

A Preliminary Human Health Risk Assessment for the Mixed Waste Landfill, Sandia National Laboratories, Albuquerque, New Mexico



by R. Johnson, D. Blunt, D. Tomasko, H. Hartmann, and A. Chan

Environmental Assessment Division

Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439

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Abstract

The Mixed Waste Landfill (MWL) at Sandia National Laboratories, Albuquerque, New Mexico (SNL,NM) was used as a disposal facility for radioactive and chemical wastes for approximately thirty years. Over time, tritium in the form of tritiated water has proven the most mobile of contaminants, having reached depths in excess of 100 feet, and having spread laterally in the vadose zone beyond the confines of the MWL fence line. This report presents a screening approach to evaluate the current and future human health risks posed by tritium via transport to the water table. In addition, this report places the human health risks posed by tritium in the context of risks posed by other contaminants known to be present at the site, based on sampling evidence to date. In the case of the MWL, a screening approach is utilized as an effective tool for demonstrating that tritium in groundwater poses minimal current or future human health risks at this facility.

1 Introduction

The Department of Energy's (DOE) various facilities include thousands of sites that have been identified as potentially posing human health risks because of past environmental contamination. Sandia National Laboratories, located in Albuquerque, New Mexico (SNL,NM), has more than 200 such sites. Fully characterizing the threats posed by all of these sites using traditional characterization methodologies is an impractical approach, both in terms of the fiscal resources and time that would be required. The danger of applying traditional characterization methodologies to these sites is that inordinate attention may be paid to sites that pose little or no human health risk, while sites with immediate human health risk concerns go unattended.

The EPA has recognized that human health risk concerns should be used to prioritize actions. EPA guidance on the application of human health risk assessment techniques to site characterization can be found in the series "Risk Assessment Guidance for Superfund (RAGS) (EPA 1989a; 1991a-c). One difficulty in the application of Superfund health risk assessment procedures is the quantification of uncertainty. A variety of approaches have been proposed for dealing with risk assessment uncertainty, including explicit treatment of uncertainty through Monte Carlo procedures. While Monte Carlo procedures are conceptually appealing, their proper application is even more data intensive than deterministic risk assessment methodologies, and the results can be misleading if uncertainties associated with model choice and assumed parameter probability distributions are not adequately

addressed.

The approach demonstrated in this report relies on screening techniques applied to contaminant transport mechanisms. These screening techniques have been recommended by the U.S. EPA as part of the characterization process for sites regulated under the Resource Conservation and Recovery Act (RCRA) (EPA 1989b, 1990). The objective of screening techniques is not to fully quantify the probability distribution associated with the final risk assessment, but rather, where possible, to demonstrate that the probability of a particular pathway delivering contaminants that pose human health risks above a pre-specified threshold is highly unlikely. If, at an early stage of investigation and using very conservative assumptions on contaminant concentrations and transport parameters, it can be demonstrated that significant human health risks are unlikely, then lengthy and costly full-scale health risk assessments generally would not be necessary. This report demonstrates how a screening approach to human health risk assessments can be used to determine whether tritium in the form of tritiated water poses a significant current or future threat to the water table at the Mixed Waste Landfill (MWL), at SNL,NM. The screening approach is also used to address risks from other contaminants, based on available information.

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2 Site History

Sandia National Laboratories occupies land within Kirtland Air Force Base (KAFB), located along the southeastern edge of Albuquerque, New Mexico. The MWL is located in the north-central portion of SNL,NM's Technical Area 3 (Figure 1). The 2.6 acre site (1.1 hectare) was established in 1959 as a disposal area for radioactive, mixed, and hazardous wastes generated by SNL,NM's research facilities. The landfill accepted low-level radioactive wastes, mixed wastes, and hazardous wastes from 1959 through 1962, and low-level and mixed wastes from 1962 through December, 1988. Wastes were placed in a series of pits and trenches within the landfill. These pits and trenches are now backfilled and/or capped. Approximately 100,000 cubic feet of radioactive waste containing 6,300 Ci of activity at the time of their disposal were deposited at the MWL (SNL 1993b).

The MWL consists of two disposal areas: the classified area and the unclassified area (Figure 2). Low-level radioactive wastes, mixed wastes, and hazardous wastes have been disposed of in both areas. The classified area is the oldest part of the MWL. Classified wastes (including materials which by shape or content contained information important to national security) were buried in a series of approximately 40 unlined pits. The classified area pits were cylindrical or square, about 1.5 to 3 m (5 - 10 ft) in width and 7.6 m (25 ft) deep. Unclassified wastes were disposed of in seven trenches occupying the major portion of the landfill. The unclassified area trenches were typically 10.6 m (35 ft) wide and 55 m (180 ft) long at the top, and between 4 and 7.6 m (13 and 25 ft) deep. Their exact dimensions and location have not been determined.

Between 1959 and 1962, chemical wastes were disposed of in Pit 1, located in the southeast corner of the classified area. These wastes included acids, solvents such as trichloroethylene (TCE) and carbon tetrachloride (CCl₄), and scintillation cocktails (typically toluene-based). Other wastes disposed of in the classified area include uranium, thorium, enriched lithium, various radioactive

sources, miscellaneous plutonium contaminated wastes, and plutonium contaminated nuclear weapons test debris. Several pits in the northeast corner of the classified area were used specifically for disposal of depleted uranium.

Starting in 1962, nonclassified waste disposal began in the unclassified area of the MWL. Early waste disposal occurred in the four northern trenches, and disposal from 1979 to 1988 occurred in the three southern trenches. Known waste disposal in the unclassified area consisted mainly of tritium, and radiologically contaminated soil, debris, laboratory equipment, and lead. It is believed that little or no hazardous wastes were disposed in the unclassified area since the Chemical Waste Landfill (CWL) (Figure 1) was established in 1962, specifically for the disposal of hazardous wastes.

In 1967, approximately 270,000 gallons of coolant water from the Sandia Engineering Reactor Facility (SERF) were disposed of in Trench D. The trench may have already contained waste at the time. Approximately 1 Curie (Ci) of total radioactivity, mainly short-lived radionuclides, was discharged into the trench with the coolant water.

All of the pits in the unclassified area were backfilled after their holding capacity was reached. The depth of the backfill covers is not known. The last trench in the unclassified area (Trench G) was backfilled in May 1990. Four of the pits in the classified area were covered with concrete, plywood or steel caps and backfilled at the time of closing. The rest of the classified area pits were simply backfilled.

3 Environmental Setting

3.1 Climatic

The closest source of meteorological information is a National Oceanic and Atmospheric Administration (NOAA) meteorological station at the Albuquerque International Airport which is located approximately four miles from the MWL. Albuquerque's climate is designated as "arid continental", characterized by low precipitation, wide temperature extremes, frequent drying winds, heavy, short rain showers, and erratic, seasonal distribution of rainfall. The average temperature in Albuquerque is 56 degrees Fahrenheit, with temperatures reaching 90 degrees an average of 63 days a year. The air is normally dry, with average annual relative humidity around 44 percent. Half of the average annual precipitation (8.4 inches) occurs during intense summer thunderstorms between July and September. Potential evapotranspiration for the Albuquerque area is 30.9 inches. Actual evapotranspiration has been estimated at 95% of the annual rainfall (Thomson and Smith 1985). The average annual wind speed for the Albuquerque area is 9 mph (4 m/s).

3.2 Soils

Soils in the vicinity of the MWL are of the Madurez Loamy Fine Sand Series. They are derived from old alluvium modified by wind. Slopes are gentle, ranging from 1 to 5 percent. Madurez Fine Sandy Loam soils are also prevalent. These soils are well drained with little runoff. Wind erosion potential is moderate to severe, particularly if vegetation has been disturbed. Vegetation in the area is sparse; the major types of vegetation include sage, tumbleweed, grass, and varieties of small cactus.

3.3 Geology

The MWL is located in the Rio Grande Valley of the Mexican Highland Subdivision of the Basin and Range Physiographic Province. The Rio Grande Valley is a depressed linear feature that extends from Colorado to Mexico. KAFB is located on the East Mesa of the Rio Grande Valley, generally west of the Sandia and Manzano mountains. The mesa is a prominent physiographic feature that appears as a level to gently sloping shelf extending from the Inner Valley of the Rio Grande River on the west to the Manzano Mountains to the east. The Inner Valley of the Rio Grande River is the lowest point in terms of surface elevation (4,900 ft above mean sea level). The mesa on which the site is located averages about 5,400 feet above sea level.

The MWL is located on the Sandia-Manzano piedmont plain in a coarse-grained, marginal portion of the Sante Fe Formation. The site is underlain by more than 500 feet of Pliocene deposits of the Ceja Member of the Sante Fe Formation and younger materials. The Ceja Member consists of sandy gravel and gravelly sand interbedded with tabular to lenticular lenses of buff colored clay, silt, and sand that range in thickness from less than one foot to more than 40 feet. The MWL is underlain by the Sante Fe Group deposits. Bedding is often of limited aerial extent. Caliche layers are commonly formed on subaerially exposed surfaces. Analysis of samples from MWL monitoring wells and soil bores show little correlation of layers between wells and borings. The coarse-grained sediments near the surface of the MWL generally grade to fine-grained sediments with depth.

Four major fault systems have been identified within the limits of KAFB (Figure 3). The Sandia Fault (normal fault, down to the west with displacements of more than 2,700 ft) is thought to cross KAFB. The influence of this fault on local groundwater movement is not presently well understood, although it has been postulated that deposition of travertine in the fault may severely limit westward migration of groundwater (Engineering Science 1981). The location of the Sandia Fault in the vicinity of the MWL is approximately one mile northeast of the site.

3.4 Ground Water Hydrology

KAFB lies within the limits of the Rio Grande underground water basin. The principal aquifer of the Rio Grande Basin and KAFB has been termed the "valley fill" (Engineering Science 1981). The valley fill is comprised of unconsolidated and semi-consolidated sands, gravels, silts, and clays of the Pliocene Sante Fe Formation, alluvial fan deposits associated with upland area erosion, and valley alluvium, associated with stream development. Groundwater exists in the valley fill in an unconfined state. Pumping of Albuquerque City wells has produced a significant lowering of the groundwater table. The underlying valley fill aquifer is the sole source for the City of Albuquerque's public water supplies.

KAFB obtains water from a system of twelve wells screened in the valley fill deposits and by purchasing additional supplies from the City of Albuquerque. Well locations are shown in Figure 4. Static water levels recorded in base wells west of the Hubbell Springs Fault vary from 123 m (403 ft) at Well 13 to 177 m (580 ft) at Well 11. The closest drinking water well to the landfill is Well 10, located about 610 m (2,000 ft) northeast of the site. The depth of groundwater beneath the MWL is about 140 m (460 ft); the direction of groundwater flow is to the west. There is no evidence of perched groundwater beneath the site (SNL 1993b). Water levels beneath the MWL are declining at a rate of about 1 ft/y because of extensive pumping of KAFB water supply wells to the northeast. The hydraulic conductivity of the saturated zone beneath the MWL is not known; however, the hydraulic conductivity of the saturated zone at the Chemical Waste Landfill (CWL) located 1.9 mi southeast of

the MWL has been estimated to be 0.39 ft/d (SNL 1993b).

The vadose zone beneath the MWL consists of unconsolidated to poorly consolidated alluvial deposits. Water can enter as infiltration, and exit either through evapotranspiration or recharge to the underlying aquifer. Evidence of net recharge to the aquifer from rain water infiltration in the area of the MWL is mixed. Soil samples from the surface and subsurface of the MWL show water contents ranging from negligible to 9% by volume, suggesting that vadose zone moisture is at or close to the residual moisture content for these soils.

3.5 Surface Water Hydrology

On KAFB, the Sandia-Manzano piedmont is dissected by two natural channels: Tijeras Arroyo and Arroyo del Coyote (Figure 5). Tijeras Arroyo is a west-trending ephemeral stream that has incised a steep-sided, flat-bottomed channel (arroyo) about 1/4 to 1/2 mile wide and 100 to 130 ft deep. Arroyo del Coyote starts on the west flank of the Manzano Mountains, and trends north-northwest until joining the Tijeras Arroyo in the City of Albuquerque. Arroyo del Coyote is about 100 to 400 ft wide and 4 to 20 ft deep. The MWL lies about 2 miles southwest of the Arroyo del Coyote drainage. Surface drainage from SNL,NM is from east to west toward the Rio Grande River. In the immediate vicinity of the MWL, there are no surface hydrologic features. Surface runoff from the MWL flows generally toward the west with eventual evaporation or infiltration to the vadose zone.

3.6 Land Use and Demographics

The MWL is located within the boundaries of SNL,NM's Technical Area 3, which is used for test facilities (e.g., sled tracks, centrifuges, and a radiant heat facility). The MWL is secured with a fence; security guards are present at the entrance to Technical Area 3 to limit access to the general area. The nearest residential areas are the City of Albuquerque which is approximately four miles west of the MWL, and the Isleta Indian Pueblo, which is approximately four miles to the south.

4 Summary of Data Collected

Systematic sample collection and analysis programs have been conducted since 1969. The following summary of past sampling programs and their findings is organized by contaminant type (radiological or chemical) to facilitate the subsequent screening risk analyses presented in Sections 5 through 7.

4.1 Radiological Contaminant Investigations

4.1.1 Surface and Subsoil Investigations

1969 Subsurface Soil Sampling at the MWL

Ten soil samples were collected from depths of 25 and 50 feet from five locations around the MWL to assess radionuclide transport from the MWL. The samples were analyzed for gross beta activity, total Sr, Cs-137, and gamma activity. Based on the results of these samples, Brewer (1973)

concluded that there was no evidence of radionuclide migration from the MWL. The exact locations of the sampling points and the raw sample results are not available.

1979 Subsurface Soil Sampling at the MWL

Thirty five soil samples were collected at one foot intervals from a pit dug to a depth of 35 feet that was adjacent to pits within the classified area known to contain tritium (Simmons 1980). The samples were analyzed for gross alpha, gross beta, total uranium and tritium. All uranium and gross alpha measurements were below the detection limit. The sample from a depth of 29 feet showed beta activity that was 10 times higher than the mean of the total number of samples. Tritium values above background were encountered in 25 of the 35 samples, particularly for samples at depths greater than 18 feet. The maximum value encountered was 389,000 pCi/L of extracted water at a depth of 23 feet. Soil moisture content values and soil densities for these samples are unavailable. The original data, along with the exact location of the sampling pit, are also unavailable.

1981 Surface and Subsurface Soil Sampling at the MWL

In 1981, 226 surface and subsurface soil samples were collected and analyzed for gross alpha, gross beta, tritium, gamma activity, and moisture content (Millard et al. 1983). Samples were collected at 10 locations and one location on the perimeter of the landfill which served as a background location. Samples were collected at the surface, and at increments of 2.5 feet thereafter to depths greater than 75 feet. Tritium levels at the background location were below the method detection limit (i.e., 450 pCi/L). The maximum tritium concentration (351 μ Ci/L) was detected in surface soil located adjacent to Pit 33 in the classified area which was active at the time. Concentrations of tritium in surface soil outside the disposal area ranged from 1,000 to 121,000 pCi/L. Subsurface tritium concentrations from borings within the disposal area ranged from 3,000 to 139,000 pCi/L. The original data, along with the exact location of the sampling points, are unavailable.

1982 Surface and Subsurface Soil Sampling at the MWL

In June, 100 surface soil samples were collected to determine the lateral extent of tritium migration (Millard et al. 1983). Samples were collected at 5 cm depths at regular intervals along transect locations along the perimeter of the fenced area, inside the unclassified area, inside the classified area, and adjacent to Pit 33 in the classified area. The study detected a maximum tritium concentration of 3.3 μ Ci/L adjacent to Pit 33. The study estimated that the total inventory of tritium within the classified area was 1180 μ Ci, with 96 percent of the total adjacent to Pit 33.

In July, four more soil borings were drilled at the MWL to a maximum depth of 27 m (90 ft). Boring 1 was adjacent to Pit 33, while borings 2, 3, and 4 were located outside the classified area fence. No detectable levels of tritium were found outside the boundaries of the classified area at any depth. The original data and exact locations of the borings/sampling locations for both studies are unavailable.

1989 Soil Samples Obtained During Monitoring Well Installation

Following standard RCRA guidance, four groundwater monitoring wells were installed in 1988 and 1989 adjacent to the MWL (Figure 2) (Ecology and Environment, Inc. 1989). Three wells, MWL-MW1, MWL-MW2 and MWL-MW3, were completed down gradient from the landfill. MWL-BW1 was completed up gradient and serves as the background reference well for the site. During well installation, soil samples were collected at different depths for MW1, MW3 and BW1 and analyzed

for tritium, gross beta, volatile and semi-volatile organic compounds, and gamma activity. Volatile and semi-volatile organics were not detected, and all radionuclide measurements, including tritium, were at background levels.

1990 Surface and Subsurface Soil Samples at the MWL

A total of 176 surface soil samples were collected from a surveyed grid system across the landfill (SNL and EE 1990). Ten percent (i.e., 17) of the samples were randomly selected and analyzed for gross alpha and gross beta, selected gamma emitters, and tritium. Ten of these samples had elevated tritium levels ranging from 7,000 to 390,000 pCi/L (Figure 6). Detection limits for tritium analyses were not reported.

A total of 285 subsurface soil samples were collected from 17 boreholes located around the perimeter of the landfill and one (background) borehole located 150 m (500 ft) south of the MWL (Figure 7). Soil samples were collected at 1.5 m (5 ft) intervals to a depth of 15 m (50 ft), and at 3 m (10 ft) intervals from 50 feet to a total depth of 30 to 46 m (100 - 150 ft). Five of the bores were angled to collect samples from beneath the landfill. All samples were analyzed for gross alpha, gross beta, selected gamma emitters, and tritium. In addition, 20 samples were analyzed for isotopic uranium and isotopic plutonium. Results are reported in the Phase 1 RCRA Facility Investigation (SNL and EE 1990).

Results for radionuclide analyses, other than tritium, were all below the method detection limit. Tritium was detected in samples from 14 of the 18 bores (detection limit of 2,000 pCi/L extracted water). Figure 7 shows the maximum value of tritium encountered in each bore and the depth at which it was seen. These values ranged up to 17 μ Ci/L encountered in bore SB-3 at a depth of 4.6 m (15 ft). Since many of these bores lie outside the fence line of the MWL, lateral tritium migration has obviously taken place, predominantly from the classified area. Figure 8 provides a profile view of the vertical distribution of tritium encountered by four bores: SB-2, SB-3, SB-4, and SB-5. The grey-shaded surface in this figure shows the logarithm of the tritium values observed. As is clear from this figure, the bulk of the contamination lies near the surface. Of the 18 bores drilled, only one, SB-5, encountered detectable tritium at depths greater than 100 feet. For this bore, the deepest detectable tritium concentration was measured at a depth of 110 feet.

