]arium up to almost 1 mg/l," suggesting leakage from the site septic system as well as from the chemical and radioactive waste trenches. Soils from the shallow unsaturated zone were sampled from dry wells near the disposal trenches and the four corners of the site. Dry wells were mostly located at the south side of completed trenches, and were dug to depths of at least 3.0 m below the bottom of the trench (see Table 1). Two dry wells were located south of the site, and additional off-site surface samples were obtained about 60 m from the site to the N, E, SE, and W (Conference of Radiation Control Program Directors, 1996). Gross alpha counts exceeding action levels in soils were first detected in 1975, and gross beta counts in 1972 (Table 4).

Tritium contamination in an offsite borehole close to the LLRW site (see Fig. 7, UZB-2) was documented in samples collected from near the surface to depths to 94 m in the unsaturated zone in 1992-1996, and ^{14}C in samples collected to depths of ~45 m in 1994-1995 (Table 6; Fig. 9) (Prudic and Striegl, 1995; Striegl and others, 1996; Prudic and others, 1997). Tritium concentrations have increased throughout the period of measurement, to concentrations to 64,000 pCi/L at a depth of 1.7 m, 4,300 pCi/L at 49 m, and 2,500 pCi/L at 94 m in 1996. ^{14}C activity also increased between 1994 and 1995 (Striegl and others, 1996).

Vegetation (not identified) showed no gross alpha values in excess of action levels (20 pCi/g), but gross beta exceeded action levels (200 pCi/g) in 1972, 1974, and 1976 (Table 6).

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[1] "Action levels" are defined by the Conference of Radiation Control Program Directors (1996). Reporting level values are cited here in the absence of reliable data on ambient levels of the constituents, and thus may or may not represent an anthropogenic addition to the natural system.

Tritium contamination (Table 6) of identified off-site vegetation to levels greater than 30,000 pCi/L was reported by Striegl and others (1996).

Approximately 1,135 m^3 of phosphoric acid sludge was disposed directly into trenches in the chemical waste facility (Jacobs Engineering Group, 1987; USEPA, 1987). This practice ceased in 1973 when phosphoric liquid contaminant was detected in a 12-m deep observation well. Emplacement of 20 observation wells and test holes revealed a plume of phosphoric acid contamination with a vertical extent between 0.6 and 2.4 m; the plume extended southward beyond the site boundary approximately 5 to 8 m by 1973. Concentrations of the contaminants are not known (Jacobs Engineering Group, 1987; USEPA, 1987), nor is it known whether further migration has occurred since 1973.

A report prepared for the USEPA (Johnson, 1990; see also, USEPA, 1987) indicated that vapor and "shallow ground water" samples collected between 1988 and 1992 show widespread contamination by volatile organic compounds derived from the chemical waste. Contamination of the "upper water-bearing zone" was detected in monitoring wells 308-311 and 316 (Fig. 7) at the eastern and southern perimeter of the chemical waste facility. Contamination of the "lower water-bearing zone" was detected in monitoring well 307 within the chemical waste area (Fig. 7).

<u>Richland Site</u>. Much less information is available on contaminant distribution at the Richland site than at Beatty. Five ground-water-monitoring wells (Fig. 8, Nos. 003, 005, 008, 010, and 013) were installed in 1985. Well 013 is at the western edge of the site, upgradient from the trenches for ground water flow. Data obtained from 1986 through 1996 (Table 8) show relatively elevated levels of ^3H in ground water throughout the monitoring period. All wells show similar patterns of ^3H concentration with time, first decreasing through 1989, then increasing progressively through 1996 (Fig. 10). G. Robertson , State of Washington Department of Health (written comm., 1997), believes that the upgradient well (013) is affected by the leading edge of a tritium-rich plume from the 200 West Area (Fig. 11), but this is not supported by ^3H concentrations of similar magnitude (Table 8) in upgradient well 013 and downgradient well 003, or the position(s) of the tritium plume(s) from the 200 West and 200 East Areas (Fig. 11). Delaney and Lindsey (1991) indicate further that the ground water flow direction from 200 West is northeast, and that from 200 East is northwest, both away from the LLRW site (Fig. 12).

Three test holes (Fig. 8, VW-100, 101, and 102) were drilled in 1991 to monitor the unsaturated zone (US Ecology, 1992a). VW-100 was drilled in the NW corner of the site to serve as a control. Pore water from core samples taken from an 11 m interval at the bottom of each well was analyzed for ^3H (Table 9), showing very low concentrations in samples from VW-100. VW-101 shows ^3H concentrations from 2,000 to 28,000 pCi/L, with a maximum at a depth of 14 m, whereas VW-102 has a maximum of 55,000 pCi/L of ^3H at a depth of 10 m, the shallowest level sampled (Fig. 12). Subsequent vapor sampling from 1993 to 1996 (Table 10) indicates maximum values for the 4 years ranging from 700 to 1,700 pCi/L (VW-100), 239,000 to 337,000 pCi/L (VW-101), and 450,000 to 497,000 pCi/L (VW-102). Solar stills installed at the locations of the VW wells, and sampling vapor from depths of 46 cm, gave results like those of the VW boreholes (Table 10). The unsaturated zone monitoring wells sample the entire 11 m screened interval (US Ecology, 1992a). The maximum depth of sampling for each well is 25.6 m (VW-100), 17.4 m (VW-101), and 21.3 m (VW-102).

Details of the extent and nature of unsaturated zone contamination from leakage of the resin tanks, in which ^{60}Co, ^{137}Cs, ^{3}H, ^{14}C, among other anthropogenic constituents, were identified, are not reported (Kearney, 1987; USEPA, 1992).

Tritium contents of trench-cap vegetation for the period 1987 to 1996 are given in Table 12. Values reported range from less than detection level (one sample) to 4,270,000 pCi/L. Because of this variability, alternative analytical procedures are being investigated (Conference of Radiation Control Program Directors, 1996).

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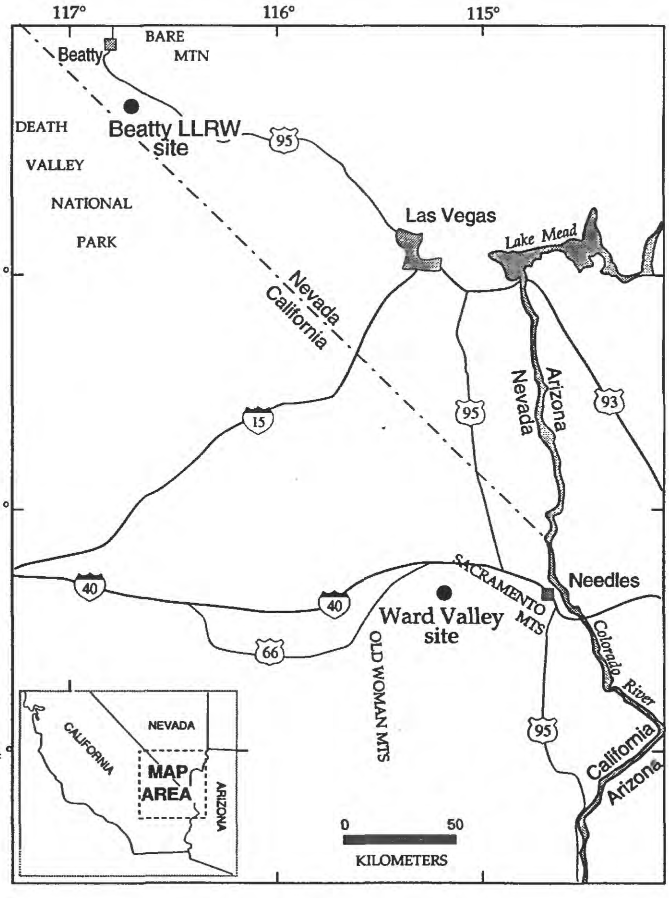


Fig. 1. Map showing location of the Beatty, Nevada LLRW site.