1993 Slant Bore Drilling

A slant bore MWL-MW4 was completed beneath the MWL in March 1993, with entry just north of Trench D. The well was drilled to a total depth of 167 m (548 ft), and was screened in two zones beneath Trench D. During drilling, subsurface soil samples were collected and analyzed for potential contaminants. Appendix E contains the tritium results for these analyses. Figure 9 shows the vertical distribution of the tritium results for extracted water, the vertical distribution of soil moisture content for those samples with moisture content estimates, and the tritium values per liter of soil for those samples with both moisture content values and tritium extracted water results. The maximum value observed, 7,000 pCi/L, occurred within the top 11 m (35 ft) of soil. All subsequent measurements were less than 1,000 pCi/L. Since water content for all samples with moisture content values was less than 10% by volume, all samples had tritium concentrations less than 700 pCi/L of soil.

1993 Tritium Surface Soil Sampling Program

In July, 102 surface soil samples were collected and analyzed for tritium. Figure 10 shows the locations of the soil samples. Figure 10 also shows a grey-scale surface of the logarithm of tritium

values observed based on the sample results. These values range from less than 100 pCi/L of soil to approximately one $\mu\text{Ci/L}$ of soil. Assuming a conservative soil density of 1.2 g/cm^3 , this would translate to less than 1 pCi/g to 830 pCi/g. Again, as previous studies have shown, the highest concentrations of tritium in surface soil are found in the classified area, with contamination extending out beyond the MWL fence line. A complete list of the tritium soil sampling results is presented in Appendix C.

4.1.2 External Radiation and Air Investigations

1990 Radiation and VOC Walkover at the MWL

In 1990, a general radiation and VOC survey of the unclassified area was completed. The survey targeted ambient surface radiation and volatile organic vapors, and was conducted approximately 1 meter above ground surface. For volatile organic compounds, no measurements above background were obtained. Elevated radiation levels were detected along the north and east fence line of the classified area (i.e., 60 - 130 $\mu\text{R/hr}$), and along the fence line dividing the classified and unclassified areas. One location at the west central border of the classified area had an exposure rate of 5 mR/hr. The source of this radiation was thought to be associated with buried waste in pits that had not yet been capped in the classified area (SNL and EE 1990). Elevated exposure rates were also detected in the southwest corner of the unclassified area, which is used as a temporary above-ground storage facility. Exposure rates ranged from 80 - 1,000 $\mu\text{R/hr}$.

1989-1990 Air Sampling at the MWL

Air sampling for tritium vapor and radioactive particulates was conducted at several locations in and around the MWL to determine fugitive emissions from the MWL (SNL and EE 1990). Sorbent tubes were used to collect water vapor for tritium analysis, and cellulose filters were used to collect airborne particulates for gross alpha and gross beta analysis. Air monitoring was also conducted during soil sampling activities. All samples indicated activity at or below background levels.

1992 Air Monitoring Program

During the summer of 1992, a 16 week air-monitoring program was conducted to monitor for fugitive VOC, particulate radionuclide and vapor-phase tritium emissions from the MWL. Tritium flux measurements were taken from 15 locations spread across the landfill (Figure 11). Measured values ranged from 41 to 6,170 $\text{pCi/m}^2/\text{hr}$. Maximum flux values were observed in and adjacent to the classified area, an observation consistent with earlier surface and subsurface soil sampling results. The PM10 filter samples were analyzed for beryllium, total uranium and plutonium. All particulate measurements were below background (Radian Corp. 1992).

1992 Radiation Walk-Over Survey

A gamma survey of the northern portion of the unclassified area was conducted in October, 1992. The walk-over was done with an NaI scintillator at a height of 1 m (3 ft). The survey consisted of 10 background points southwest of the MWL, and 420 grid locations in the north unclassified area. Exposure rate measurements ranged from 10 to 600 $\mu\text{R/hr}$. The highest measurements were located on the boundary of the classified area and are believed to be associated with a buried reactor vessel in the classified area. Figure 12 provides an indication of the spatial distribution of exposure rates. A complete list of data generated by this survey can be found in Appendix B.

1993 Tritium Flux Monitoring

In the fall of 1993, Radian Corporation completed a passive soil gas monitoring program for tritium and VOC fluxes at the MWL. A total of 27 sampling locations were monitored for tritium flux. Their locations are shown in Figure 13. Of the 27 locations, 26 were selected to represent potential tritium flux "hot-spots" based on past near-surface tritium sampling results. One location was remote from the MWL and was used as a background measurement. Observed values ranged from 100 pCi/m²/hr to 166,000 pCi/m²/hr. The distribution of tritium fluxes does in fact show a strong correlation with the tritium soil sample results shown in Figure 10. A complete list of data generated by the Radian tritium sampling is contained in Appendix F.

4.1.3 Groundwater Monitoring Program

Groundwater monitoring has been conducted at the MWL on a regular basis since September, 1990. Three down-gradient monitoring wells and one background location monitoring well were installed in 1988 and 1989 (see Figure 2 for locations). The monitoring wells were sampled quarterly from September 1990 to January 1992, and semiannually thereafter. Samples are analyzed for radionuclides including tritium. Tritium measurements for the monitoring wells adjacent to the MWL have consistently yielded tritium values that are below detection limits. Detection limits for these analyses range between 200 and 400 pCi/L. No elevated levels of other radionuclides have been observed (SNL 1993a).

4.2 Chemical Contaminant Investigations

4.2.1 Soil Investigations

1990 Surface and Subsurface Soil Samples at the MWL

A total of 285 subsurface soil samples were collected from 18 bore holes. Seventeen bore holes were located around the perimeter of the landfill and one (background) was located 500 feet south of the MWL (Figure 7). Soil samples were collected at 5 foot intervals to a depth of 50 feet, and at 10 foot intervals from 50 feet to a total depth of 100 to 150 feet. Five of the bores were angled to collect samples from beneath the landfill. A total of 185 samples were analyzed for VOCs and SVOCs on the EPA's standard Target Compound List (TCL), and 70 samples were analyzed for Target Analyte List (TAL) metals. An photo-ionization detector was used to monitor samples collected during the bore hole drilling process---some volatile organics were detected. Levels of toluene, chloroethane, methylene chloride, 1,2-dichloroethene, di-n-butyl phthalate and bis(2-ethylhexyl)phthalate up to 1.3 mg/kg were detected in some samples from bores adjacent to the landfill (i.e., angled boreholes SB-8, SB-10 and SB-17). Interpretation of these values is difficult, however, because methylene chloride, acetone, toluene and bis(2-ethylhexyl)phthalate were also detected in background samples at concentrations of up to 0.5 mg/kg, suggesting laboratory contamination.

In general, for the seventy subsurface soil samples from bore holes surrounding the landfill analyzed for metals, the concentrations in landfill boreholes were within the range reported for the background location (SNL and EE 1990). No surface soil samples were analyzed for metals.

4.2.2. Air Investigations

August-September 1993 Passive Soil Gas Survey by Quadrel Inc.

A passive soil gas survey for VOCs was conducted in two rounds by Quadrel Inc. (Quadrel Services 1993a). The first round was completed August 2, 1993; the second round was completed September 20, 1993. The classified area where samples were concentrated corresponded to inactive burial pits where past VOC disposal was suspected. Seventy-one and 22 collection devices were used in the first and second sampling rounds, respectively. The collection devices were analyzed for VOCs on the EPA's standard TCL. Three additional compounds (isopropyl ether, dichloroethyne, 1,1,2-trichlorotrifluoroethane) were also identified. The following compounds were detected (number in parentheses shows number of detections): acetone (8), 1,1-dichloroethene (1), dichloroethyne (12), ethyl benzene (1), isopropyl ether (2), styrene (1), tetrachloroethene (63), toluene (17), 1,1,1-trichloroethane (27), trichloroethene (46), 1,1,2-trichlorotrifluoroethane (9), and xylene (1). Figures 14 and 15 show the spatial distribution for tetrachloroethene and trichloroethene flux values, respectively. Table 1 shows the range of flux levels for the 12 compounds detected.

The survey also included nine control samples. The purpose of these samples was to detect and measure ambient-air contamination by exposing each control sample to an ambient-air volume equivalent to that to which the field samples were also exposed. Methylene chloride was detected in a control sample at a concentration higher than was found in site samples, and was therefore not considered to be due to contaminant flux from the MWL. Additionally, 1,1,2-trichlorotrifluoroethane was detected in one control and acetone was detected in two controls. The highest level detected was subtracted from each detected field sample value.

The flux values are measures of vapor escaping the soil surface. The locations of detected VOC flux levels may not correspond spatially to the subsurface location of contamination because vapor escaping the subsurface follows the path of least resistance which may not be directly vertical. Also, although the flux measurements indicate the presence of VOCs, it is difficult to draw any correlation between their values and the level of contamination present in the soil.

October 1993 Soil Gas Investigation by Radian Corp

Another soil gas survey for VOCs was conducted by Radian Corp. in October 1993 to confirm the results of the August-September 1993 survey (Radian 1994). VOC flux measurements were obtained from 10 sampling locations in and around the MWL (Figure 16). Location and analyte selection was based on the results of the previous survey. Samples were analyzed for 21 different VOCs, and additional chromatogram screening was done to determine whether other VOCs were present at concentrations greater than 2 ppb (by volume). Table 1 shows the number of detections and range of flux levels for detected compounds.

Six compounds were detected in the Radian survey, two of which had not been detected in the previous survey by Quadrel (i.e., benzene and methylene chloride). However, results were fairly comparable to the previous survey, in that all compounds with the highest detection frequency in the first survey were also detected in the second survey, and at comparable flux levels (e.g., the maximum value for tetrachloroethene in the Quadrel survey was 400 ng/m²/min; the maximum in the Radian survey was 1,000 ng/m²/min). A background location 500 ft west of the northwest corner of the MWL was also included in the survey; however, the location was subsequently found to have possible contamination from recent construction activities and the data were, therefore, not considered representative of background concentrations.

Groundwater sampling results for MWL are described in Sandia Annual Reports (SNL 1992; SNL 1993a). For calendar year 1991, quarterly samples were analyzed for drinking water supply parameters (metals, pesticides, herbicides, nitrate, coliform bacteria, alpha activity, beta activity and radium), groundwater quality parameters (Cl, Fe, Mn, Na, sulfate and phenols) and groundwater contamination parameters (pH, SC, TOX, and total organic carbon [TOC]). Detected chemical parameters included barium, chromium, iron, manganese, sodium, chloride, fluoride, nitrate, phenolics, sulfate and TOC. Only TOC and phenolics were detected in amounts above the State of New Mexico maximum contaminant levels (MCL). TOC was detected in MW2 and in the background monitoring well at concentrations of 0.51 to 0.64 mg/L, as compared with an MCL of 0.50 mg/L. Phenolics were detected in the January and April sampling rounds at concentrations of 0.011 and 0.013 mg/L, respectively, as compared with an MCL of 0.005 mg/L. Phenolics were also detected in the January method blank. Phenolics were not detected in the July and October sampling rounds.

For calendar year 1992, sampling frequency was lowered to semi-annually and annually for various analyte groups. Detected parameters included calcium, barium, magnesium, sodium, nickel, iron, chromium, aluminum, mercury, chloride, sulfate, and TOC. TOC was detected at a concentration of 0.71 mg/L in MW-1 and 0.65 mg/L in MW-2, as compared with the MCL of 0.50 mg/L. The past presence of TOC in the background well at similar levels indicates that this screening parameter probably does not indicate site-related contamination. Based on the results from these six sampling rounds, there is no indication that groundwater beneath the MWL is contaminated (SNL 1993b). No other compounds exceeded state MCL levels.

5 Conceptual Model for the Mixed Waste Landfill

A conceptual site model for the MWL was developed to identify contaminant source areas, potential release and transport mechanisms, environmental media of concern, potential human receptors, and potential routes of exposure. The model was developed on the basis of current understanding of the site and is depicted in Figure 17. Individual components of the model are described below.

5.1 Contaminant Sources

For the MWL, the contaminant sources are radioactive and chemical wastes buried in the landfill. The waste is estimated to extend to a depth of 7.6 m (25 ft). The MWL consists of two distinct areas, the classified area where wastes containing information important to national security were buried in pits, and the unclassified area where radioactive and chemical wastes were buried in a series of seven trenches. Disposal activities in the unclassified area ceased in 1988, but a few of the pits in the classified area have only recently been closed and capped. The south side of the unclassified area is currently being used for the temporary storage of containerized waste. Because of the temporary nature of this waste storage, the containerized wastes are not considered in the conceptual site model.

A summary of the nature and extent of radioactive and chemical contaminants that are buried in the MWL is presented below. The summary of radioactive contaminants is based on data from the

Solid Waste Information Management System (SWIMS), a computerized database. Although records contained in SWIMS are incomplete, it serves as the best source of information for the MWL (SNL 1993b). Information about the contents of the MWL was also obtained from interviews with former SNL/NM employees (Peace 1994).

5.1.1 Radioactive Contaminants

It is estimated that approximately 100,000 ft³ (2,800 m³) of radioactive waste containing 6,300 Ci of activity were buried in the landfill. In the unclassified area, buried wastes consist of contaminated equipment, decontamination materials, and miscellaneous solid wastes. A summary of the known contents of each trench is presented in Table 2. The specific contents of the classified area are not known. Radioactive wastes contained in the pits are believed to include uranium, thorium, plutonium, various leaky sources, and tritium. Large quantities of tritium were disposed of in the classified area. The major source of tritium is from neutron generator tubes.

In summary, by waste type, the following were believed to have been disposed of in the MWL:

Transuranic Wastes (TRU)

The SWIMS database indicates that about 50 ft³ (1.4 m³) of TRU waste containing 1.2 mCi of total activity was disposed at the MWL. Memoranda and Waste Management Site Plans from the early 1970s indicate that the amount of TRU waste could be as high as 600 ft³ (17 m³). The major contaminants included in this waste category are Pu-238 and Pu-239.

Uranium and Thorium Wastes

Approximately 22,000 ft³ (620 m³) of uranium and thorium wastes containing 10 Ci of activity were disposed of in the MWL.

Fission-Product Wastes

An estimated 12,000 ft³ (340 m³) of fission product wastes containing 410 Ci of activity were disposed of in the MWL. A conservative estimate of the remaining activity based on Cs-137 and Sr-90 is 200 Ci.

Induced Activity Wastes

An estimated 54,000 ft³ (1,530 m³) of wastes containing 3,500 Ci of induced activity were disposed of in the MWL. These wastes were the largest contributor both in volume and activity to the MWL waste stream. Most induced activity wastes have a relatively short half-life, with the exception of Co-60, Nickel-63, and Barium-133.

Tritium-Containing Wastes

An estimated 12,000 ft³ (340 m³) of wastes containing 2,400 Ci of tritium were disposed of at the MWL. This waste consisted primarily of contaminated equipment, dry solids, and minor amounts of decontamination debris. In the classified area, tritium waste is believed to be associated with neutron generator tubes.

Alpha-Emitting Wastes

An estimated 2,600 ft³ (74 m³) containing 6 Ci of low-level alpha emitting wastes were disposed of at the MWL. This waste consisted primarily of dry solids and smaller quantities of contaminated equipment, decontamination debris, and miscellaneous waste.

5.1.2 Chemical Contaminants

The types of chemical contaminants known to have been disposed in the MWL include acids, solvents such as trichloroethylene (TCE) and carbon tetrachloride (CCl₄), scintillation cocktails (typically toluene-based), lead shielding, oils and petroleum products and beryllium (SNL 1993b). It is believed that little or no hazardous wastes were disposed in the unclassified area subsequent to the establishment of the CWL in 1962, specifically for the disposal of hazardous wastes.

5.2 Potential Release and Transport Mechanisms

Four potentially significant release and transport mechanisms were identified in the conceptual site model. These mechanisms include infiltration and percolation, advection and volatilization, animal burrowing, and biotic uptake. These mechanisms are discussed in sections 5.2.1 through 5.2.4.

Surface water transport of contaminants via run-off is also possible, assuming that surface contamination is present. Contaminants could be transported as particles carried by water, or dissolved in the water itself. However, since infiltration is rapid in this arid region and no nearby surface water bodies are present, exposure to contaminated surface water is not a pathway of concern. Therefore, the environmental medium of concern with respect to the runoff water migration pathway is surface soil, and no surface water pathway is shown in the conceptual site model (Figure 17).

It should be noted that if liquid containerized wastes are present in the MWL, potential transport mechanisms may not yet have occurred. Migration could occur at some time in the future when corrosion causes the containers of liquid to be breached. Information on wastes disposed in the MWL is incomplete. Because the possibility of increased migration exists if liquid containerized wastes are present, limited long term monitoring at the landfill will likely be needed (e.g., semi-annual measurement of flux rates).

5.2.1 Infiltration/Percolation

Vertical transport of contamination could occur by infiltration and percolation of precipitation through the unsaturated zone to the water table and then laterally to water supply wells. Due to low annual precipitation rates, high evapotranspiration, the depth to groundwater (i.e., 460 ft), and layers of low permeability materials, vertical migration of wastes is expected to be a very slow process. A large portion of the buried waste is in solid form; the rate of dissolution and desorption of contaminants would depend on the contaminant-specific distribution coefficient, K_d , which describes the partitioning between the liquid and solid phases. Characterization data indicate that tritium, which has a very low K_d (indicating high migration potential) has migrated vertically through the vadose zone to a depth of at least 33.5 m (110 ft). Other radionuclides that were disposed of in the MWL (e.g., uranium and plutonium) have much higher K_d values, and hence would have a much lower rate of vertical migration than tritium.

Based on the known disposal history and the results of the soil gas surveys and subsurface soil analyses, several VOCs (e.g., benzene, tetrachloroethene toluene, 1,1,1-trichloroethane and

trichloroethene) have been determined to be present in the MWL. In general, these VOCs are mobile contaminants with fairly low K_d values.

5.2.2 Advection and Volatilization

Volatile constituents contained in the buried waste, such as VOCs and tritium, could migrate from the subsurface to the surface or laterally by advective forces: transport could occur in the liquid or vapor phase. Tritium closely follows the reactions of ordinary hydrogen: when tritium interacts with water, it incorporates into the water molecule as tritiated water (HTO) and can move as water vapor or liquid soil water. HTO behaves essentially like normal water, except it has a slightly lower vapor pressure and concomitant higher boiling point (Jacobs 1968). VOCs can migrate as dissolved constituents in liquid soil water or as free-phase organic vapor or liquid. Migration of volatile constituents in the vapor phase is governed by gradients induced by differences in temperature, barometric pressure, concentration, and density.

Characterization data indicate that tritium has migrated from the buried waste to surface soils with lateral spreading that extends beyond the boundaries of the MWL. Concentrations of tritium in soil moisture are elevated over most of the MWL, but are the highest in the classified area (Figure 10). Tritium flux measurements in air also indicate that the highest levels of tritium volatilizing from soil are in the classified area (Figure 13).

Data from the various soil gas surveys conducted at the MWL show that tetrachloroethene in surface soils has migrated past the boundaries of the unclassified area (Figure 14). Levels present outside the unclassified area are much lower than those within the unclassified area. Additionally, trichloroethene has been detected in surface soil gas at the southwestern boundary of the classified area (Figure 15). Detections of other volatile organic compounds have generally been within the landfill boundaries.

5.2.3 Animal Burrowing

Surface soil contamination via the activity of small burrowing animals was considered as a potential transport mechanism in the conceptual site model. The trenches and pits have been backfilled, but the cover depth is unknown. Prairie dogs are common in the area, and could burrow into shallow subsurface soils and redistribute the waste to the surface. Any volatile wastes (e.g., tritium and VOCs) would be expected to reach the surface soil only in small quantities by this mechanism, where they would rapidly dissipate into the atmosphere. Therefore, this migration mechanism would likely only be of concern with respect to semi-volatile organic constituents, metals, and radionuclides other than tritium. To date, surface soil analyses for these constituents have not been conducted.

5.2.4 Biotic Uptake of Contaminants

Biotic uptake of contaminants was also considered as a potential transport mechanism in the conceptual site model. Plants could take up contaminants from soil via their roots, or could become contaminated through foliar deposition of resuspended particulates. Animals ingesting contaminated soil or plants could also accumulate contaminants in their tissues. To date, surface soil analyses have only been conducted for tritium, so potential for contamination by foliar deposition is unknown.

Absorption of HTO by plants is a likely transport mechanism at the MWL. HTO is readily absorbed by plants either from root uptake or exchange of HTO vapor by plant leaves. Although data are limited, bioaccumulation of the volatile organic compounds detected at MWL (e.g. tetrachloroethylene and trichloroethylene) is not expected to be significant (ATSDR 1993a,b).

5.3 Potential Receptors and Routes of Exposure

Currently the MWL is actively used for the temporary storage of containerized waste and is fenced to prevent unrestricted access. Under the current land-use, the most likely receptors are workers or trespassers. The worker is involved with maintaining the unclassified area where waste is stored. The potential pathways of concern for this scenario include external gamma irradiation, inhalation of particulate or gaseous emissions, dermal absorption, and incidental ingestion of contaminated particulates. The same pathways of concern would also apply for the trespasser, but the exposure frequency and duration would be significantly less.

Under future land-use conditions, the receptor with the greatest potential for exposure would be a resident at the site. For this receptor, possible significant exposure pathways include external gamma irradiation, incidental ingestion of soil, inhalation of soil-derived particulates, inhalation of soil-derived volatile contaminants and tritium vapor, ingestion of garden-grown produce, and ingestion, inhalation and dermal contact with groundwater.

For this assessment, it was assumed that a limited degree of institutional control would be present for the MWL over the long-term. Specifically, it was presumed that excavation at this small site would not be allowed, since long-lived radionuclides are present in the pits and trenches. In addition to the implausibility of excavation under actual future land use, exposure to buried wastes could not be adequately addressed with existing data. Therefore, the future resident receptor was presumed to reside immediately adjacent to the MWL. Inhalation exposures were assumed to be as large as if the resident were located on the MWL, but no direct contact with buried wastes was assumed. The resident was assumed to drill a well in the aquifer directly below the MWL, from which all household water needs would be obtained.

6 Human Health Risk Assessment for Radiological Contaminants

6.1 Contaminants of Concern

Based on the data collected to date, the only confirmed radiological contaminant of concern at the MWL is tritium. A large amount of data has been collected and analyzed which indicate widespread tritium contamination in soil across the landfill and adjacent to the site boundary. Tritium soil concentrations are the highest in the classified area; the maximum surface soil concentration detected in 1993 was 1×10^6 pCi per liter of soil. Several boreholes on the perimeter of the MWL have been drilled to measure tritium levels in subsurface soil. In general, the highest levels of tritium were measured in the uppermost 8 m (25 ft) of the soil column. Elevated levels of tritium were detected to a maximum depth of 34 m (110 ft) in a borehole located at the southeast corner of the classified area. Data have also been collected to measure the rate at which tritiated water vapor is emitted from the landfill. Elevated tritium flux rates have been measured over the entire site and east of the boundary. The highest tritium flux rates were found in the classified area; flux rates measured on the perimeter,

or outside the MWL were lower by a factor of at least 300. A good correlation between tritium soil concentration and flux rate measurements was found.

Other potential radiological contaminants of concern in the MWL are those believed to be buried in the landfill based on information contained in historical records (see Section 5.1.1). Potential contaminants of concern buried in the trenches may include plutonium, uranium, thorium, cesium-137, cobalt-60, nickel-63, and barium-133. The available data collected and analyzed for radionuclides in subsurface soil in the vicinity of the waste trenches and pits have not detected any contamination other than tritium. Groundwater data also indicate that leaching of contamination from the MWL has not occurred. Data are required to investigate potential contamination in surface soil.

6.2 Exposure Assessment

The purpose of the exposure assessment is to estimate the nature and magnitude of potential exposures associated with the contaminated site. The components of this assessment include the contaminants of concern, exposure setting, potential human exposure pathways, and the estimated exposure point concentrations.

As identified in Section 6.1, the only confirmed radiological contaminant of concern for the MWL is tritium. The potential exposure routes associated with tritium include inhalation, ingestion, and dermal absorption. Several other radionuclides have been identified as potential contaminants of concern (e.g. uranium, plutonium, thorium), but the available data indicate that waste is contained in the trenches and pits, and has not migrated vertically. Surface soil data have not been collected to measure levels of contaminants other than tritium. Potential exposure pathways associated with these potential contaminants of concern include external irradiation, incidental ingestion of soil, ingestion of groundwater, ingestion of contaminated food, and inhalation of contaminated particulates.

Elevated levels of external radiation have been measured at the MWL, although only the unclassified area has been surveyed. The highest level of external radiation was measured on the western perimeter fence line of the classified area. In 1993, the measured exposure level at the fence line was 600 μ R/hr; the exposure rate decreased with distance from the fence line. Measurements taken in 1990, reported an exposure rate of 5 mR/hr in the same general location; however, the classified area was still active at this time, and some of the pits may still have been open to the environment. The major source of this radiation is thought to be associated with a buried reactor vessel in the classified area which is covered with approximately 6 m (20 ft) of sand (Peace 1994). Surface soil measurements for potential contaminants of concern, and a gamma survey of the classified area are necessary to discern the contribution from buried waste versus surface contamination. Elevated exposure rates have also been measured in the temporary storage area, located in the southwest corner of the unclassified area, but are not included as part of the assessment because the structure is temporary. For this assessment, preliminary dose estimates are presented for the external irradiation pathway using the available exposure rate measurements collected to date. A comprehensive gamma survey of the entire MWL, and surface soil data are required to fully assess this pathway.

The exposure setting at the MWL is described in Chapter 3. The MWL is situated in a remote area within the KAFB and is fenced to restrict access to the site. The classified area is separately fenced off from the unclassified area. Additionally, security guards are posted outside of Technical Area 3 to restrict access by non-authorized personnel. Under current land-use conditions, the MWL is inactive (i.e., no longer accepts waste in either the unclassified or classified areas; all trenches and pits are capped and sealed). Therefore, only limited personnel are allowed into the area and only for brief durations. The primary activities currently performed at the landfill are associated with the

temporary storage area; minimal maintenance activities may be conducted in the other areas.

As described in Section 5.3, the most likely current and future receptors for the site are a worker and resident, respectively. For the worker scenario, the pathways of concern are inhalation and dermal absorption of tritium, and external irradiation. Inhalation of airborne particulates was not considered because the limited amount of data collected indicate that radioactive particulate emissions are below the detection limit. In addition, the lack of surface soil data precludes modeling the potential airborne emissions from the site. The potential pathways of concern for the future resident include inhalation and absorption of tritium, external irradiation, and ingestion of groundwater. Inhalation of radioactive air particulates was not assessed for the same reason as for the worker scenario. Incidental ingestion of soil, and ingestion of contaminated food also were not assessed because surface soil data have not been collected.

Conservative estimates of exposure time, exposure frequency, and exposure duration were assumed for both the worker and resident. The on-site worker was assumed to spend 8 hours per day at the site, 1 day per week over a 25-year period. These estimates are very conservative given the actual conditions at the MWL. Under future land-use conditions, it was assumed that a resident would construct a house adjacent the perimeter of the MWL. The resident was assumed to be present at their residence 24 hours per day (23 hours indoors), 350 days per year, over 30 years. These values are recommended by the EPA for reasonable maximum residential exposures (EPA 1991c). The methodology used to estimate exposure point concentrations for the air and groundwater pathway is discussed below.

6.2.1 Air Pathway

A screening level assessment was performed to assess the potential health impacts from inhalation and dermal absorption of tritiated vapor (i.e., HTO). As a screening approach, the maximum observed tritium flux measurement was used to estimate the exposure point concentration for the worker and future resident. This should be an overestimate (i.e. conservative) because tritium flux measurement locations were selected based on where tritium soil contamination existed, and there was a good correlation between tritium concentrations in soil and tritium flux measurements.

The average concentration of tritium in air was estimated from the measured tritium flux, using the methodology documented in the RESRAD computer code (Yu et al. 1993):

$$C_{H-3} = (3.17 \times 10^{-8} \cdot 0.5 \cdot \text{Flux} \cdot \sqrt{A}) / (H_{\text{mix}} \cdot U) \quad (1)$$

where:

- C_{H-3} = average concentration of tritium in air over a contaminated area of finite size (pCi/m³),
- 3.17×10^{-8} = unit conversion factor (yr/s),
- 0.5 = time fraction wind is blowing toward receptor (dimensionless),
- Flux = tritium flux from the contaminated area (pCi/m²-yr),
- A = area of contaminated zone (m²);
- H_{mix} = height at which the tritiated water vapor is uniformly mixed (2 m); and
- U = annual average wind speed (m/s).

Radioactive decay was not considered in this screening level approach, which would overestimate tritium concentrations since tritium has a 12.3 year half-life. The assumptions used for each parameter are listed in Table 3.

For the external irradiation pathway, the range of measured exposure rates reported in the 1993 survey of the unclassified area were used as the exposure point concentrations for both the worker and resident. Because data are not available to determine the nature of the external radiation (e.g., buried or surface contamination, specific radionuclides and activity concentrations), the pathway is presented for comparative purposes only. Additionally, the radiation field strength in the classified area has not been measured.

6.2.2 Groundwater Pathway

To date, groundwater data collected from monitoring wells located adjacent to the MWL do not indicate any contamination from the MWL. To determine whether the MWL poses a future threat to the groundwater, a tiered screening approach was used. Vertical transport of tritium was evaluated because tritium is the most mobile of the contaminants disposed of in the MWL, and because soil data have indicated that both vertical and lateral migration of tritium has occurred. Transport of other potential contaminants of concern could also be inferred from this analysis. The tiered approach uses successively more involved and detailed vadose zone fate and transport models to determine the potential for tritium disposed of in the landfill to reach the water table at significant levels. For this screening process, a significant level is indicated by a concentration higher than EPA's maximum contaminant level (MCL) for tritium in drinking water (i.e., 20,000 pCi/L). At each screening level, a decision is made as to whether a significant human health risk is posed under conservative fate and transport assumptions. If the answer is no, the analysis is stopped, and the pathway under evaluation is determined to pose no significant threat. If the answer is yes, then the screen is taken to the next level of analysis. If the conclusion at every screening level is that a potentially significant human health risk is posed, then a decision must be made whether to accept that conclusion, or to collect further information in the field that allows a more refined screen to be carried out. One of the products of a screening approach is the identification of what additional data would be necessary to refine the risk screen further.

A tiered screening approach is an alternative to either a deterministic human health risk analysis or a Monte Carlo-based human health risk analysis. In a deterministic analysis, the reasonable maximum exposure from tritium based on available information would be calculated and compared to the EPA's range of acceptable incremental risks, regardless of the uncertainty associated with the estimate. The problem with deterministic risk estimates is that the uncertainty associated with the estimate may be so large relative to the estimate that it renders the risk estimate meaningless. A screening approach does not focus on the reasonable maximum exposure, but rather on plausible, worst case transport scenarios, and the results compared to the EPA's range of acceptable incremental risks. If this test is passed, the deterministic test would be passed as well. In this sense a screening approach is significantly more conservative than a traditional deterministic analysis.

Monte Carlo-based risk analyses attempt to quantify the uncertainty associated with the risk estimate by assigning probability density functions (pdfs) to model parameters and assumptions, and then propagating the uncertainty through Monte Carlo simulations to derive a pdf for the final estimate. While Monte Carlo analyses are attractive from a conceptual standpoint, they suffer two fundamental weaknesses. First, their data demands are significantly greater than a deterministic anal-

ysis since one requires the entire probability density function for each input parameter to the risk model, rather than just point estimates. Secondly, the resulting probability density function for the risk estimate can be misleading if the uncertainties associated with model and input parameter pdf selection are not addressed. Tiered screening approaches have several advantages relative to Monte Carlo analyses. First, they focus on the parameter values associated with worst case scenarios, limiting the analysis to only the portions of the underlying model parameter pdfs that are important to the analysis. Secondly, by using several different analysis tiers with models becoming more complex at each step, tiered screening analyses can at least partially address the issue of model choice and validity relative to the final risk estimate. Properly conducted Monte Carlo analyses provide significantly more information than tiered screening analyses, but much if not most of this additional information will have little bearing on the final question that needs answering: does the pathway of concern contribute significantly to incremental human health risks?

First Tier Screen: Volumetric Estimations

The first tier screen for the possibility of transport of tritium vertically downward through the unsaturated zone to the water table relies on simple volumetric calculations. Given the volume of reactor water known to be disposed, the depth to the water table, and the approximate residual moisture content of the vadose zone soils, one can determine the maximum penetration depth of the reactor water as a function of assumed lateral dispersion. For example, if one assumes that 270,000 gallons of reactor water were placed in trench D, and that the amount of water left behind as residual moisture as the reactor water moves downward is one percent of total soil volume, then one can derive a relationship between lateral spreading and total expected depth of penetration, as shown in Figure 18. If one assumes that the reactor water ponded in Trench D (35 feet wide by 180 feet long, or 6,300 ft²) and then moved vertically downward with no lateral spreading, a total depth of penetration would be approximately 570 feet, or to the water table.

This analysis neglects the time it would take for the reactor water to reach the water table. Given the relatively short half life of tritium, by the time the tritiated water encountered the saturated zone, sufficient half lives might have passed so that the level of activity was below the level of concern. This analysis also neglects the effects of lateral spreading, which would occur via both capillary action and the tendency of water in the vadose zone to pool at stratigraphic layer interfaces. For example, if the reactor water pulse spread laterally to twice the extent of the original interior dimensions of the pit, the depth of penetration would be cut by a factor of four, to only 140 feet. The effects of evapotranspiration are also neglected. Evapotranspiration of the reactor water would have reduced the volume of water available for downward migration, limiting the downward penetration. Finally, this analysis neglects the effects of natural recharge occurring at the site, which would have a tendency to accelerate the downward movement of the tritium. However, with effective recharge rates less than 0.5 inches per year, the contribution of recharge to downward tritium mobility would be negligible. The conclusion of this brief analysis is that it is possible that the reactor pulse would arrive at the water table, but not likely.

Second Tier Screen: One-Dimensional Analytical Modeling

The conclusion of the first tier screen is that it is possible but unlikely that tritiated water would reach the water table as a result of activities at the MWL. The second tier screen of the evaluation was conducted using a one dimensional analytical solution to the partial differential equation that describes

the time dependent fate and transport of a reactive compound moving vertically along a one-dimensional path while undergoing sorption, dispersion, volatilization, and radioactive decay. This partial differential equation was first posed by Jury et al. in 1983 and has the form:

$$\frac{\partial C}{\partial t} = \frac{D}{R} \frac{\partial^2 C}{\partial z^2} - \frac{V}{R} \frac{\partial C}{\partial z} - \lambda C \quad (2)$$

where:

- C = total concentration of tritium for all phases in the soil;
- D = effective diffusion/dispersion coefficient;
- R = retardation for the contaminant;
- V = volumetric soil-water flux; and
- λ = first-order rate constant for radioactive decay.

Assuming that the concentration of tritium becomes zero as the depth of the soil goes to infinity, and that at the land's surface the tritium concentration behaves as a step concentration, i.e., at a specified value during the infiltration of the reactor water and zero afterwards, then using Laplace transform methodologies (Ditkin and Prudnikov 1967) a closed form analytical solution can be obtained that expresses the concentration of tritium as a function of time and depth. Details about the analytical solution and the assumptions behind its derivation can be found in Appendix A. Note that this solution is inherently conservative (i.e., will over predict tritium penetration) in that neglects lateral dispersion of tritium. However, it does allow for time dependent decay as the reactor pulse moves downward, and so provides a more realistic evaluation of the probability that tritium transported by the reactor water will reach the water table than the first tier screen. The trade-off is that this form of analysis is more complex and data intensive.

The analytical solution derived for equation (2) is sensitive to C_0 , the initial concentration of tritium at the time of disposal, D, the effective diffusion/dispersion coefficient for tritium's vadose zone transport, V, the assumed volumetric soil water flux for the system, and the initial length of time over which the tritium infiltration takes place. R is one in the case of tritium, and λ for tritium is 0.0563, with tritium's half life equal to 12.3 years. A conservative screen at this stage assumes that C_0 is 2.5×10^9 pCi/L (all 2,400 Ci of tritium disposed of at the site is mobilized by the reactor water rather than the 1 Ci reported), that the infiltration time is 30 days, and that D (dispersivity) is scale dependent and equal to 0.1 times the distance to the water table (Lallemant-Barres and Peaudecerf 1978). Under these conservative assumptions, the remaining unknown is V, the assumed volumetric soil water flux for the system. V is a proxy for saturated hydraulic conductivity.