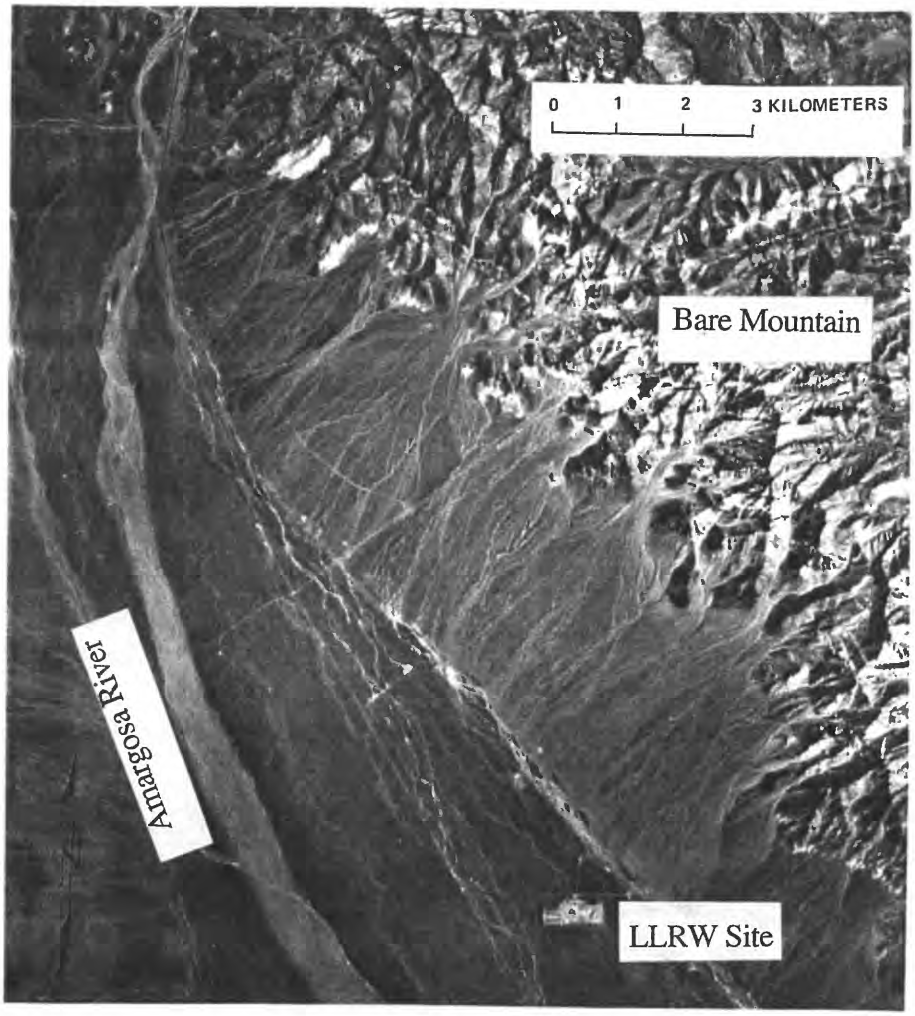


Fig. 2. Aerial photograph showing the Beatty, Nevada LLRW site, and its position on the Amargosa River flood plain. Main Amargosa River channel on left, subsidiary channels concentrated just west of LLRW site. Note that LLRW site intercepts small flood plain channels. The flood plain is a Holocene erosional surface cut in late Pleistocene valley fill. Photograph 1976.

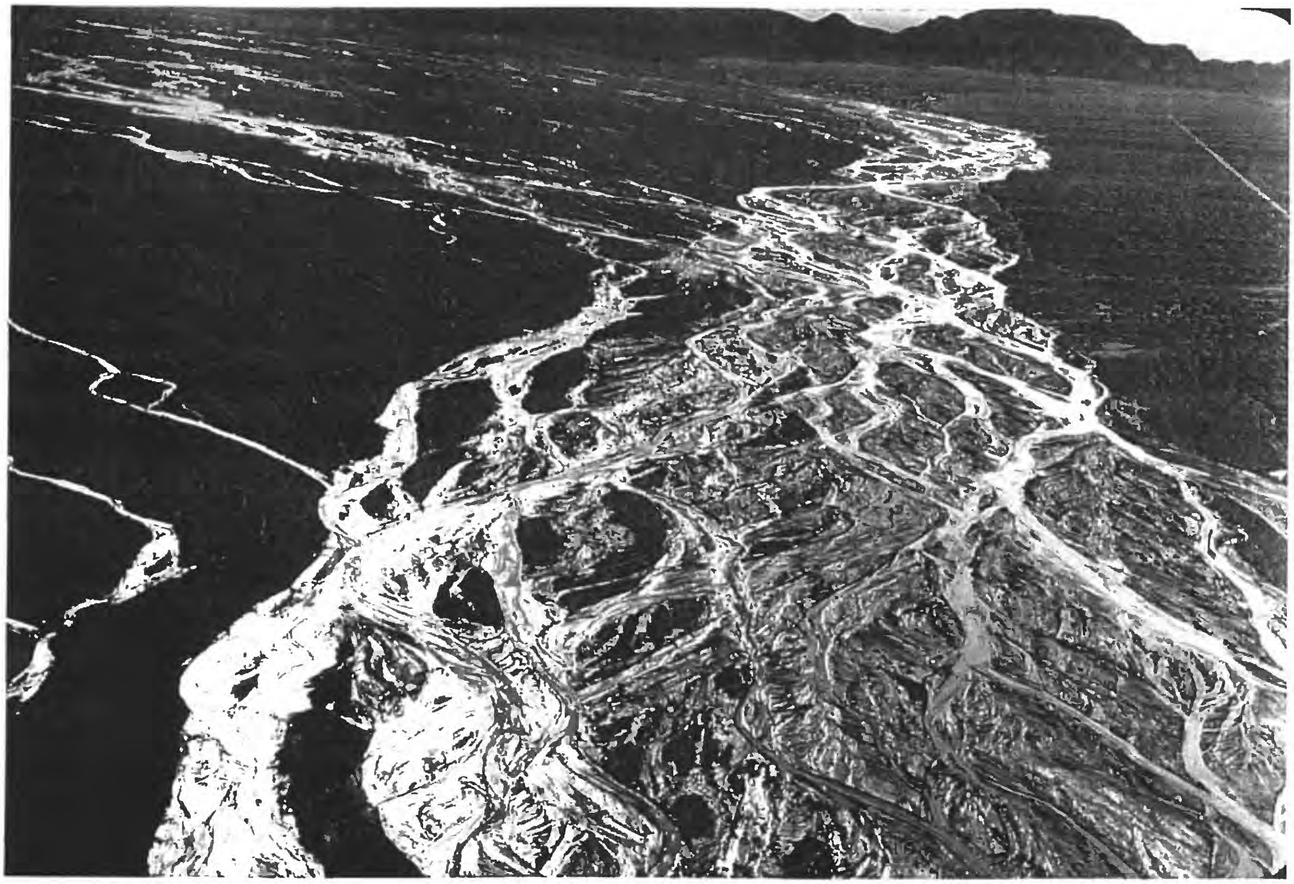


Fig. 3. Photograph of the Amargosa River in flood, August 20, 1977. Flooding caused by Hurricane Doreen. Photograph taken 125 km south of Beatty illustrates that in major storms all distributaries on the flood plain are in flood, not just the incised main channels. View east from between Saddle Peak Hills and Salt Spring Hills, California.