The analytical solution to equation (2) requires an estimate for V. In reality, the hydraulic conductivity for the vadose zone beneath the MWL is a function of moisture content. As moisture content falls beneath full saturation, as it would after the disposal of the reactor water as the reactor water moved down through the vadose zone, the hydraulic conductivity is reduced to something significantly less than its value for a saturated system. Figure 19 shows the results of a sensitivity study where the maximum dimensionless concentration of tritium at the water table is plotted as a function of V. If the coolant water is assumed to contain the entire inventory of tritium disposed at the site, then the V required to produce a concentration equal to the Drinking Water Standard (20,000 pCi/L) at the water table is about 0.01 ft/d. This velocity corresponds to the saturated hydraulic conductivity of a silty loess (Freeze and Cherry 1979).

Assuming a V of 0.01 ft/d, the analytical solution predicts that the maximum tritium concentra-

tion at the water table exceeds the EPA Drinking Water Standard after about 57 years. After 27 years (current status) the analytical solution moves the tritium pulse downward from the land's surface and shows peak tritium concentrations at the depth of about 110 ft (approximately 1.5×10^6 pCi/L). At the water table the current concentration would be about 750 pCi/L. Recall that Figure 8 shows the depth distribution of tritium as measured down several bores at the MWL with maximum penetration at around 120 feet and maximum concentrations at depths of 20 to 30 feet, and that current sample results for the monitoring wells located at the MWL show no signs of tritium above background. This evidence would suggest that the actual vertical velocity for tritium since disposal has been less than the 0.01 ft/d required by the analytical solution for tritium to pose an eventual threat to the water table.

A hydraulic conductivity of 0.01 ft/day is plausible for this site under saturated conditions, but highly unlikely given that most of the downward movement of tritium would have occurred under unsaturated conditions. Given this fact, along with the fact that with this value for V the analytical model appears to significantly over predict tritium penetration after 27 years relative to what has been actually observed, one would conclude that at this screening level the pathway from the tritium point of disposal to the water table would not contribute significantly to incremental risk. To verify this finding, a final screen is conducted that provides for the most realistic tritium transport modeling possible for this site: a full three-dimensional, two phase tritium flow and transport simulation.

Third Tier Screen: Three-Dimensional Two Phase Flow and Tritium Transport Modeling

A three-dimensional numerical transport model called TRACR3D (Travis and Birdsell 1990) was used to evaluate the movement of tritium through the vadose zone beneath the MWL. TRACR3D is a multi-purpose flow and transport model originally developed at Los Alamos National Laboratory. TRACR3D can be used to model transient or steady-state flow, saturated and vadose zone conditions, and deformable, heterogeneous, sorptive porous media. TRACR3D allows for two phase flow, with mass transfer between phases, and multi-component flow, with mass transfer between components. TRACR3D also allows the modeling of radioactive contaminants undergoing decay. TRACR3D allows constitutive relationships in the vadose zone to be formulated either using the Brooks-Corey model, the Mualem-van Genuchten model, or via user-supplied tables. TRACR3D solves its water and/or air flow equations with an implicit finite difference scheme, and contaminant transport with an implicit or semi-implicit scheme.

TRACR3D has several characteristics of particular interest to the MWL. TRACR3D is fully three dimensional. TRACR3D is applicable to vadose zone conditions. TRACR3D allows for both aqueous and vapor phase transport of contaminants, with mass transfer permissible between the phases. Finally, TRACR3D models radioactive decay. Several assumptions and simplifications were made in applying TRACR3D to the MWL tritium transport problem. First, the MWL was divided into four equal quadrants, centered on the middle of Trench D in the unclassified area. To reduce the computational burden associated with three-dimensional two-phase numerical modeling, only one quadrant (the northeast) was modeled. Second, it was assumed that there were homogeneous and isotropic hydrogeologic conditions at the MWL. This is a conservative assumption since it is known that there are layers of non-uniform materials beneath the MWL. In vadose zone aqueous phase transport, boundaries between stratigraphic layers function as barriers to flow. Their existence would increase lateral movement of tritium, and reduce vertical penetration. Third, the tritium introduced into the subsurface beneath the MWL was assumed to be contained in one quarter of the 271,500 gallons of coolant wastewater from the Sandia Engineering Reactor Facility (SERF). As a conservative estimate, the initial level of tritium was assumed to be 2,400 Ci of tritium, the total

amount of tritium estimated by the Sandia ER program as having been disposed of at the MWL, rather than the one Ci thought to have been contained in the SERF coolant wastewater. This assumption translates into an initial aqueous phase concentration of tritium equal to 2.34×10^9 pCi/L. Finally, the third assumption was that there was no mass transfer of tritium from the aqueous phase to the vapor phase after the introduction of the reactor coolant wastewater. This is also a conservative assumption from the standpoint of incremental risks associated with tritium reaching the water table since any tritium vapor loss would reduce the vertical penetration of the remaining tritium.

As a base case simulation of tritium transport beneath the MWL, a variable spaced orthogonal grid with 4,000 nodes (20x20x10) was used. Figure 20 shows the lateral location of the grid relative to the MWL. The finest horizontal grid cell was 16 ft by 16 ft. The lateral grid spacing in both the east-west and north-south directions was five 16 ft wide cells, ten 48 ft wide cells, and five 144 ft wide cells. In the vertical direction, there were ten 46 ft thick layers spanning from the ground surface to the water table. There were five no flow boundaries, located at the four sides and the top, and one constant head boundary at the bottom. The total lateral extent of the grid was set so that the no flow boundaries at the sides would not affect the lateral migration of the tritiated reactor water. Since trench D was estimated to be approximately 180 ft long at the top, the tritium introduction was modelled as a source that spanned five grid cells, with surface area equal to 1,280 ft². Assuming that the overall material beneath the MWL was a silty loess, the best-guess estimate of the saturated permeability was 7×10^{-3} darcy (equivalent to 0.0192 ft/day for a saturated hydraulic conductivity) (Freeze and Cherry 1979). The Mualem-van Genuchten option for defining the constitutive relationships was used, with the parameters n set to 6 and α set to 0.02. Porosity was set to 0.27, and the irreducible water content to 10% of the total porosity. The subsurface was assumed to be at hydrostatic equilibrium initially.

Using the model parameters described in the base case, TRACR3D was used to estimate the present vertical penetration of tritiated reactor water into the subsurface beneath the MWL. Twenty seven years after the introduction of the reactor water, which would reflect the present distribution of tritium, tritium contamination reaches down to a maximum depth of 184 ft below ground surface, with a maximum concentration of 2.8×10^6 pCi/L (Figure 21). The current depth of penetration as predicted by TRACR3D is comparable to that encountered by the 18 bore holes completed in 1990. However, the maximum concentrations modeled are several orders of magnitude greater than observed, reflecting the conservative nature of the TRACR3D assumptions about the initial tritium activity introduced by the reactor coolant water. After an additional 100 years, the tritium introduced by the reactor coolant water travels halfway down the vadose zone to a depth of 230 ft, with a maximum concentration of 5,400 pCi/L (Figure 21), which is well below the 20,000 pCi/L drinking water standard set by the EPA. The base case TRACR3D results support the second tier screening conclusions: tritium from the MWL will not reach the water table in concentrations sufficient to pose a human health risk.

The values used by TRACR3D for the saturated hydraulic conductivity of the soils beneath the MWL and their constitutive relationships were based on values for comparable soils reported in the literature. A sensitivity analysis was performed on TRACR3D to explore the sensitivity of the results to the base case assumptions. Four sets of sensitivity runs were completed: the first addressed different values for the van Genuchten parameters n and α which define the vadose zone constitutive relationships; the second addressed a range of values for the assumed porosity; the third addressed a range of values for the saturated hydraulic conductivity; and the last considered changes in the way the reactor water was introduced into the MWL.

The first set of sensitivity analyses addressed the impact variations in the van Genuchten parameters n and α had on TRACR3D results. Variation of n between the values of 4 and 8 had little

effect, while changes in the assumed value of α produced significant changes in the penetration of tritium beneath the MWL. Increasing α from 0.02 to 0.8 resulted in an increased depth of penetration by the tritiated reactor coolant water. After 57 years, the tritiated water plume reached halfway down to the water table, with a maximum concentration of 190,000 pCi/L. After 127 years, the plume extends almost 300 feet below the MWL's surface, with a maximum concentration of 650 pCi/L. Although varying α did have an impact on the depth of penetration, no value of α within the range considered increased penetration depth to the point where tritium posed a human health risk to the water table.

The second set of sensitivity analyses addressed the impacts of porosity on the tritium penetration depth. These analyses revealed that decreasing porosity led to increasing penetration. The range of porosity values associated with unconsolidated alluvial deposits ranges between 0.25 and 0.5. The base case porosity value of 0.27 is on the conservative end of this range. Porosity values for soils beneath the MWL would have to be on the order of 0.05 for tritiated reactor water to reach the water table with tritium concentrations that exceed the 20,000 pCi/L EPA drinking water standard. Porosity values this small are associated with rock formations, and not with the alluvial layers underlying the MWL.

The third set of sensitivity analyses addressed the impact that changes in assumed saturated hydraulic conductivity would have on the depth of tritium penetration. Saturated permeability values were allowed to vary between 7×10^{-3} darcy (0.0192 ft/day) to 7 darcy (19.2 ft/day). Not surprisingly, increasing the saturated permeability increased the depth of penetration for tritium. However, for reactor water to reach the water table with tritium concentrations greater than the 20,000 pCi/L EPA standard requires a saturated permeability on the order of 7 darcy, which is in the range of gravels and clean sands. A value of 7 darcy for a silty sand is highly unlikely. An aggregated value of 7 darcy for the soils underneath the MWL is even more unlikely when the interbedded nature of the alluvial deposits is considered.

Finally, the last set of sensitivity analyses addressed the impact that variations in the assumed mode of coolant water disposal would have on tritium penetration depth. The base case assumed that the coolant water placed in Trench D uniformly infiltrated over the entire length of the trench. As an alternative scenario, TRACR3D was run with the infiltration of the coolant water concentrated on just one of the 16 ft grid cells, or over only one fifth of the area assumed in the base case. A one cell injection allows tritium to reach the water table with a maximum concentration of 3,300 pCi/L after 47 years, still significantly below the 20,000 pCi/L drinking water limit.

The conclusion from these sensitivity analyses is that it is highly unlikely that any tritium introduced by the disposal of reactor coolant water would reach the water table at levels above the drinking water standards. In each of the worst case scenarios considered in the sensitivity analyses where tritiated reactor water did eventually reach the water table in significant concentrations, after 27 years from the disposal time the bulk of the transport had already taken place (i.e., tritiated reactor water had already reached depths of more than 300 ft with high concentrations of tritium). Based on data from soil bores completed at the MWL to date, this is obviously not the case.

6.3 Toxicity and Risk Assessment

6.3.1 Risk Factors Used for the Assessment of Radiological Effects

The potential health effects associated with exposure to radioactive contaminants at the MWL are expressed as the increased risk of cancer induction. In the first stage of the assessment, radiation

doses were calculated using dose conversion factors based on dosimetry models developed by the International Commission on Radiological Protection (ICRP), as reported by Yu et al. (1993). The radiation dose estimates (i.e. committed effective dose equivalents) can be compared to established radiation protection standards and criteria. Health impacts, expressed in terms of the likelihood of cancer induction, were obtained by multiplying the total effective dose equivalent by a risk factor of 6×10^{-7} per mrem. This risk factor is a lifetime average value, and was used by the EPA in developing revisions to the National Emission Standards for Hazardous Air Pollutants (NESHAPS) for radionuclides under Section 112 of the Clean Air Act (EPA 1989d).

6.3.2 Estimated Doses and Risks

The committed effective dose equivalent for the inhalation pathway was calculated using the following equation:

$$CEDE = C_{H-3} \cdot IR \cdot ET \cdot EF \cdot ED \cdot DCF_{inh} \quad (3)$$

where:

CEDE =	committed effective dose equivalent (mrem);
IR =	inhalation rate (m^3/hr);
ET =	exposure time (hr);
EF =	exposure frequency (hr/d);
ED =	exposure duration (d/y);
DCF_{inh} =	inhalation dose conversion factor for tritium (6.3×10^{-8} mrem/pCi).

Water vapor is also absorbed through the skin at approximately 50% of the inhalation rate of water vapor (ICRP 1979-1982; Hamby 1993). Consistent with the RESRAD methodology, the dose from inhalation was multiplied by a factor of 1.5 to account for the dermal absorption of HTO vapor in air. The assumptions for the parameters used in the worker and resident scenarios are listed in Table 3.

For the external gamma irradiation pathway, the effective dose equivalent was calculated by multiplying the length of time an individual is exposed to a radiation field strength by a DCF of 0.95 mrem/mR. For the future resident scenario, a shielding factor of 0.6 for indoor exposures was used to account for attenuation by the walls and floors (Yu et al. 1993).

The resulting doses and risks for the worker scenario are presented in Table 4. The estimated dose from inhalation of tritium is 0.009 mrem/yr. and 0.23 mrem over the entire exposure duration. The range of estimated doses from external radiation is 3.8 to 230 mrem/yr. The total dose from external radiation over the 25-year duration ranges from 95 to 5,700 mrem.

For the resident scenario, exposure point concentrations were based on on-site measurements. The estimated dose from inhalation of tritium is 0.19 mrem per year, and 5.7 mrem over a lifetime. The maximum dose from external radiation is estimated to be 3.4 rem/yr, and 102 rem over a lifetime. Under any reasonable assumptions, it was demonstrated that the tritium contamination in the landfill would decay before it reached the groundwater table. Therefore, the incremental risk of cancer induction to a resident at the site from ingestion of groundwater would be zero.

In summary, the predominant pathway for human health risk at the MWL is from external radiation. The risks from inhalation of tritium to a worker or future resident are negligible under very

conservative exposure assumptions. For comparison, DOE orders limit the annual dose for a radiation worker to 5 rem/yr, and 100 mrem/yr for members of the general public (USDOE 1988; 1990). As is shown in this assessment, the potential dose to a worker at the MWL could exceed 5 rem/yr if a worker spent a significant amount of time near the western fence line of the classified area.

To put the estimated risks from tritium in perspective, a comparison with the annual risk from background radiation was made. The national average dose from background radiation is 0.3 rem/yr (NCRP 1987). The components that contribute to background radiation include cosmic radiation, terrestrial radiation, radionuclides in the body, and inhalation of radon; approximately two-thirds of the total dose is from inhalation of radon. In comparison, the annual risk from inhalation of tritium to an on-site receptor is about 0.04% of the average annual risk from background radiation. The potential for groundwater tritium contamination at the MWL was shown to be extremely low under any reasonable assumptions. Hence, potential deterioration of Albuquerque's drinking water aquifer from the MWL is not a concern. Additional sampling for tritium contamination at the MWL is unnecessary.

7 Human Health Risk Assessment for Chemical Contaminants

7.1 Contaminants of Concern

Based on available information, the contaminants of concern for the MWL are the volatile organic compounds detected in the passive soil gas surveys. In this assessment, the risks from exposure to volatile organic compounds only will be quantitatively assessed. Additionally, risk-based action levels for these and other substances will be presented to be used in screening and interpreting additional field data as it becomes available (see Section 8.0).

7.2 Exposure Assessment

For the volatile organic compounds (VOCs), the only exposure route of concern for current receptors is inhalation. Incidental ingestion or dermal absorption of these substances is unlikely, because these substances volatilize rapidly from surface soils. Additionally, ingestion of contaminated plants is not of concern for current exposure scenarios (e.g., no edible plants currently grown on-site).

For exposure of future resident receptors to VOCs, it is assumed that long-term institutional controls at the MWL prevent excavation of a house foundation within the trenches or pits. As for the current receptors, the most plausible exposure route is inhalation of contaminants volatilizing from the landfill surface. Contact with VOCs in surface soil would be minimal because of rapid volatilization.

To evaluate the potential for VOCs to infiltrate to the groundwater, a screening analysis was conducted for the two VOCs detected most frequently and at the highest concentrations in the soil gas surveys (i.e., tetrachloroethene (PCE) and trichloroethene (TCE)). The concentration at the source area was assumed to be the solubility limit of the chemicals. The longest half life of each chemical reported in the literature reviewed was assumed, as well as a 30 year duration of the source. Under these extremely conservative conditions, it was found that the maximum aqueous phase concentration of either chemical that could reach the water table would be less than 1% of the solubility concentration (i.e., a maximum concentration of 11,000 µg/L for TCE as compared with the MCL of 5 µg/L, and a maximum concentration of 1,500 µg/L for PCE as compared to the MCL of 5 µg/L).

These maximum concentrations would present significant carcinogenic risks if the water were used for human consumption, but the breakthrough time for TCE and PCE to reach the water table is 250 years. Although the extremely conservative assumptions made in this screening calculation make it likely that concentrations at the water table would be much lower than 1% of the solubility limits, continued monitoring is warranted to ascertain that infiltration to groundwater is not occurring. To date, neither TCE or PCE have been observed in samples from MWL monitoring wells.

At the nearby chemical waste landfill (CWL), low levels of TCE have been detected in the capillary fringe above the water table, and in the first few centimeters in the groundwater beneath the site (23 ppb). This contamination is believed to be derived from the significant quantities of dense non-aqueous phase liquids (DNAPLs) disposed at the site, and vapor phase transport to the underlying groundwater. The quantity of DNAPLs disposed at the MWL is unknown, but likely much smaller than that disposed at the CWL. TCE and PCE were not detected in MWL subsurface soil samples obtained at depths of up to 150 ft (see Section 4.2.1), so no evidence of downward migration exists. Therefore, it is not expected that vapor phase transport of TCE or PCE to the water table is occurring at the MWL. However, monitoring should continue to confirm that TCE and/or PCE have not reached the groundwater.

7.3 Toxicity and Risk Assessment

For this screening level assessment, ambient air concentrations of VOCs were calculated from the maximum flux rates measured at the MWL in either the Quadrel Inc. or Radian Corp. investigations. Better estimates of exposure would be provided by using long-term average flux levels. Air concentrations were estimated using the same model as was applied to estimate tritium air concentrations (Section 6.2.1). This model simply multiplies the flux rate by a dilution factor to attain the air concentration estimate, and is equivalent to the use of the equation given to calculate soil-to-air volatilization factors in EPA's Risk Assessment Guidance for Superfund (EPA 1991a).