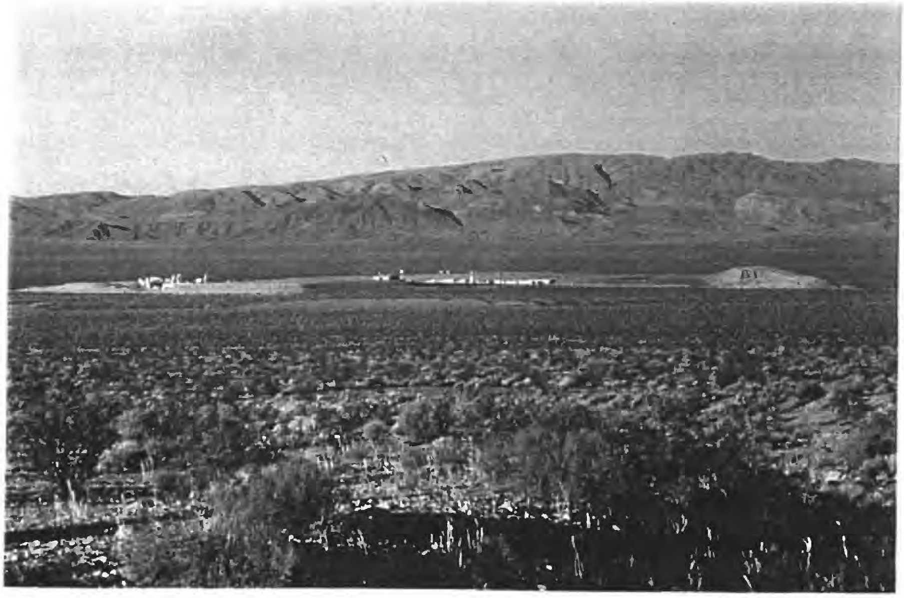
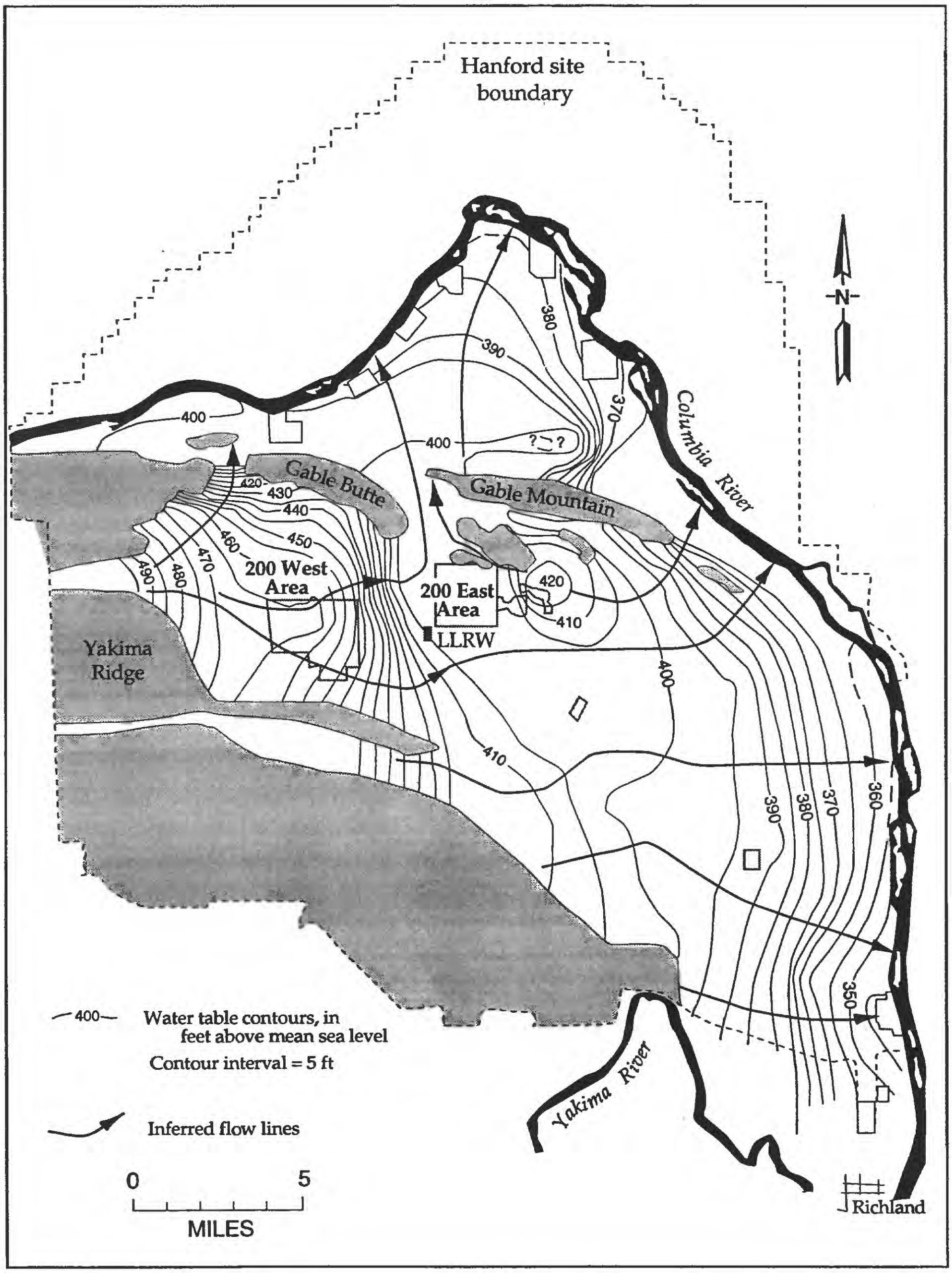


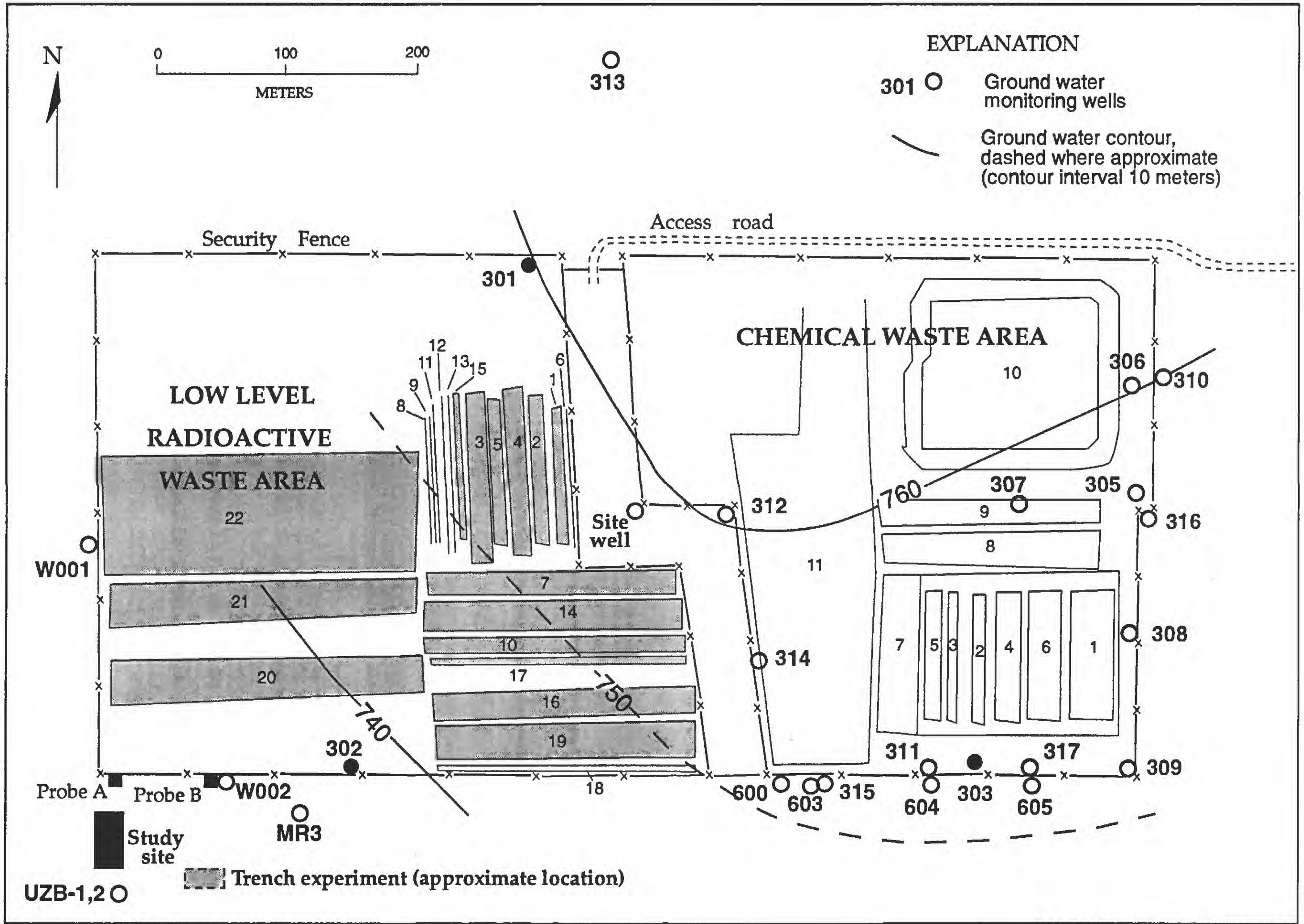
Fig. 4. View (westward) of the Beatty LLRW site from west flank of Bare Mountain, showing berm on north side of the facility. Funeral Mountains distant across the Amargosa River flood plain.

Fig. 6. View east across 200 West Area, Hanford Reservation, from U.S. Highway 240, showing general terrain and vegetation features shared by the Richland LLRW site farther east.



Modified from Lindsey and others (1994)

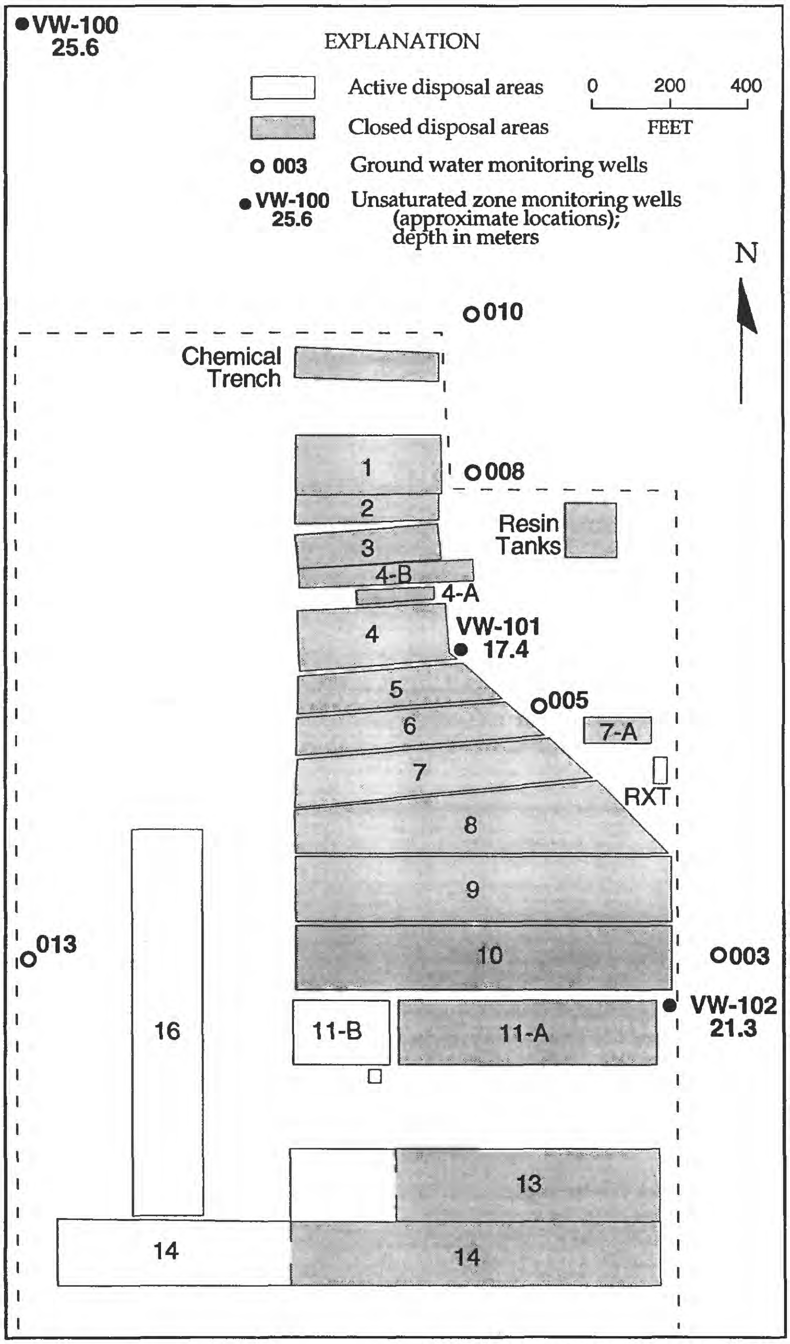
Fig. 5. Map of the Hanford Reservation site, Washington, showing location of the Richland LLRW site, the nearby 200 West and 200 East Areas, and contours on the water table. Generalized ground water flow paths shown by arrows.



Base from US Ecology, Inc., 1990

Modified from Fischer (1992)

Fig. 7. Site map of the Beatty, Nevada LLRW and chemical waste disposal site, showing disposal trench locations, monitoring boreholes, contours (meters) on the water table, and (lower left), USGS Study Site.



Modified from US Ecology, Inc. (1992)

Fig. 8. Site map of the Richland LLRW site, showing locations of disposal trenches and resin tanks, and ground water (003-013) and unsaturated zone (VW-100 - VW-102) monitoring boreholes.