The estimated air concentrations of VOCs were compared with action levels calculated using a risk-based methodology suggested for use in RCRA site investigations (EPA 1990). Toxicity reference levels for the contaminants of concern are obtained from EPA's Integrated Risk Information System (IRIS; EPA 1994a) or Health Effects Assessment Summary Tables (HEAST; EPA 1994b). These reference levels are exposure levels which would not be expected to result in any adverse effects over a lifetime for systemic contaminants, or corresponding to an increased lifetime cancer risk of one in one million (10^{-6}) for carcinogenic contaminants. The reference levels are converted to concentrations in air by assuming the human receptor's inhalation rate to be $20 \text{ m}^3/\text{day}$, body weight to be 70 kg, and exposure duration to be 70 years. These assumptions are appropriate for a worst case residential exposure scenario. As a screening level approach, action levels for residential receptors are sufficient to evaluate exposures at the MWL, since the future residential receptor would have higher exposure levels than either a current worker or trespasser (i.e., the resident would spend more time at the site). In fact, the assumptions used would overestimate risk for the residential receptor, because 90% of the population resides in the same location for less than 30 years (EPA 1989), as opposed to the 70 years assumed in calculating the action level. Additionally, the $20 \text{ m}^3/\text{day}$ inhalation rate assumes 24 hr/day occupancy at the site, which would be highly unlikely.

Action levels could only be calculated for 5 of the 14 substances detected in the soil flux surveys, because toxicity reference levels were not available for all substances. However, the substances for which toxicity reference levels were available included those detected most often and at the highest concentrations. Also, reference levels were available for all the carcinogenic substances

detected (i.e., benzene, 1,1-dichloroethene, methylene chloride, tetrachloroethene and trichloroethene). Therefore, the most significant contaminants have been addressed by the screening procedure.

Table 5 shows the results of the comparison of action levels with estimated site air concentrations of VOCs. In all cases, site concentrations were less than action levels, indicating that site concentrations would not be associated with human health risks for any of the receptors of concern (i.e., workers, trespassers, or residents). The concentration of methylene chloride was closest to its action level (1.0 mg/m³ vs. 2.2 mg/m³, or 45%). However, the methylene chloride concentration reported in Table 1 was suspect, because the substance was also detected in the background sample, and is a common laboratory contaminant.

8 Data Gaps for Radioactive and Chemical Parameters

Surface soil samples at the MWL have not been analyzed for either radioactive or chemical contaminants. Such sampling and analysis is needed to determine whether radionuclides, metals or semi-volatile compounds are present at elevated levels in surface soil, because contact with contaminants present in surface soils is a potential exposure route under both current and future exposure scenarios. Since all trenches and pits have been backfilled, it is unlikely that surface contamination is present. However, confirmation of this assumption is needed. If contamination is found in surface soil, incidental ingestion of soil, inhalation of contaminated particulates, ingestion of contaminated food, and dermal contact should be re-evaluated. In addition, the classified area has not yet been surveyed for external radiation. This is necessary to refine the risk estimates for the external irradiation pathway.

Table 6 provides risk-based action levels for typical chemical contaminants found at hazardous waste sites. The action levels apply for soil, water and air, and are calculated for both carcinogenic and toxic effects using the methods specified in guidance for RCRA investigations (EPA 1990). The lowest action level for each medium would be used for the initial evaluation of levels measured in site samples. Table 7 provides a list of action levels for radionuclides in soil that can be used to evaluate future surface soil data. The list contains potential radioactive contaminants of concern for the MWL. These action levels were developed for soils at the Los Alamos National Laboratory (DOE 1993). The levels were derived using the RESRAD computer code, assuming a residential scenario and input data that typify the range of soil properties encountered at Los Alamos. These levels can be used as field based screening action levels at the MWL. In order to use these levels, adequate characterization of background radionuclide levels in soils is required. Generally, if all constituent levels in soil, water, or air are found to be less than the action levels, then those levels may be considered insignificant, and no further remedial investigation or action should be required for the area. If levels are found to exceed action levels listed in these tables, then site-specific factors should be used to assess the associated risks. Because of the positive identification of PCE and TCE in soil gas surveys, continued monitoring of groundwater, surface and/or subsurface vapor monitoring for these contaminants would be prudent.

The soil action levels presented in Tables 6 and 7 can also be used to assess the risk associated with these contaminants in subsurface soil, if samples are obtained from the trenches or pits in the future. However, excavation of the pits and trenches (and therefore direct contact with the contaminants) is considered highly unlikely, and the low probability of future excavation is unlikely to warrant the risks to workers associated with sampling areas where radiological sources are known

to have been disposed.

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Table 1 VOC Flux Levels Detected at the Mixed Waste Landfill

August-September 1993 Survey (Quadrel, Inc.)

<u>Compound</u>	<u>Number of Detections</u>	<u>Flux Range^a (ng/m²/min)</u>
Acetone	8	0.40-17
1,1-Dichloroethene	1	1.3
Dichloroethyne	12	0.90-100
Ethyl Benzene	1	1.2
Isopropyl Ether	2	0.90-36
Styrene	1	1.0
Tetrachloroethene	63	0.80-400
Toluene	17	0.80-2.2
1,1,1-Trichloroethane	27	0.60-24
Trichloroethene	46	0.60-330
1,1,2-Trichlorotrifluoroethane	9	0.10-1.2
Xylene (total)	1	0.80

October 1993 Survey (Radian Corp.)

<u>Compound</u>	<u>Number of Detections</u>	<u>Flux Range^a (ng/m²/min)</u>	<u>Background^a (ng/m²/min)</u>
Acetone	(b)	(b)	(b)
Benzene ^c	9	8.3-30	15
Methylene Chloride ^c	9	1100-4800	2300
Tetrachloroethene	9	25-1000	37
Toluene	7	8.3-52	37
1,1,1-Trichloroethane	6	5.0-100	ND
Trichloroethene	4	8.4-100	ND

^aFlux and background values rounded to two significant figures.

^bData not available---not an analyte of primary concern (Radian 1994).

^cDenotes a compound not detected in the previous survey by Quadrel Inc.

ND denotes not detected.

Table 2 **Known Contents of Unclassified Area Trenches at the MWL**

Trench A (1962 to 1966)

- * Cobalt-60 (Co-60) contaminated lead (Pb) bricks and cinder blocks.
- * Large quantities of tritium.

Trench B (1969 to 1975)

- * Low specific activity waste (e.g., HEPA filters, paper and plastic trash).
Contaminated Pb.
- * Stainless-steel shell from Sandia Engineering Reactor Facility (SERF).
- * 5,000 gal (19,000 L) of water to extinguish a fire in trench B (June 1975).

Trench C (1975 to 1979)

- * 2 to 3 tons of Pb contaminated with uranyl nitrate.

Trench D (1966 to 1969)

- * Tons of contaminated equipment from the Nevada Test Site.
- * Components of laboratory that used Pu.
- * 271,500 gal of SERF primary coolant water containing about 1 Ci of total activity.

Trench E (1979 to 1986)

- * 3,000 ft³ of waste containing 20 Ci of fission products and alpha emitters from the Lovelace Inhalation Toxicology Research Institute. Waste comprised of contaminated laboratory equipment, biological waste, and possibly empty transuranic drums.
- * 10,000 lbs of soil contaminated with depleted uranium.
- * A 23-Ci Co-60 source.
- * 20,000 lb of soil contaminated with Cs-137.
- * A truck trailer contaminated with Cs-137.

Trench F (1986 to 1987)

- * 6 large spent fuel shipping casks and equipment totaling 364,000 lbs, contaminated with fission products.

Trench G (1987 to 1988)

- * 5 Polaris missile sections contaminated with Th.
- * Construction materials from the Sandia Pulsed Reactor (SPR).

Source: SNL, Phase II RFI Work Plan 1993b

Table 3 Summary of Input Parameters for the Radiological Assessment

Parameter	Units	Scenario	
		Worker	Resident
Flux	pCi/m ² -yr	1.5x10 ⁹	1.5x10 ⁹
Area (A)	m ²	10,070	10,070
Wind Speed (U)	m/s	4	4
Inhalation Rate (IR)	m ³ /hr	2.1	0.8
Exposure Time (ET)	hr	8	24
Exposure Frequency	d/y	50	350
Exposure Duration	y	25	30

Table 4 Summary of Radiological Doses and Risks for the Mixed Waste Landfill

Scenario	Exposure Pathway	Dose (mrem) ^a	Carcinogenic Risk
Worker	External Radiation	95 - 5,700	6×10^{-5} - 3×10^{-3}
	Inhalation of tritium	0.23	1×10^{-7}
Resident	External Radiation	3,400 - 102,000	2×10^{-3} - 6×10^{-2}
	Inhalation of tritium	5.7	3×10^{-6}

^aBased on a 25-yr exposure duration for the worker and a 30-yr exposure duration for the resident.

Table 5 Comparison of Modeled Site Air Concentrations of VOC^as with Action Levels

<u>Chemical</u>	<u>Max Flux</u> <u>ng/m²-yr</u>	<u>Site Concentration</u> <u>mg/m³</u>	<u>Action Level</u> <u>mg/m³</u>
Acetone	8.94	3.54x10 ⁻⁶	
Benzene	15.77	6.25x10 ⁻⁶	1.20x10 ⁻⁴
1,1-Dichloroethene	0.68	2.71x10 ⁻⁷	1.9x10 ⁻⁴
Dichloroethyne	52.56	2.08x10 ⁻⁵	
Ethylbenzene	0.63	2.5x10 ⁻⁷	
Isopropyl Ether	18.92	7.5x10 ⁻⁶	
Methylene Chloride	2522.88	1.0x10 ⁻³	2.20x10 ⁻³
Styrene	0.53	2.08x10 ⁻⁷	
Tetrachloroethene	525.60	2.08x10 ⁻⁴	1.80x10 ⁻³
Toluene	27.33	1.08x10 ⁻⁵	
1,1,1-Trichloroethane	52.56	2.08x10 ⁻⁵	
Trichloroethene	173.45	6.87x10 ⁻⁵	5.80x10 ⁻⁴
1,1,2-Trichlorotrifluoroethane	0.63	2.5x10 ⁻⁷	
Xylene	0.42	1.67x10 ⁻⁷	

^aSite Concentration = $3.17 \times 10^{-8} \cdot 0.5 \cdot \text{Flux} \cdot \text{sqrt}(A) / H_{\text{mix}} \cdot U$

where

- A = area of contaminated zone (10,000 m²)
- H_{mix} = height at which the water vapor is uniformly mixed (2 m for human inhalation pathway)
- U = annual average wind speed (2 m/s)

Table 6 Action Levels for Chemical Analytes in Soil, Water and Air For Environmental Characterization of the Mixed Waste Landfill at SNL, NM²

Chemical ^p	Chronic Oral RfD mg/kg-d	Oral Slope Factor (mg/kg-d) and Group ^c	Chronic Inhalation RfD mg/kg-d	Inhalation Slope Factor (mg/kg-d) and Group ^c	VF ^k m ³ /kg	Soil Action Level Systemic Toxicant mg/kg	Soil Action Level Carcinogen mg/kg	Water Action Level Systemic Toxicant µg/L	Water Action Level Carcinogen µg/L	Air Action Level Systemic Toxicant µg/m ³	Air Action Level Carcinogen µg/m ³	CRQL mg/kg and µg/L ^d
Inorganics												
Aluminum, 7429-90-5 ^e												40, 200
Antimony, 7440-36-0	0.0004					32	14					0
Arsenic, 7440-38-2	0.0003	1.75, A		15, A		24	0.4		0.02	0.00023		12, 60
Barium, 7440-39-3	0.07		0.00014 ^f			5,600						0
Beryllium, 7440-41-7	0.005	4.3, B2		8.4, B2		400	0.16		0.0081	0.00042		2, 10
Cadmium, 7440-43-9	0.001			6.3, B1		80				0.00056		40, 200
Calcium, 7440-70-2 ^e												1, 5
Chromium III, 16065-83-1	1.0					80,000		35,000				1000, 5000
Chromium IV, 7440-47-3	0.005			42, A		400		170		0.000083		2, 10
Cobalt, 7440-48-4 ^e												10, 50
Copper, 7440-50-8	0.037					3,000		1,300				5, 25
Cyanide, 57-12-5	0.02	ND, D		ND, D	8.20e+3	1,600		700				2, 10
Iron, 1543-83-10 ^e												20, 100
Lead, 7439-92-1 ^e		ND, B2		ND, B2								0.5, 3
Magnesium, 7786-30-3 ^e												1000, 5000
Manganese, 7439-96-5	0.14	ND, D	0.00011	ND, D		11,000		4,800		0.4		3, 15
Mercury, 7439-97-6	0.0003	ND, D	8.6e-5 ^f	ND, D		24		11		0.3		0.1, 0.2
Nickel, 7440-02-0	0.02			0.84, A		1,500		700			0.0012	8, 40

Table 6 Action Levels for Chemical Analytes in Soil, Water and Air For Environmental Characterization of the Mixed Waste Landfill at SNL, NM (cont.)

Chemical ^b	Chronic Oral RfD mg/kg-d	Oral Slope Factor (mg/kg-d) ¹ and Group ^c	Chronic Inhalation RfD mg/kg-d	Inhalation Slope Factor (mg/kg-d) ¹ and Group ^c	VF ^k m ³ /kg	Soil Action Level Systemic Toxicant mg/kg	Soil Action Level Carcinogen mg/kg	Water Action Level Systemic Toxicant µg/L	Water Action Level Carcinogen µg/L	Air Action Level Systemic Toxicant µg/m ³	Air Action Level Carcinogen µg/m ³	CRQL ^d mg/kg and µg/L
Potassium, 7447-40-7												1000, 5000
Selenium, 7782-49-2	0.005	ND, D		ND, D		400		170				1, 5
Silver, 7440-22-4	0.005					400		170				2, 10
Sodium ^e , 7647-14-5												1000, 5000
Thallium, 7440-28-0	0.00008 ^m					6.4		2.8				2, 10
Vanadium, 7440-62-2	0.007 ^f					560		240				10, 50
Zinc, 7440-66-6	0.3	ND, D		ND, D		24,000		10,000				4, 20
Volatile Organic Compounds												
Acetone, 67-64-1	0.1				1.4e+4	8,000		3,500				0.01, 10
Benzene, 71-43-2		0.029, A		0.029, A	5.7e+3		^h 0.67		1.2		0.12	9
Bromodichloromethane, 75-27-4	0.02	0.062, B2		ND, B2	8.0e+2	1,600	11	700	0.56			0.01, 10
Bromoform, 75-25-2	0.02	0.0079, B2		0.0039, B2		1,600	89	700	4.4		0.9	9
Bromomethane, 74-83-9	0.0014	ND, D	0.0014	ND, D	3.9e+2	^h 0.43		49		4.9		0.01, 10
2-Butanone (Methyl ethylketone), 78-93-3	0.6	ND, D	0.29	ND, D	1.9e+4	^h 4,000		21,000		1,000		0.01, 10
Carbon disulfide, 75-15-0	0.1		0.0029 ^f		3.2e+3	^h 7.4		3,500		10		0.01, 10
Carbon tetrachloride, 56-23-5	0.0007	0.13, B2		0.053, B2	3.3e+3	56	^h 0.21	25	0.27		0.965	9
Chlorobenzene, 106-90-7	0.02	ND, D	0.0057 ^f	ND, D	1.5e+4	^h 67		700		20		0.01, 10

Table 6 Action Levels for Chemical Analytes in Soil, Water and Air For Environmental Characterization of the Mixed Waste Landfill at SNI, NM¹ (cont.)

Chemical ^b	Chronic Oral RID mg/kg-d	Oral Slope Factor (mg/kg-d) and Group ^c	Chronic Inhalation RID mg/kg-d	Inhalation Slope Factor (mg/kg-d) and Group ^c	VF ^k mg/kg	Soil Action Level Systemic Toxicant mg/kg	Soil Action Level Carcinogen mg/kg	Water Action Level Systemic Toxicant µg/L	Water Action Level Carcinogen µg/L	Air Action Level Systemic Toxicant µg/m ³	Air Action Level Carcinogen µg/m ³	CRQL ^d mg/kg and µg/L
Chloroethane, 75-00-3			2.9		1.4e+3	h 3,300				10,000		0.01, 10
Chloroform, 67-66-3	0.01	0.0061, B2		0.081, B2	4.8e+3	800	h 0.21	350	5.7		0.043	0.01, 10
Chloromethane, 74-87-3		f 0.013, C		f 0.0063, C	1.2e+3		h 0.64		2.7		0.56	0.01, 10
Dibromochloromethane, 124-48-1	0.02	0.084, C		ND, C		1,600	8.3	700	0.42			0.01, 10
1,1-Dichloroethane, 75-34-3	0.1	ND, C	f 0.14	ND, C	3.8e+3	h 410		3,500		500		0.01, 10
1,1-Dichloroethene, 75-35-4	0.009	0.6, C		0.18, C	2.1e+3	720	h 0.04	310	0.058		0.019	0.01, 10
1,2-Dichloroethane, 107-06-2		0.091, B2		0.091, B2	5.5e+3		h 0.2		0.38		0.038	0.01, 10
1,2-Dichloroethene (total), 540-59-0	0.009	f			4.6e+3	720		315				0.01, 10
1,2-Dichloropropane, 78-87-5		f 0.068, B2	0.0011	ND, B2	7.1e+3	h 6.5	10		0.51	4.0		0.01, 10
cis-1,3-Dichloropropene, 10061-01-5	0.0003	f 0.18, B2	0.0057	0.13, B2	6.8e+3	h 14	h 0.17	11	0.19	20	0.027	0.01, 10
trans-1,3-Dichloropropene, 10061-02-6	0.0003	f 0.18, B2	0.0057	0.13, B2	6.8e+3	h 14	h 0.17	11	0.19	20	0.027	0.01, 10
Ethyl benzene, 100-41-4	0.1	ND, D	0.29	ND, D	2.2e+4	h 3,100		3,500		1,000		0.01, 10
2-Hexanone, 591-78-6					5.5e+4							0.01, 10
4-Methyl-2-pentanone (MIBK), 108-10-1	0.08	f	0.023	f	3.2e+4	530		2,800		80		0.01, 10
Methylene Chloride, 75-09-2	0.06	f 0.0075, B2	0.86	0.0016, B2	2.9e+3	h 1,400	h 5.9	2,100	4.7	3,000	2.2	0.01, 10
Styrene, 100-42-5	0.2		0.29		1.8e+4	h 3,200		7,000		1,000		0.01, 10
1,1,2,2-Tetrachloroethane, 79-34-5		0.2, C		0.2, C	2.9e+4		h 0.44		0.18		0.018	0.01, 10

Table 6 Action Levels for Chemical Analytes in Soil, Water and Air For Environmental Characterization of the Mixed Waste Landfill at SNI, NM¹ (cont.)