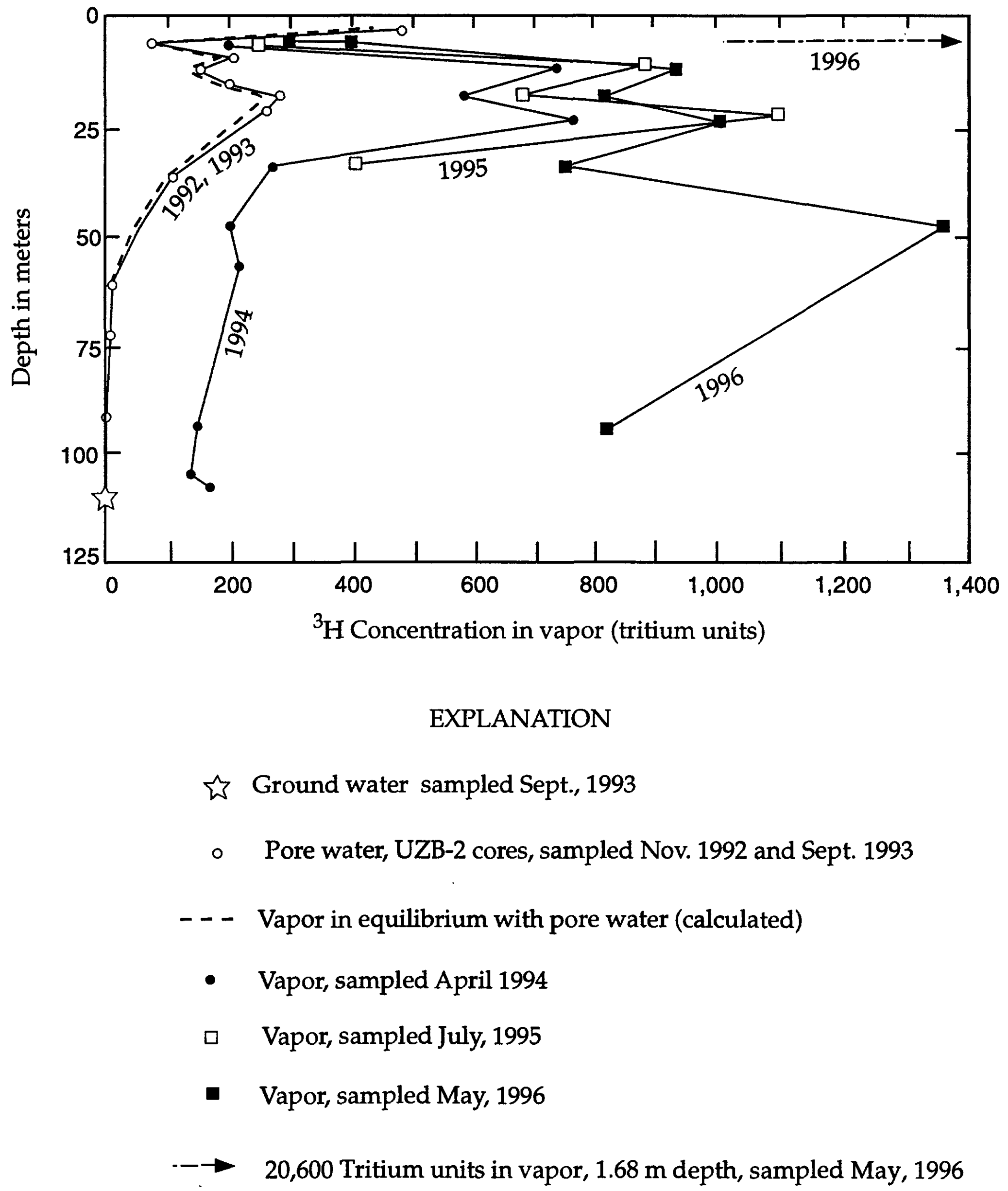


Fig. 9. Tritium concentrations (tritium unit = 3.2 pCi/L) in pore water from cores taken in 1992-93 and in vapor sampled in 1994-1996 from ports in borehole UZB-2 (see Fig. 7), Beatty Nevada site (from Prudic and others, 1997).

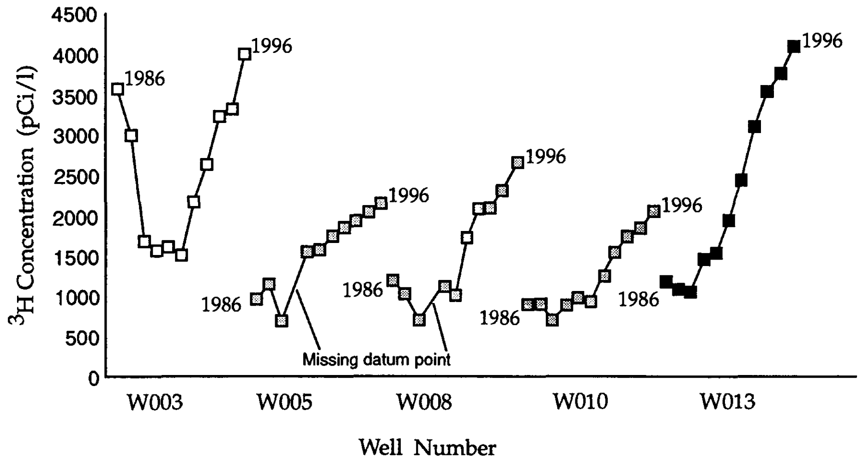
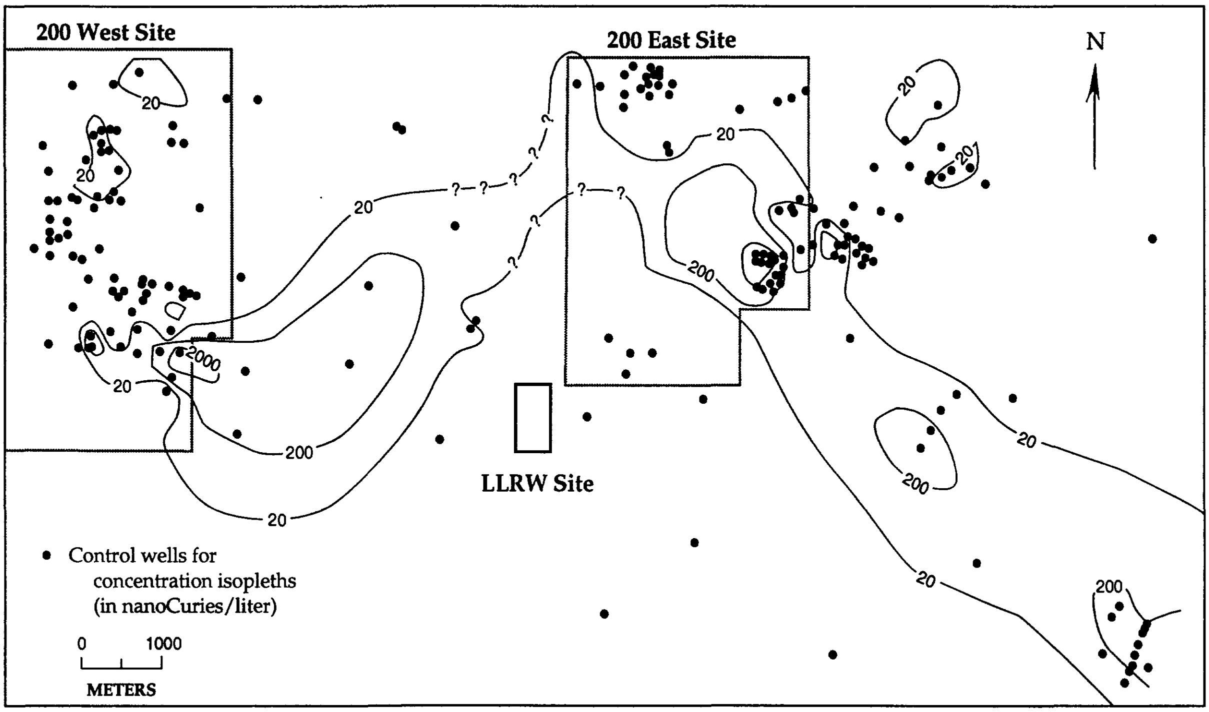


Fig. 10. Tritium concentrations (pCi/L) in ground water at five monitoring well sites annually from 1986 through 1996, Richland LLRW site.



Modified from Connelly and others (1992), and Trent (1992)

Fig. 11. Tritium plume isopleths (nCi/L) in ground water, Hanford Reservation, relative to location of Richland LLRW site. Contaminant sources in 200 West and 200 East Areas. Modified from Connelly and others (1992) and Trent (1992).

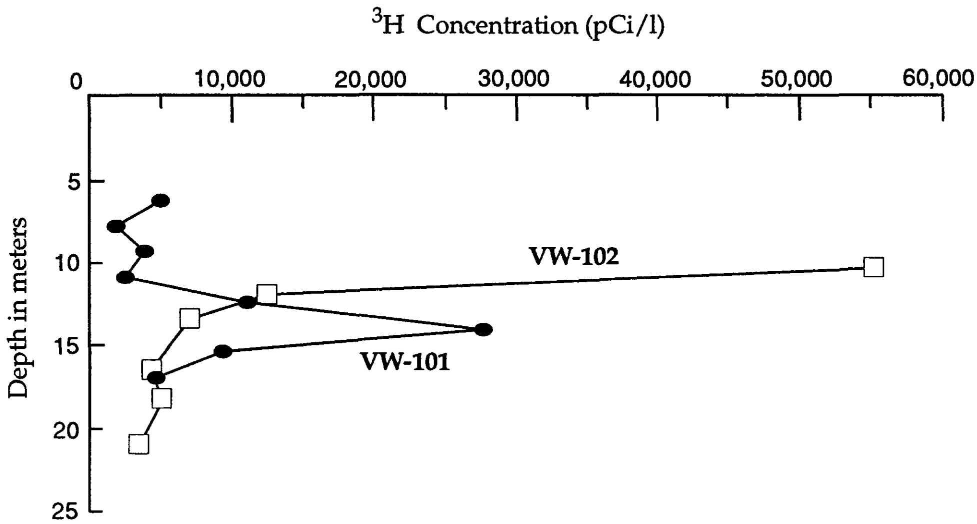


Fig. 12. Tritium concentrations (pCi/L) in pore water from unsaturated zone monitoring wells VW-101 and VW-102, Richland site. Samples collected in 1993 from lower 11 m of monitoring wells; this 11 m interval was screened (perforated casing) for subsequent vapor sampling (Table 9).

Table 1. LLRW Trench Data, Beatty Site[1]

Trench No.	Width (m)	Length (m)	Depth (m)	Volume (m^3)	Date Opened	Date Closed	Time Open (Mos)
1	9.4	101.8	6.1	5,837	Oct. 1962	Jan. 1963	3
2	12.5	115.5	6.1	8,807	Jan. 1963	Sept. 1963	8
3	12.5	125.6	6.1	9,577	Oct. 1963	Aug. 1964	10
4	17.4	129.8	6.1	13,777	Sept. 1964	June 1965	9
5	12.2	114.6	6.1	8,529	June 1965	Feb. 1966	8
6	1.5	105.5	1.8	285	July 1965	July 1966	11
7	18.6	195.1	6.1	22,136	Jan. 1966	Sept. 1967	20
8	1.2	109.4	1.8	236	July 1966	Oct. 1966	3
9	1.5	109.1	1.8	295	Mar. 1967	May 1968	14
10	12.2	203.0	6.1	15,107	Aug. 1967	Jan. 1970	29
11	1.5	109.4	1.8	295	May 1968	Dec. 1968	7
12	1.2	112.5	1.8	243	Dec. 1968	June 1969	6
13	1.2	112.5	1.8	243	June 1969	Nov. 1969	5
14	21.9	202.1	6.1	26,999	Dec. 1969	May 1973	41
15	3.0	104.9	3.0	944	Dec. 1969	Jan. 1971	13
16	22.3	206.0	6.1	28,022	Jan. 1972	Sept. 1974	31
17	4.3	200.9	1.8	1,555	Jan. 1972	Jan. 1973	12
18	3.0	203.3	1.8	1,098	Jan. 1973	Dec. 1973	11
19	27.4	204.2	9.1	50,915	Apr. 1974	Jan. 1979	57
20	34.1	240.8	10.7	87,861	Feb. 1977	Sept. 1979	31
21	30.8	235.3	15.2	110,158	Sept. 1979	Apr. 1982	30
22	91.4	243.8	15.2	338,706	Mar. 1981	Dec. 1992	141

[1]Data from Jacobs Engineering Group (1987), Table 4-2, and date of site closure for No. 22.

Table 2. Precipitation Estimates in and on Trenches at the Beatty LLRW Site[1]

Trench No.	Vol. of PPT on Open Trench (m^3)	Vol. of PPT on Trench after Closure (m^3)	Total Vol. of PPT in and on Trench (m^3)	Time Elapsed Before Sampling[2] (Yrs)
1	27	2,694	2,721	31.2
2	94	4,297	4,391	30.6
3	117	4,168	4,286	29.7
4	105	4,051	4,157	28.8
5	94	3,958	4,051	28.2
6	13	390	403	27.8
7	435	6,937	7,372	26.6
8	4	386	390	27.5
9	16	364	381	25.9
10	552	5,537	6,089	24.2
11	8	356	364	25.3
12	7	349	356	24.8
13	6	343	349	24.4
14	1,672	10,234	11,906	20.9
15	38	817	855	23.2
16	1,264	9,582	10,846	19.6
17	65	2,376	2,442	21.2
18	60	1,326	1,386	20.3
19	2,907	9,332	12,238	15.2
20	2,294	12,950	15,244	14.6
21	1,971	9,459	11,430	12.0
22	28,466	5,537	34,003	1.6
Total	40,213	95,446	135,659	

[1]Calculated on the basis of average annual precipitation of 108 mm (Andraski, 1996), trench dimensions, period of time trenches were open, and date of site closure (see Table 1).
[2]Sampling for tritium and carbon-14, April, 1994 (Striegl and others, 1996).

Table 3. Trench Data, Richland LLRW Site[1]

Trench Number	Date Opened	Date Closed	Trench Depth (m)	Trench Volume (m^3)
1	9/16/65	9/12/66	?	1,829
2	8/18/66	11/30/71	?	4,193
3	12/1/71	3/31/75	?	3,669
4	4/1/75	8/10/78	9.1	8,514
4A	4/30/82	6/18/82	6.1	344
4B	7/9/84	8/23/85	12.2	12
5	4/29/78	9/5/79	9.1	13,762
6	8/22/79	6/10/80	9.1	20,950
7	10/29/82	10/12/83	12.8	30,811
7A	6/3/85	7/16/85	7.3	205
8	5/5/80	5/22/81	10.7	31,695
9	9/9/83	11/30/84	13.7	43,658
10	5/5/81	12/20/82	13.7	61,849
11A	10/29/84	11/7/85	13.7	32,731
11B	10/29/84	open	13.7	open
13	7/29/85	3/31/95	13.7	35,336
14	2/2/87	open	13.7	open
16	1/8/92	open	13.7	open
18	11/21/95	open	13.7	open
Tank Farm	6/12/72	5/4/87	6.7	209
Chemical	No info.	1971	?	

[1]Data from Washington State Department of Health (G. Robertson, written comm., 1997)

Table 4. Gross Alpha, Gross Beta, and Tritium Activity (pCi/L) in Ground Water at the Beatty LLRW Site[1]

Year	Gross Alpha[2]	Gross Beta[2]	Tritium	Year	Gross Alpha[2]	Gross Beta[2]	Tritium
1962	3±2	54±4	No data	1978	3±2	<20	No data
1963	No data	No data	No data	1979	10±5	<20	**3,800±1,100**
1964	8±3	50±6	No data	1980	<5	10±4	1,700±900
1965	20±5	60±31	No data	1981	21±7	31±4	0
1966	10±5	60±34	No data	1982	**710±183**	**340±49**	**410,000±1,000**
1967	10±4	40±28	No data	1983	**140±98**	**930±150**	**48,900±3,000**
1968	14±5	52±3	No data	1984	**63±29**	**140±24**	**3,600±200**
1969	6±3	41±41	No data	1985	**560±160**	**710±50**	**2,164±838**
1970	**39±7**	**94±30**	No data	1986	**61±20**	**99±10**	700±200
1971	No data	No data	No data	1987	**60±2**	**106±10**	No data
1972	10±4	9±4	320±290	1988	**31±11**	**68±3.9**	240±96
1973	**46±7**	**549±47**	No data	1989	**20±14**	**30±23**	1,457±526
1974	16±10	**132±77**	No data	1990	**78±24**	**63±11**	<500
1975	**47±9**	**173±55**	No data	1991	10±6	11±5	1,079±551
1976	12±5	40±32	No data	1992	7±3	13±3	<500
1977	<3	<30	No data				

[1]Data from Conference of Radiation Control Program Directors, Inc., 1994, Table 4-3. Values for gross alpha, gross beta, and tritium that exceeded action levels are shown in bold: gross alpha = 30.0 pCi/L; gross beta = 90.0 pCi/L; tritium = 2,000 pCi/L.
[2]Highest value for each year

Table 5. Gross Alpha and Gross Beta (pCi/g) in Soils at the Beatty LLRW Site[1]