Chemical ^p	Chronic Oral RfD mg/kg-d	Oral Slope Factor (mg/kg-d) and Group ^c	Chronic Inhalation RfD mg/kg-d	Inhalation Slope Factor (mg/kg-d) and Group ^c	Vf ^k mg/kg	Soil Action Level Systemic Toxicant mg/kg	Soil Action Level Carcinogen mg/kg	Water Action Level Systemic Toxicant µg/L	Water Action Level Carcinogen µg/L	Air Action Level Systemic Toxicant µg/m ³	Air Action Level Carcinogen µg/m ³	CRQL mg/kg and µg/L ^d
Tetrachloroethene, 127-18-4	0.01	n 0.052,B-C		n 0.002,B-C	6.0e+3	800	h 5.9	350	0.67		1.8	g 0.01, 10
Toluene, 108-88-3	0.2	ND, D	0.11	ND, D	1.1e+4	h 920		7,000		360		0.01, 10
1,1,1-Trichloroethane, 71-55-6	0.09	ND, D	f 0.29	ND, D	5.1e+3	h 1,000		3,100		1,000		0.01, 10
1,1,2-Trichloroethane, 79-00-5	0.004	0.057, C		0.056, C	1.1e+4	320	h 0.63	140	0.61		0.063	g 0.01, 10
Trichloroethene, 79-01-6		n 0.011,B-C		n 0.006,B-C	5.8e+3		h 3.2		3.2		0.58	g 0.01, 10
Vinyl Chloride, 75-01-4		f 1.9, A		f 0.3, A	1.1e+3		h 0.013		0.018		0.012	g 0.01, 10
Xylenes (Total), 1330-20-7	2				9.6e+3	160,000		70,000				0.01, 10
Semi-Volatile Organic Compounds												
Acenaphthene, 83-32-9	0.06				3.4e+5	4,800		2,100				0.33, 10
Acenaphthylene ^e , 208-96-8					6.1e+4							0.33, 10
Anthracene, 120-12-7	0.3	ND, D		ND, D	1.8e+5	24,000		10,000				0.33, 10
Benzo(a)anthracene, 56-55-3		ND, B2		ND, B2								0.33, 10
Benzo(b)fluoranthene, 205-99-2		ND, B2		ND, B2								0.33, 10
Benzo(k)fluoranthene, 207-08-9		ND, B2		ND, B2								0.33, 10
Benzo(ghi)perylene, 191-24-2		ND, D		ND, D								0.33, 10
Benzo(a)pyrene, 50-32-8		7.3, B2		ND, B2			0.1		0.0048			g 0.33, 10

Table 6 Action Levels for Chemical Analytes in Soil, Water and Air For Environmental Characterization of the Mixed Waste Landfill at SNI, NM (cont.)

Chemical ^b	Chronic Oral RfD mg/kg-d	Oral Slope Factor (mg/kg-d) ¹ and Group ^c	Chronic Inhalation RfD mg/kg-d	Inhalation Slope Factor (mg/kg-d) ¹ and Group ^c	VF ^k m ³ /kg	Soil Action Level Systemic Toxicant mg/kg	Soil Action Level Carcinogen mg/kg	Water Action Level Systemic Toxicant µg/L	Water Action Level Carcinogen µg/L	Air Action Level Systemic Toxicant µg/m ³	Air Action Level Carcinogen µg/m ³	CRGL mg/kg and µg/L ^d
Bis(2-chloroethoxy)methane, ^e 111-91-1		ND, D		ND, D								0.33, 10
Bis(2-chloroethyl)ether, 111-44-4		1, 1, B2		1, 2, B2	4.9e+4		0.12 ^h	0.032		0.0029		0.33, 10
Bis(2-ethylhexyl)phthalate, 117-81-7	0.02	0.014, B2		ND, B2		1,600	50	700	2.5			0.33, 10
4-Bromophenylphenylether, 101-55-3												0.33, 10
Butyl benzyl phthalate, 85-68-7	0.2	ND, C		ND, C		16,000		7,000				0.33, 10
Carbazole, 86-74-8		0.02, B2		ND, B2			35		1.8			0.33, 10
4-Chloroaniline, 106-47-8	0.004					320		140				0.33, 10
4-Chloro-3-methylphenol (p-chloro-m-cresol), 59-50-7	0.2					16,000		7,000				0.33, 10
2-Chloronaphthalene, 91-58-7	0.08				1.4e+5	6,400		2,800				0.33, 10
2-Chlorophenol, 95-57-8	0.005					400		170				0.33, 10
4-Chlorophenyl phenyl ether, 7005-72-3		ND, B2		ND, B2								0.33, 10
Chrysene, 218-01-9 ^e		ND, B2		ND, B2								0.33, 10
Dibenz(a,h)anthracene, 53-70-3		ND, B2		ND, B2								0.33, 10
Dibenzofuran, 132-64-9												0.33, 10
Di-n-butylphthalate, 84-74-2	0.1	ND, D		ND, D		8,000		3,500				0.33, 10
1,2-Dichlorobenzene, 95-50-1	0.09		0.057 ^f		4.5e+4	1,600 ^h		3,100		200		0.33, 10

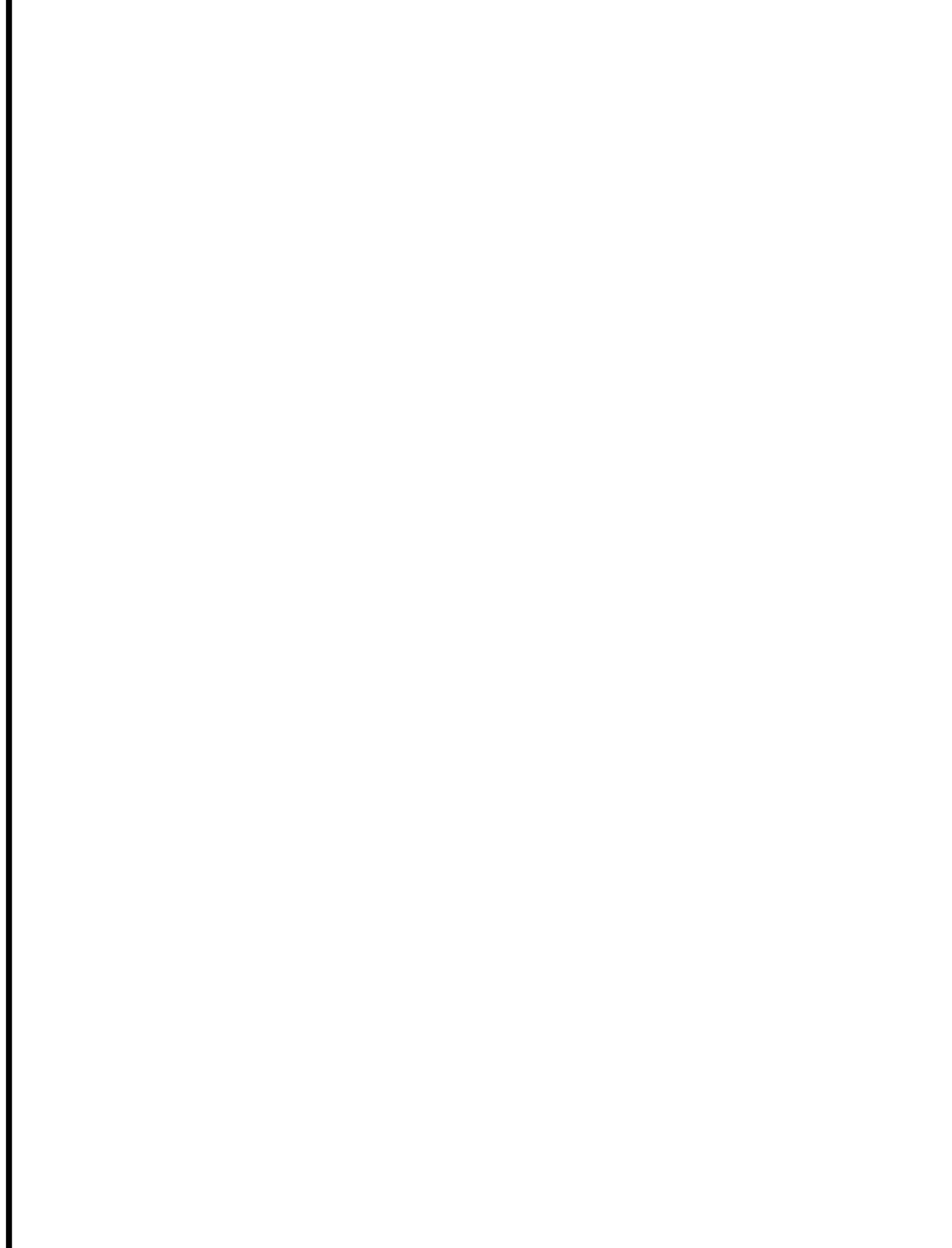


Table 6 Action Levels for Chemical Analytes in Soil, Water and Air For Environmental Characterization of the Mixed Waste Landfill at SNI, NM³¹ (cont.)

Chemical ^b	Chronic Oral RID mg/kg-d	Oral Slope Factor (mg/kg-d) ^c and Group	Chronic Inhalation RID mg/kg-d	Inhalation Slope Factor (mg/kg-d) ^c and Group	VF ^k m ³ /kg	Soil Action Level Systemic Toxicant mg/kg	Soil Action Level Carcinogen mg/kg	Water Action Level Systemic Toxicant µg/L	Water Action Level Carcinogen µg/L	Air Action Level Systemic Toxicant µg/m ³	Air Action Level Carcinogen µg/m ³	CRQL mg/kg and µg/L ^d
1,3-Dichlorobenzene, 541-73-1 ^e					3.3e+4							0.33, 10
1,4-Dichlorobenzene, 106-46-7		0.024, B2	0.23	ND, B2 ^f	3.6e+4	6,600 ^h	29		1.5	800		0.33, 10 ^g
3,3-Dichlorobenzidine, 91-94-1		0.45, B2		ND, B2		240	1.6		0.078			0.33, 10 ^g
2,4-Dichlorophenol, 120-83-2	0.003							100				0.33, 10
Diethylphthalate, 84-86-2	0.8	ND, D		ND, D		64,000		28,000				0.33, 10
2,4-Dimethylphenol, 105-67-9	0.02			ND, D	1.1e+5	1,600		700				0.33, 10
Dimethylphthalate, 131-11-3	^f 10	ND, D		ND, D		800,000		350,000				0.33, 10
4,6-Dinitro-2-methylphenol (4,6-dinitro-o-cresol), 534-52-1												0.8, 25
2,4-Dinitrophenol, 51-28-5	0.002					160		70				0.8, 25
2,4-Dinitrotoluene, 121-14-2	0.0002	^o 0.68, B2		ND, B2		160	1.0		0.051			0.33, 10 ^g
2,6-Dinitrotoluene, 506-20-2		^o 0.68, B2		ND, B2			1.0		0.051			0.33, 10 ^g
Di-n-octylphthalate, 117-84-0	^f 0.02					1,600		700				0.33, 10
Fluoranthene, 206-44-0	0.04	ND, D		ND, D		3,200		1,400				0.33, 10
Fluorene, 86-73-7	0.04				5.1e+5	3,200		1,400				0.33, 10
Hexachlorobenzene, 118-74-1	0.0008	1.6, B2		1.6, B2		64	0.41	28	0.022		0.0022	0.33, 10 ^g
Hexachlorobutadiene, 87-68-3	^f 0.0002	0.078, C		0.077, C		16	9.0	7	0.45		0.045	0.33, 10 ^g

Table 6 Action Levels for Chemical Analytes in Soil, Water and Air For Environmental Characterization of the Mixed Waste Landfill at SNI, NM¹¹ (cont.)

Chemical ^p	Chronic Oral RID mg/kg-d	Oral Slope Factor (mg/kg-d) ¹ and Group ^c	Chronic Inhalation RID mg/kg-d	Inhalation Slope Factor (mg/kg-d) ¹ and Group ^c	VF ^k m ³ /kg	Soil Action Level Systemic Toxicant mg/kg	Soil Action Level Carcinogen mg/kg	Water Action Level Systemic Toxicant µg/L	Water Action Level Carcinogen µg/L	Air Action Level Systemic Toxicant µg/m ³	Air Action Level Carcinogen µg/m ³	CRQL ^d mg/kg and µg/L
Hexachlorocyclopentadiene, 77-47-4	0.007		f 0.00002			560		240		0.07		0.33, 10
Hexachloroethane, 67-72-1	0.001	0.014, C		0.014, C		80	50	35	2.5		0.25	0.33, 10
Indeno[1,2,3-cd]pyrene, 193-39-5		ND, B2		ND, B2								0.33, 10
Isophorone, 78-59-1	0.2	0.00095, C		ND, C		16,000	740	7,000	37			0.33, 10
2-Methylnaphthalene, 91-57-6					1.9e+5							0.33, 10
2-Methylphenol (o-cresol), 95-48-7	0.05	ND, C		ND, C		4,000		1,700				0.33, 10
4-Methylphenol (p-cresol), 106-44-5	0.005	ND, C		ND, C		400		175				0.33, 10
Naphthalene, 91-20-3	0.04				6.8e+4	3,200		1,400				0.33, 10
2-Nitroaniline (o-nitroaniline), 88-74-4			f 5.7e-05							0.20		0.33, 10
3-Nitroaniline (m-nitroaniline), 99-09-2												0.8, 25
4-Nitroaniline (p-nitroaniline), 100-01-6												0.8, 25
Nitrobenzene, 98-95-3	0.0005	ND, D	f 0.00057	ND, D	1.3e+4	h 5.3		18		2.0		0.33, 10
2-Nitrophenol, 88-75-5												0.33, 10
4-Nitrophenol, 100-02-7					1.9e+4							0.8, 25
N-Nitrosodiphenylamine, 86-30-6		0.0049, B2		ND, B2			140		7.1			0.33, 10
N-Nitroso-di-N-propylamine, 62-1-64-7		7, B2		ND, B2			0.10		0.0050			0.33, 10

Table 6 Action Levels for Chemical Analytes in Soil, Water and Air For Environmental Characterization of the Mixed Waste Landfill at SNL, NM²¹ (cont.)

Chemical ^p	Chronic Oral RfD mg/kg-d	Oral Slope Factor (mg/kg-d) ¹ and Group ^c	Chronic Inhalation RfD mg/kg-d	Inhalation Slope Factor (mg/kg-d) ¹ and Group ^c	VF ^k m ³ /kg	Soil Action Level Systemic Toxicant mg/kg	Soil Action Level Carcinogen mg/kg	Water Action Level Systemic Toxicant µg/L	Water Action Level Carcinogen µg/L	Air Action Level Systemic Toxicant µg/m ³	Air Action Level Carcinogen µg/m ³	CRQL ^d mg/kg and µg/L
2,2-Oxybis(1-chloropropane) (bis[2-chloroisopropyl]ether), 108-60-1	0.04	^f 0.07, C		^f 0.035, C		3,200	10	1,400	0.50		0.10	^g 0.33, 10
Pentachlorophenol, 87-86-5	0.03	0.12, B2		ND, B2		2,400	5.8	1,000	0.29			^g 0.8, 25
Phenanthrene ^e , 85-01-8		ND, D		ND, D	4.4e+5							0.33, 10
Phenol, 108-95-2	0.6					48,000		21,000				0.33, 10
Pyrene, 129-00-0	0.03	ND, D		ND, D		2,400		1,000				0.33, 10
1,2,4-Trichlorobenzene, 120-82-1	0.01	ND, D	^f 0.057	ND, D		^h 680		350		200		0.33, 10
2,4,5-Trichlorophenol, 95-95-4	0.10					8,000		3,500				0.8, 25
2,4,6-Trichlorophenol, 88-06-2		ⁱ 0.011, B2		0.011, B2			64		3.2		0.32	^g 0.33, 10

^aAction levels based on methodologies given in EPA 1990 and EPA 1991a except that action levels for all carcinogens (including Class C) are based on a target risk level of 10^{-6} . Reference dose (RfD) and slope factor data obtained from EPA 1994a (IRIS), unless otherwise noted. Action levels are rounded to two significant figures. Lowest action level for a given medium (systemic vs. carcinogenic) is used for comparing with site levels. Water action levels are used for both ground and surface water. ND - not determined; NA - not applicable.

^bChemicals and CAS numbers as given by EPA (1991d and 1991e).

^cCarcinogens grouped as follows: Group A-human carcinogen; Group B1-probable human carcinogen, limited evidence in humans; Group B2-probable human carcinogen, sufficient evidence in animals and inadequate evidence in humans; Group C-possible human carcinogen; Group D - not classifiable as to human carcinogenicity.

^dContract-Required Quantitation Limits (CRQLs) for soil and water, respectively. The soil CRQL given is for low soil samples (wet weight). CRQLs not available for air.

^eToxicity data (e.g. RfDs and/or slope factors) were not available; therefore, action levels were not calculated.

^fToxicity data obtained from EPA 1994a (HEAST). For copper, RfD calculated as $[MCL (1.3 \text{ mg/L}) \times 2 \text{ L/day}] / 70 \text{ kg}$.

^gA CRQL is close to or greater than the action level; Special Analytical Services may be required.

^hAction level incorporates inhalation pathway - see below for equation.

ⁱOral RfD for 1,2-dichloroethene mixed isomers used.

^jChronic RfD for 4-chloro-3-methylphenol not available; value given is subchronic RfD/10.

^kSoil-to-Air Volatilization Factor; calculated based on equation given in EPA 1991a and chemical-specific parameters given in Streng and Peterson (1989) and EPA 1988. VF is given only for substances with molecular weight less than 200 and Henry's Law Constant greater than $10^{-5} \text{ atm/m}^3\text{-mole}$.

^lOral RfD for cadmium and manganese in food/solids.

^mOral RfD for thallium (I) sulfate.

ⁿValues obtained from the Superfund Health Risk Technical Support Center, Cincinnati, OH.

^oValue for 2,4,2,6-dinitrotoluene mixture.

General equations for calculation of Action Levels:

Systemic Toxicants

$AL = (THI \times RfD \times BW \times CF) / (I \times A)$, where:

AL = action level (mg/kg for soil ALs; ug/L for water ALs; ug/m³ for air ALs).

THI = Target Hazard Index; I

RfD = chronic reference dose (mg/kg/day); oral RfD used for soil and water ALs; inhalation RfD used for air ALs.

BW = body weight; 16 kg for child (used for soil AL); 70 kg for adult (used for water and air ALs).