Year	Gross alpha[2]	Gross beta[2]	Year	Gross alpha[2]	Gross beta[2]
1962	No data	No data	1978	18±6	60±24
1963	No data	No data	1979	31±13	80±31
1964	No data	No data	1980	23±6.1	**90±16**
1965	1.9±0.63	72±4.4	1981	**32±9.8**	60±15
1966	2.7±1.2	73±5.3	1982	25±6	66±18
1967	1.7±0.64	3.5±0.34	1983	24±7	52±15
1968	2.94±0.41	5.03±0.57	1984	25±7	52±15
1969	9.5±3.7	37±4.1	1985	16±3	40±17
1970	No data	No data	1986	10.2±1.6	9.6±1.0
1971	8.9±3.8	80±4.9	1987	1.3±0.3	7.0±0.8
1972	13±5	**108±32**	1988	5.7±1.1	6.6±0.9
1973	6±3	**110±40**	1989	9.3±2.5	21.5±1.3
1974	18.2±8.2	**253.6±111**	1990	12.8±3	51.5±7
1975	**64±15**	**614±60**	1991	3.5±1.0	22.0±1.3
1976	**42±7.7**	**257±28**	1992	5.4±2.7	28.4±2.3
1977	20±6.1	60±24			

[1]Data from Conference of Radiation Control Program Directors, Inc. (1994, Table 4-5). Values for gross alpha and gross beta that exceeded action levels are shown in bold: gross alpha = 30.0 pCi/g; gross beta = 90.0 pCi/g. Dry well samples from adjacent to the trenches, minimum of 3 m below trench bottom.

[2]Highest value for each year.

Table 6. Gross Alpha and Gross Beta (pCi/g) and Tritium (pCi/L) in Vegetation at and Near the Beatty LLRW site[1]

Year	Gross alpha[2]	Gross beta[2]	Year	Gross alpha[2]	Gross beta[2]
1962	0.73±0.32	126±3.1	1978	0.7±0.03	36.9±9
1963	No data	No data	1979	0.7±0.6	29.3±4.2
1964	No data	No data	1980	2.4±1	50±5.1
1965	0.13±0.04	21±0.5	1981	9±4	17.6±1.4
1966	0.9±0.45	110±5.4	1982	2.4±2	30±4.9
1967	0.39±0.22	8.0±0.4	1983	6±3	55.7±4.9
1968	0.16±0.04	13.3±0.2	1984	6.3±1.8	15.5±2.3
1969	0.17±0.12	31.3±0.27	1985	7.2±1.3	16±1
1970	No data	No data	1986	0.8±0.2	5.8±0.2
1971	0.19±0.16	2.8±0.3	1987	5.3±2.7	77.6±2.5
1972	1.4±1.0	**722±35**	1988	3.2±0.4	10±0.3
1973	0.36±0.32	27.2±3	1989	0.6±0.2	65.5±8.1
1974	3.8±4.1	**420±110**	1990	3.1±2.4	16.3±3.6
1975	3.49±2.2	146±30	1991	0.5±0.2	5.9±0.3
1976	9±3	**220±20**	1992	11.4±2.3	48.9±2.8
1977	0.3±0.006	39.6±14.5			

Year	Vegetation	Tritium	Year	Vegetation	Tritium
1994	6 creosote shrubs SW corner	9,472±160 to 31,360±288	1994	1 tumbleweed SW corner	13,184±160

[1]Data from Conference of Radiation Control Program Directors, Inc. (1994, Table 4-7), tritium data from Striegl and others (1996). Values for gross alpha and gross beta that exceeded action levels are shown in bold: gross alpha = 20.0 pCi/g; gross beta = 200.0 pCi/g.

[2]Highest value for each year.

Table 7. Tritium (^{3}H) and Carbon-14 (^{14}C), Unsaturated Zone Adjacent to and Near the Beatty LLRW Site[1]

Depth Below Surface (m)	Date Sampled	^{3}H Concentration (pCi/L)	^{14}C (% modern carbon)
Pore Water[2], Test Holes UZB-1, 2			
2.8-2.90	1992	1,514±115	
5.9-6.00	do	224	
9.1-9.2	do	634	
11.9-12.0	do	474	
15.2-15.3	do	634	
18.0-18.1	do	890	
21.0-21.2	do	822	
36.4-36.6	1993	314	
48.5-48.6	do	147	
60.7-60.8	do	29	
72.5-72.7	do	14	
85.1-85.3	do	4	
Vapor, Test Hole ~3.2 km South of Site			
10.4	1992	10±19	101±.76
do	1995	0±19	
12.5	1992		90±.72
do	1995	16±19	
12.5	do	-3±19	
18.6	1992		78±.67
28.3	do		55±.75
Vapor, Research Shaft			
6.1	1995	294±19	
do	do	294±19	
11.0	do	1,980±32	
do	do	1,968±32	
13.1	do	733±22	
Vapor, Shallow Probe A			
1.7	1995	28,736± 224	451,000± 2,800
Vapor, Shallow Probe B			
1.7	do	94,080± 672	517,000± 2,100
1.8	1996	93,504± 1,792	
do	do	95,072± 1,856	
do	do	92,256±1 ,792	
Vapor, Shallow Probe near UZB-2			
1.7	1996	65,920± 1,280	
Vapor, Shallow Probe C			
2.0	1996	53,024± 1,088	
do	do	53,856± 1,088	
do	do	52,736± 1,024	
Vapor, Test Hole UZB-2			
5.5	1994	637±16	1,700±19
do	1995	797±26	
do	do	810±26	
do	do	768±26	
do	do	790±26	
do	do	778±26	2,160±11
do	1996	1,229±83	
do	do	954±83	
11.9	1994	2,358±32	
do	1995	2,826±38	815±5.1
do	1996	2,976±122	
do	do	2,976±122	
18.0	1994	1,859±26	
do	1995	2,314±35	
do	do	2,048±38	
do	1996	2,592±115	
24.1	1994	2,438±32	199±26
do	1995	3,529±45	201±1.5
do	1996	3,216±128	
do	do	3,219±128	
34.1	1994	851±32	81±1.2
do	1995	1,398±29	
do	do	1,190±29	133±.90
do	1996	2,374±109	
47.9	1994	634±16	
do	do	688±16	28±.69
do	1996	4,362±147	
94.2	1994	458±16	
do	1996	2,586±115	
106.1	1994	426±16	22±.17
108.8	1994	518±19	

[1]Data from Prudic and Striegl (1995), Striegl and others (1996), Prudic and others (1997)
[2]Error is two-sigma counting uncertainty

Table 8. Gross Alpha, Gross Beta, and Tritium Concentrations (pCi/L) in Ground Water, Richland LLRW Site[1]

Constituent[1]	Well # 003	Well # 005	Well # 008	Well # 010	Well # 013
			1986		
Gross Alpha					
Gross Beta					
Tritium	3,550	952	1,180	884	1,190
			1987		
Gross Alpha					
Gross Beta					
Tritium	3,000	1,140	1,010	883	1,120
			1988		
Gross Alpha					
Gross Beta					
Tritium	1,680	690	690	690	1,090
			1989		
Gross Alpha					
Gross Beta					
Tritium	1,590	--	--	870	1,490
			1990		
Gross Alpha					
Gross Beta					
Tritium	1,610	1,550	1,140	952	1,570
			1991		
Gross Alpha	<4.0±4.0	<5.0±5.0	6.0±2.0	6.0±5.0	<2.0±4.0
Gross Beta	7.0±1.0	8.0±1.0	8.0±1.0	7.0±1.0	8.0±1.0
Tritium	1,520±120	1,570±120	997±109	928±105	1,970±120
			1992		
Gross Alpha					
Gross Beta					
Tritium	2,150	1,740	1,707	1,270	2,450
			1993		
Gross Alpha	2.0±.6	2.0±.8	2.4±.8	<2	<2
Gross Beta	7.1±.8	7.7±.8	7.1±.7	6.1±.8	7.6±.8
Tritium	2,615±176	1,847±148	2,094±163	1,553±148	3,114±187
			1994		
Gross Alpha	2.5±.7	1.6±.6	1.8±.7	1.4±.6	2.0±.8
Gross Beta	8.6±.9	6.4±.7	7.8±.8	7.6±.7	8.6±.8
Tritium	3,250±177	1,920±139	2,091±151	1,728±137	3,559±178
			1995		
Gross Alpha	2.4±.6	1.8±.6	2.7±1.0	1.9±.8	2.9±1.0
Gross Beta	11.7±1.4	6.1±1.2	7.0±.7	6.7±1.2	8.7±1.4
Tritium	3,329±170	2,025±154	2,291±147	1,838±136	3,780±179
			1996		
Gross Alpha	7.5±.8	2.1±.7	2.1±.8	1.5±.8	2.8±.7
Gross Beta	7.5±.8	6.2±.7	7.6±.8	8.4±.8	8.4±.8
Tritium	3,984±190	2,121±150	2,632±157	2,039±157	4,106±188

[1]Data from Conference of Radiation Control Program Directors (1996), Washington State Department of Health (1993), Washington State Department of Health (written comm., 1997), US Ecology (1994, 1995).