CF = conversion factor; 10^6 mg/kg for soil ALs; 1000 ug/mg for water and air ALs.

I = intake assumption; 200 mg/day for soil ALs (chltd); 2 L/day for water ALs; 20 m³/day for air ALs.
 A = absorption factor; 1

Carcinogenic Constituents:

AL = (R x BW x LT x CF)/(SF x I x A x ED), where:

R = target risk; 10⁻⁶.
 BW = body weight; 70 kg.
 LT = assumed lifetime; 70 yr.
 CF = conversion factor; 10⁶ mg/kg for soil ALs; 1000 ug/mg for water and air ALs.
 SF = slope factor (mg/kg/day)⁻¹; oral SF used for soil and water ALs; inhalation SF used for air ALs.
 I = intake assumption; 100 mg/day for soil ALs; 2 L/day for water ALs; 20 m³/day for air ALs.
 A = absorption factor; 1
 ED = exposure duration; 70 yr.

47 Equation for calculation of soil action levels for volatile constituents:

Systemic Toxicants:

AL = (THI x BW)/((1/RID_o x 10⁻⁶ kg/mg x ING) + (1/RID_i x INH x (1/VF))), where:

THI = target hazard index; 1.
 BW = body weight; 16 kg.
 RID_o = chronic oral reference dose (mg/kg/day).
 RID_i = chronic inhalation reference dose (mg/kg/day).
 ING = ingestion intake assumption; 200 mg/day.
 INH = inhalation intake assumption; 20 m³/day
 VF = soil-to-air volatilization factor (chemical-specific);

Carcinogenic constituents:

AL = (R x BW x LT)/ED x ((SF_o x 10⁻⁶ kg/mg x ING) + (SF_i x INH x (1/VF))), where:

R = target risk; 10⁻⁶.

BW = body weight; 70 kg.
LT = assumed lifetime; 70 yr.
ED = exposure duration; 70 yr.
SF_o = oral slope factor (mg/kg/day)⁻¹.
ING = ingestion intake assumption; 100 mg/day.
SF_i = inhalation slope factor (mg/kg/day)⁻¹.
INH = inhalation intake assumption; 20 m³/day.
VF = soil-to-air volatilization factor (chemical-specific);

Table 7

Radionuclide Screening Action Levels for MWL Soils

Radionuclide	Screening Action Level (pCi/g dry soil)
Americium-241	22
Cesium-134	1.9
Cesium-137	4.0
Cobalt-60	0.9
Plutonium-238	27
Plutonium-239	24
Radium-226	0.73 ^a
Radium-228	1.6 ^a
Strontium-90	8.9
Thorium-230	10 ^a
Thorium-232	0.88 ^a
Uranium-233	86
Uranium-234	86
Uranium-235	18
Depleted Uranium	59 ^b
Natural Uranium	66 ^b

^aGeneric limits for Ra-226, Ra-228, Th-230 and Th-232 are set in DOE Order 5400.5 at 5 pCi/g averaged over the uppermost 15 cm of soil, and 15 pCi/g averaged over each additional 15-cm interval. The more conservative derived screening action levels are to be used for screening purposes only.

^bCalculated assuming the following isotopic abundances:

	<u>Natural Uranium (%)</u>	<u>Depleted Uranium (%)</u>
U-234	0.0057	0.0005
U-235	0.7204	0.2500
U-238	99.2739	99.7500