Table 9. Tritium (^3H) Concentrations in Soil Samples from Unsaturated Zone Monitoring Wells, Richland LLRW Site[1]

Depth Interval (m)	^3H Concentration (pCi/g)	^3H Concentration (pCi/L)[2]	Depth Interval (m)	^3H Concentration (pCi/g)	^3H Concentration (pCi/L)[2]	Depth Interval (m)	^3H Concentration	^3H Concentration (pCi/L)[2]
	VW-100			VW-101			VW-102	
14.3-14.9	<.0045	<7.2	6.1-6.7	3.105±.038	4,968	10.1-10.7	34.376±.148	55,002
15.8-16.5	<.0033	<5.3	7.6-8.2	1.176±.019	1,882	11.6-12.2	7.696±.057	12,314
17.4-18.0	<.0031	<5.0	9.1-9.8	2.403±.024	3,845	13.1-13.7	4.410±.045	7,056
18.9-19.5	<.0037	<5.9	10.7-11.3	1.583±.017	2,533	16.2-16.8	2.625±.046	4,200
20.4-21.0	<.0046	<7.4	12.2-12.8	6.896±.037	11,034	17.7-19.2	3.200±.041	5,120
21.9-22.6	<.0097	<15.5	14.0-14.3	17.261±.061	27,618	20.7-21.3	2.193±.031	3,509
23.5-24.1	<.0117	<18.7	15.2-15.8	5.840±.035	9,344			
25.0-25.6	<.0092	<14.7	16.8-17.4	2.889±.022	4,622			

[1]Data from US Ecology (1993a). Unsaturated zone monitoring wells drilled and sampled in 1991. See Figure 7 for well locations. VW-100 = "control well", in undisturbed area removed from waste trenches; VW-101, immediately south of trenches 4 and 5; VW-102, immediately south of trenches 10 and 11A. Trenches 10 and 11A are ~13.7 m deep. Trenches 4 and 5 are ~9-11 m deep. Trench 4 opened 5/1/75 and closed 8/10/78; trench 5 opened 5/29/78 and closed 9/5/79; trench 10 opened 5/5/81 and closed 12/20/82; trench 11A opened 10/29/84 and closed 11/7/85.

[2]Tritium concentrations recalculated to pCi/L using sediment density of 1.6 g/cc (SAT-UNSAT, Inc., 1992).

Table 10. Tritium Concentrations (pCi/L x 10^3) in Unsaturated Zone Vapor Samples, Richland LLRW Site[1]

SS-100	VW-100	SS-101	VW-101	SS-102	VW-102
			1993		
	1.4±.13		239±1.0		450±2.0
			1994		
.1±.08	1.7±1.02	3.6±.18	283±1.0	2.3±.15	497±1.0
			1995		
2.1±.15	.9±.90	5.2±.33	313±2.0	5.9±.22	475±2.0
			1996		
1.7±.14	.7±.12	2.8±.17	337±2.0	10.9±.29	497±2.0

[1]Data from US Ecology (1993b, 1994, 1995, 1996), maximum value from quarterly measurements. SS-100, Solar Still, sampled condensed moisture from upper 46 cm of soil at Vadose Monitoring Well VW-100 site. SS-101, Solar Still, sampled upper 46 cm of soil at Vadose Monitoring Well VW-101 site. SS-102, Solar Still, sampled upper 46 cm of soil at Vadose Monitoring Well VW-102 site.

Table 11. Tritium (pCi/L x 10^3) in Trench Cap Vegetation, Richland LLRW Site, 1987-1996[1]

Trench #	^3H	Trench #	^3H
1987			
1	1.5±.3	5	39.4±2.1
2	7.0±5.3	8	19.8±1.2
3	2.6±.40	9	47.2±2.6
4	3.8±.40	10	11.3±.70
4A	12.3±.80	11A	60.5±3.2
4B	2.3±.30		
1988			
1	2.1±.29	6	27.5±2.1
2	.9±.2	7	23.3±1.8
3	4.1±4.4	7A	1.2±.22
4	106±7.9	8	34.7±2.7
4A	17.6±1.4	9	6.1±.58
4B	5.2±.51	10	1,510±110
5	1,100±80.4	11A	752±55
1989			
4	103±7.7	6	51.3±3.9
4B	2.7±.34	11A	1,040±75.8
5	4,270±311	Resin Tank	34.7±26.5
1990			
1	.33±.21	5	466±34
2	.54±.22	6	815±60
3	18.6±1.5	7	95.3±7.1
4	24.1±1.9	8	21.8±1.7
4A	2.4±.33	9	82.6±6.2
4B	5.0±.51	Resin Tank	8.5±.76
1991			
1	2.3±1.7	6	.2±.07
2	2.0±.75	7	.9±.21
3	2.0±1.2	8	.9±.38
4	1.0±.46	9	.4±.15
4A	1.1±.65	11A	.4±.10
5	2.3±.79	Resin Tank	.6±.24

Trench #	^3H	Trench #	^3H
1992[2]			
1	.7±.10	7	2.1±.10
2	1.4±.10	7A	31.9±.50
3	1.5±.10	8	25.4±.40
4	3,.2±.20	9	26.4±.40
4A	.8±.11	10	25.2±.40
4B	1.1±.10	11A	173±1.0
5	3.1±.20	Resin Tank	9.6±.30
6	8.9±.20		
1993			
1	3.0±.20	7	3.8±.10
2	1.0±.10	7A	7.4±.20
3	<.30	8	1.3±.10
4	.7±.10	9	1.9±.10
4A	1.4±.10	10	4.1±.20
4B	.3±.10	11A	15.3±.30
5	1.2±.10	Resin Tank	2.6±.10
6	1.0±.10		
1994			
7A	.4±.07	Resin Tank	2.3±.11
10	20.8±.30		
1995			
1	12.6±.26	6	1.3±.10
2	6.9±.23	7	30±.37
3	5.2±.16	8	10.8±.23
4	.5±.06	9	37.7±.43
4A	.3±.06	10	17.7±.29
4B	.3±.06	11A	16.2±.29
5	4.2±.15	13	212±2.1
1996			
1	4.2±.20	7	21.4±.30
2	8.4±.20	7A	.3±.02
3	19.2±.30	8	1.6±.10
4	.3±.10	9	30.5±.40
4A	1.2±.10	10	18.6±.16
4B	.1±.10	11A	12.0±.12
5	.4±.10	13	5.2±.08
6	144±.90		

[1]Data from US Ecology (1988, 1989, 1990b, 1991, 1992b, 1993a,b, 1994, 1995, 1996)

[2]From 1992 on, results are reported in pCi/g of moisture derived from vegetation; conversion to pCi/L here assumes moisture has a density of 1.0 g/cc.