Source: DOE 1993

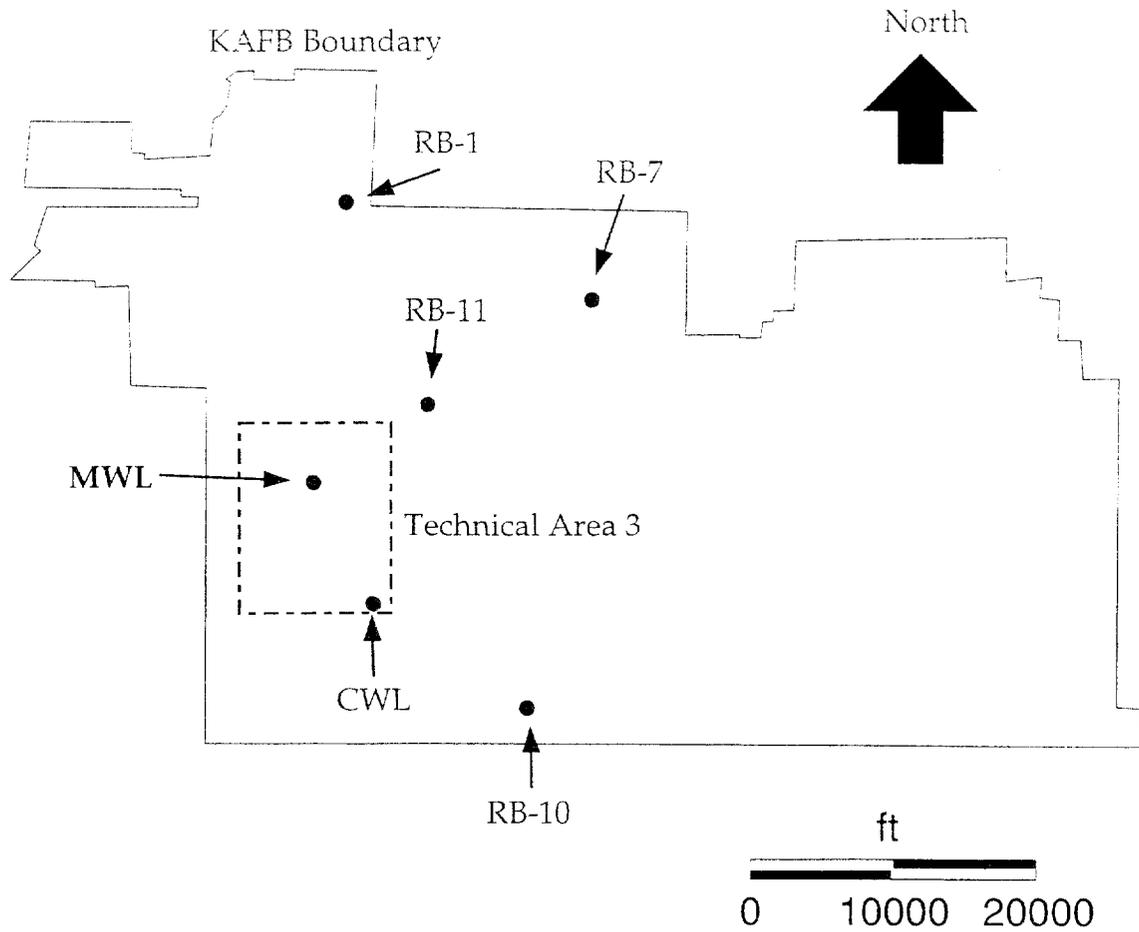


Figure 1 Kirtland Air Force Base

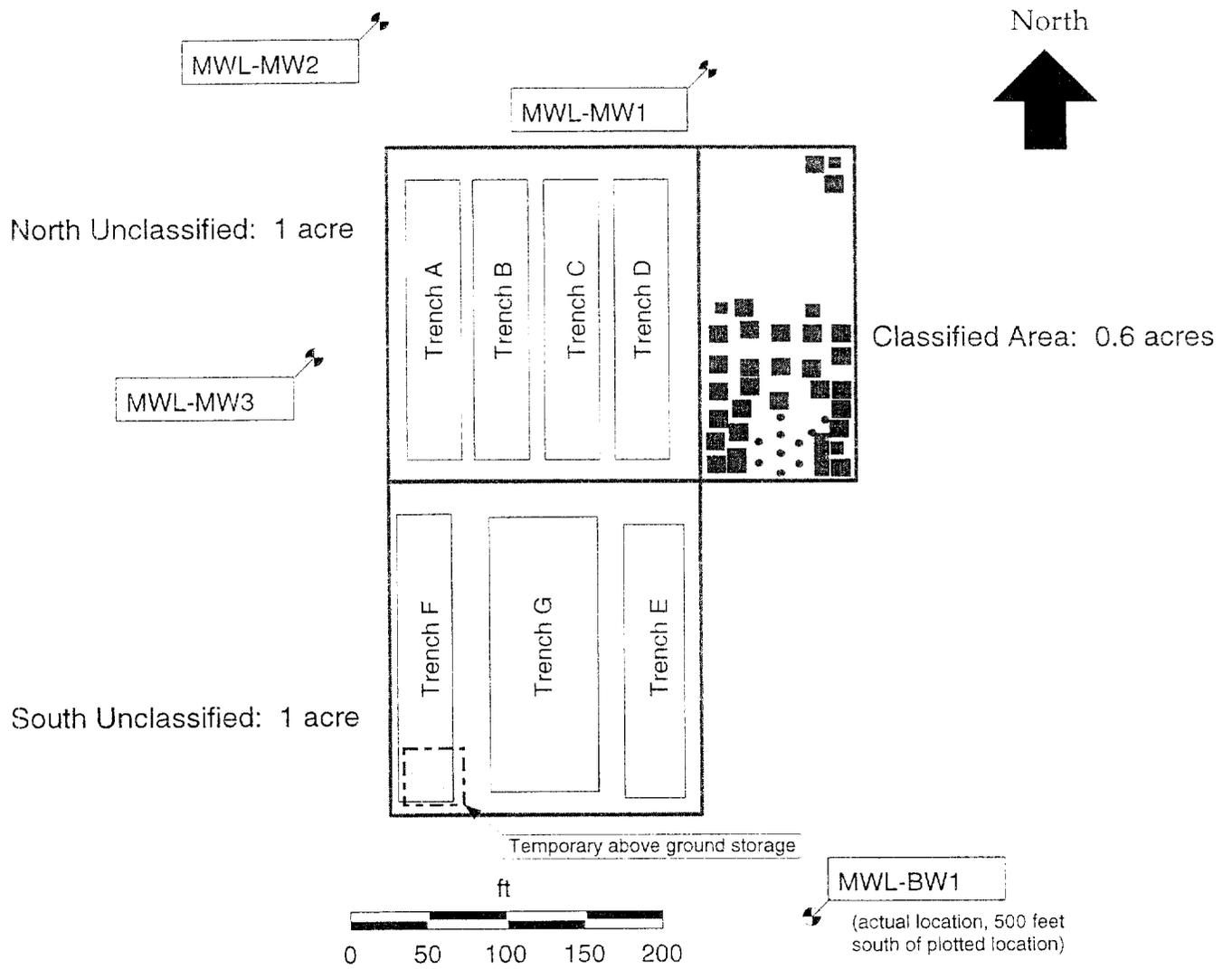


Figure 2 The Mixed Waste Landfill

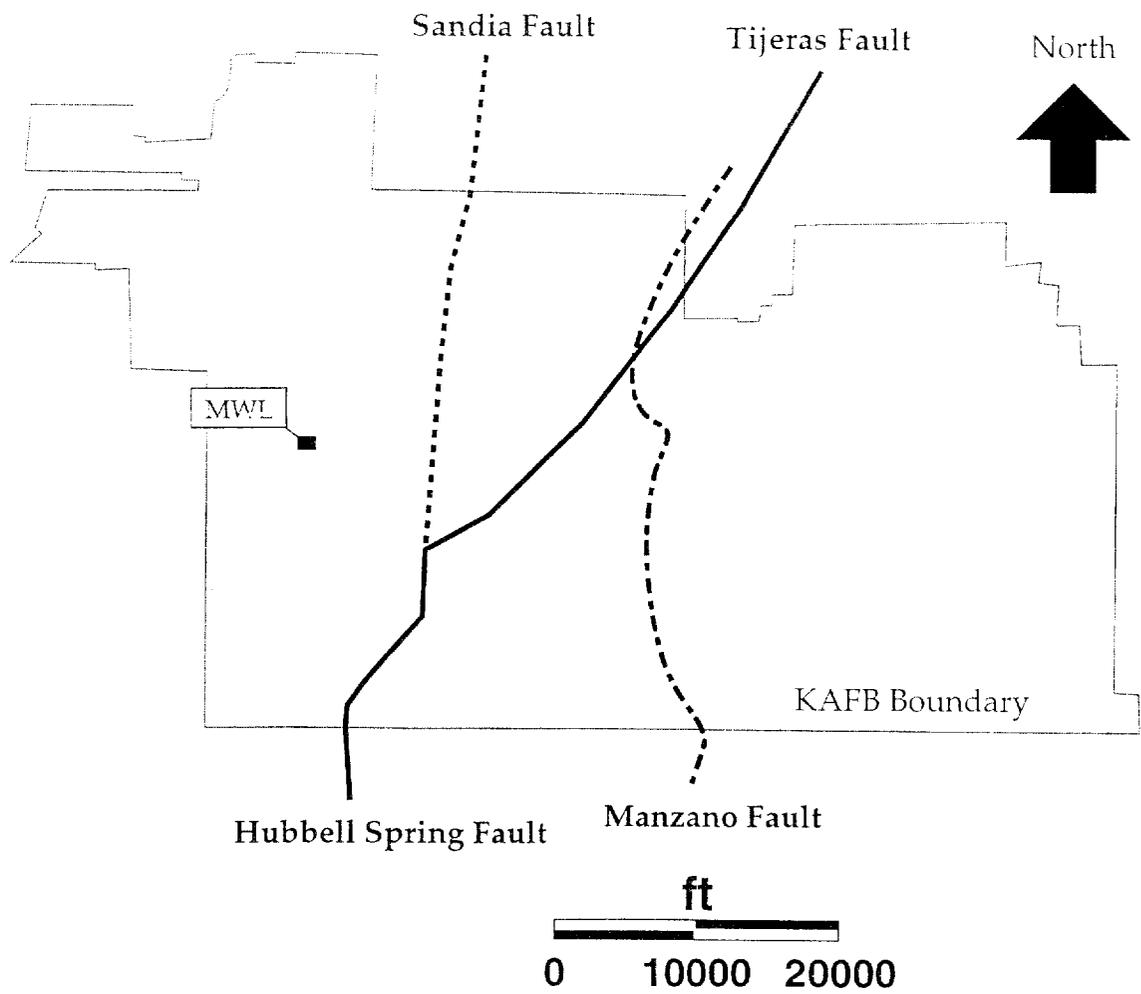


Figure 3 Fault Lines in Vicinity of Kirtland Air Force Base

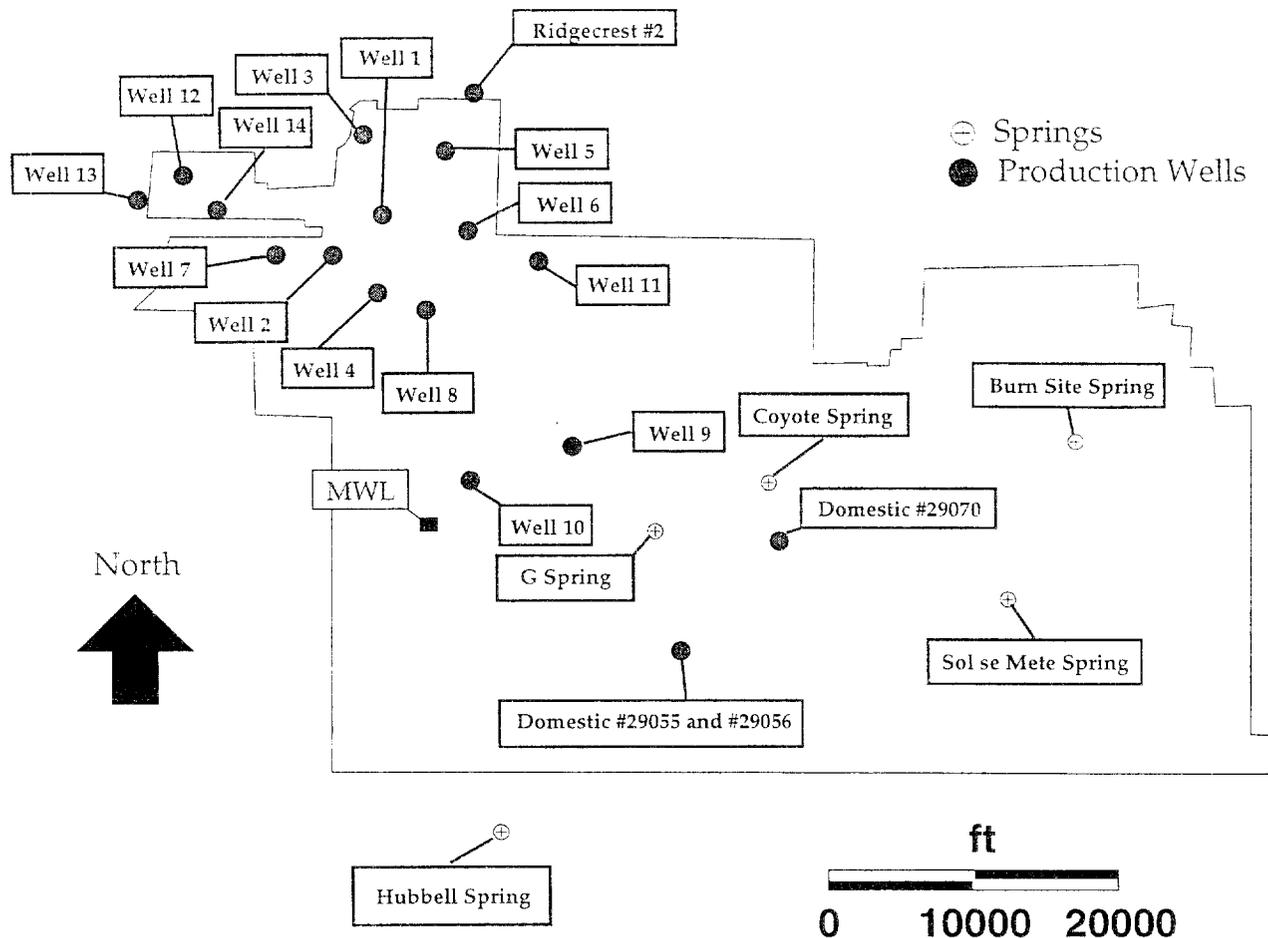


Figure 4 Production Wells and Springs at Kirtland Air Force Base

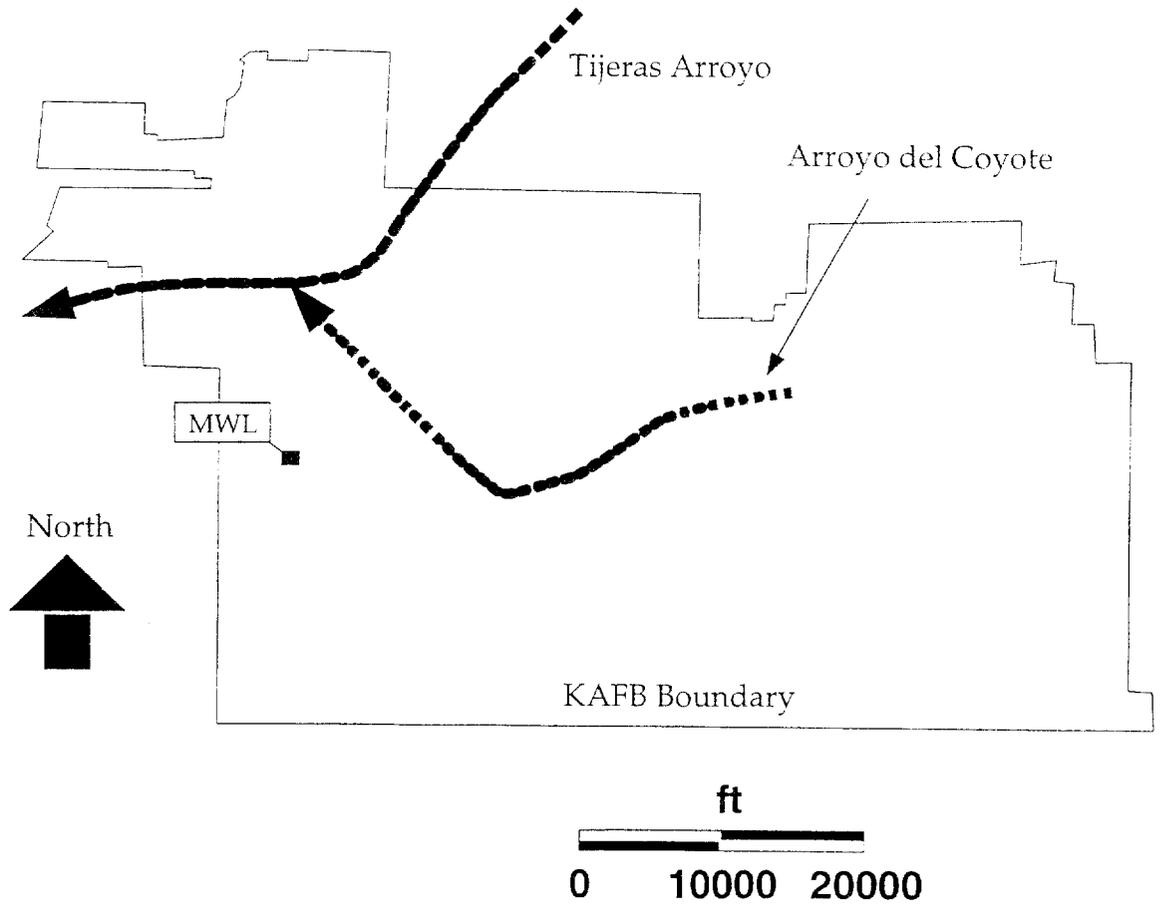


Figure 5 Major Surface Drainage Features at Kirtland Air Force Base

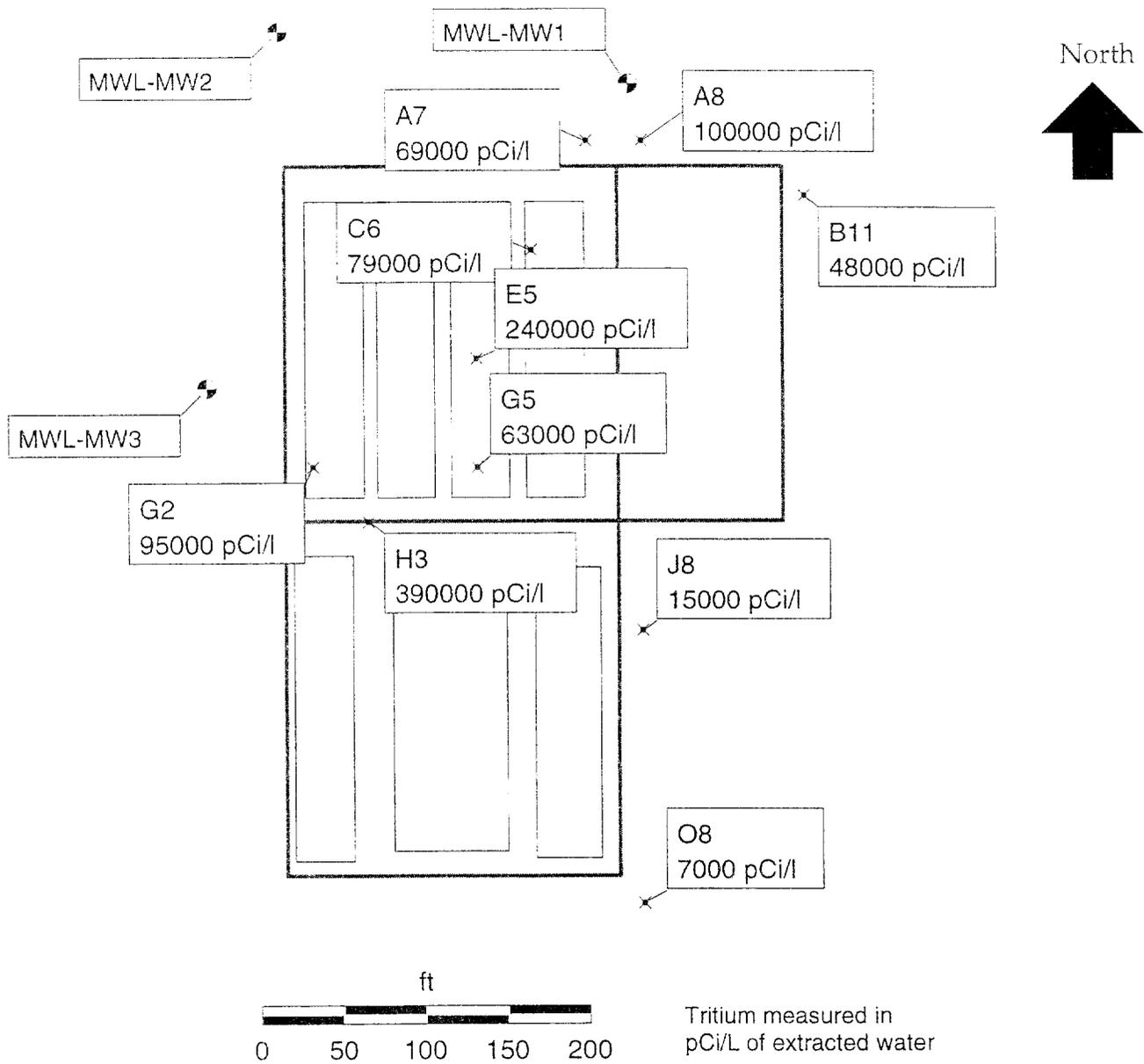


Figure 6 1990 Surface Soil Sample Tritium Results for Samples Above Background

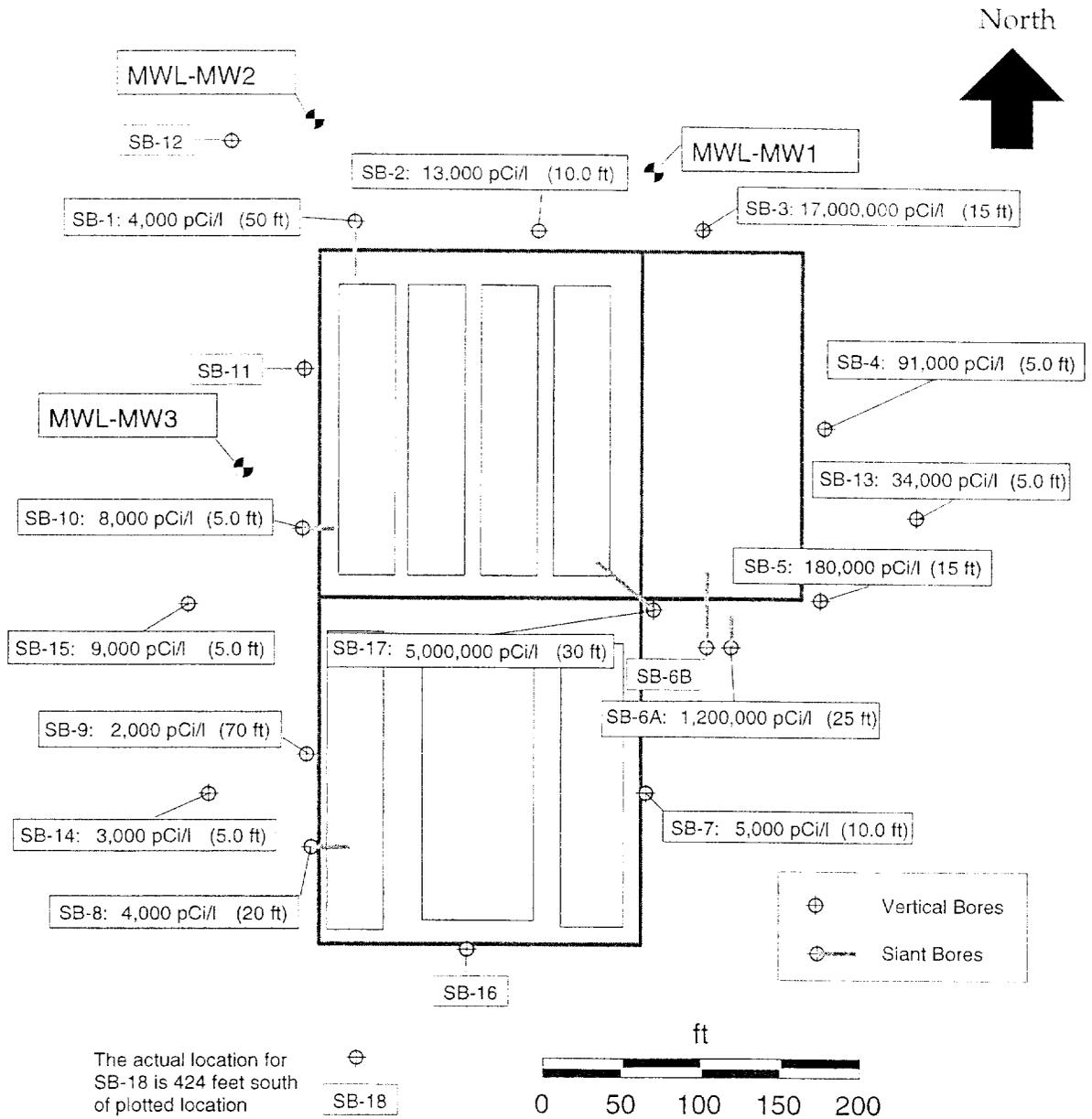


Figure 7 Location and Depth of Maximum Subsurface Tritium Soil Concentrations Measured in pCi/L of Extracted Water

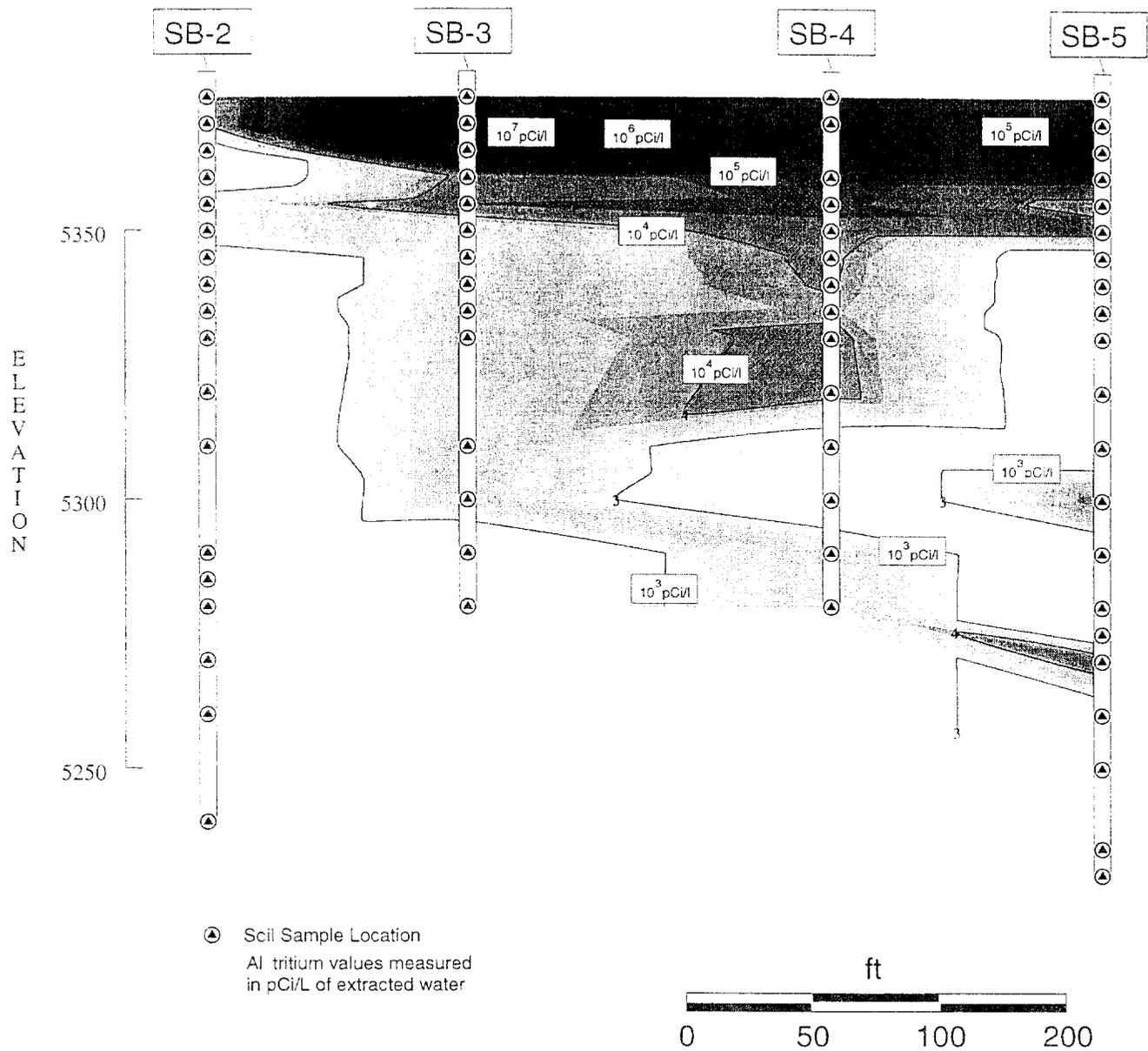


Figure 8 Vertical Distribution of Tritium for Selected Bores

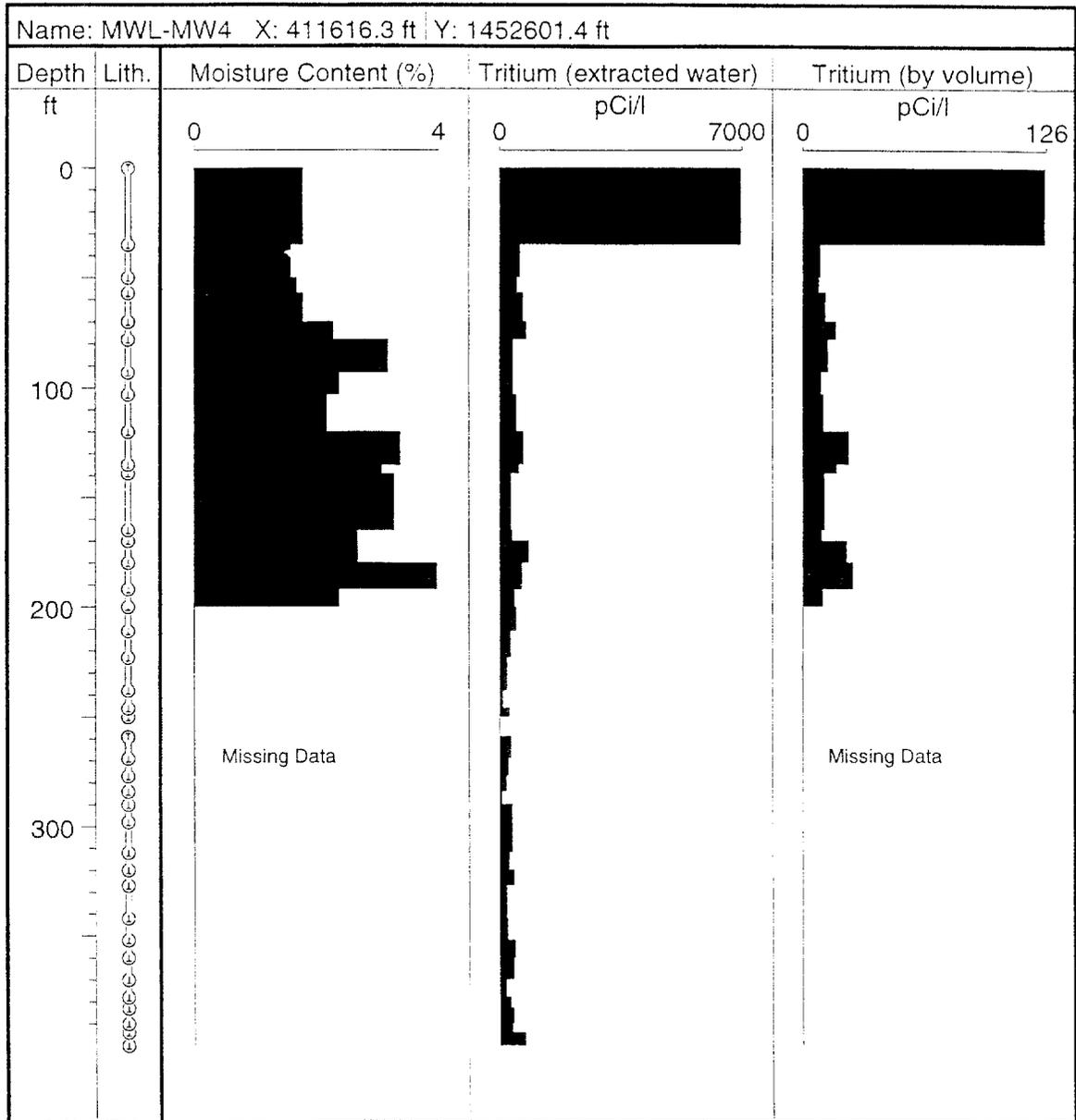


Figure 9 Subsurface Tritium Values for MWL-MW4

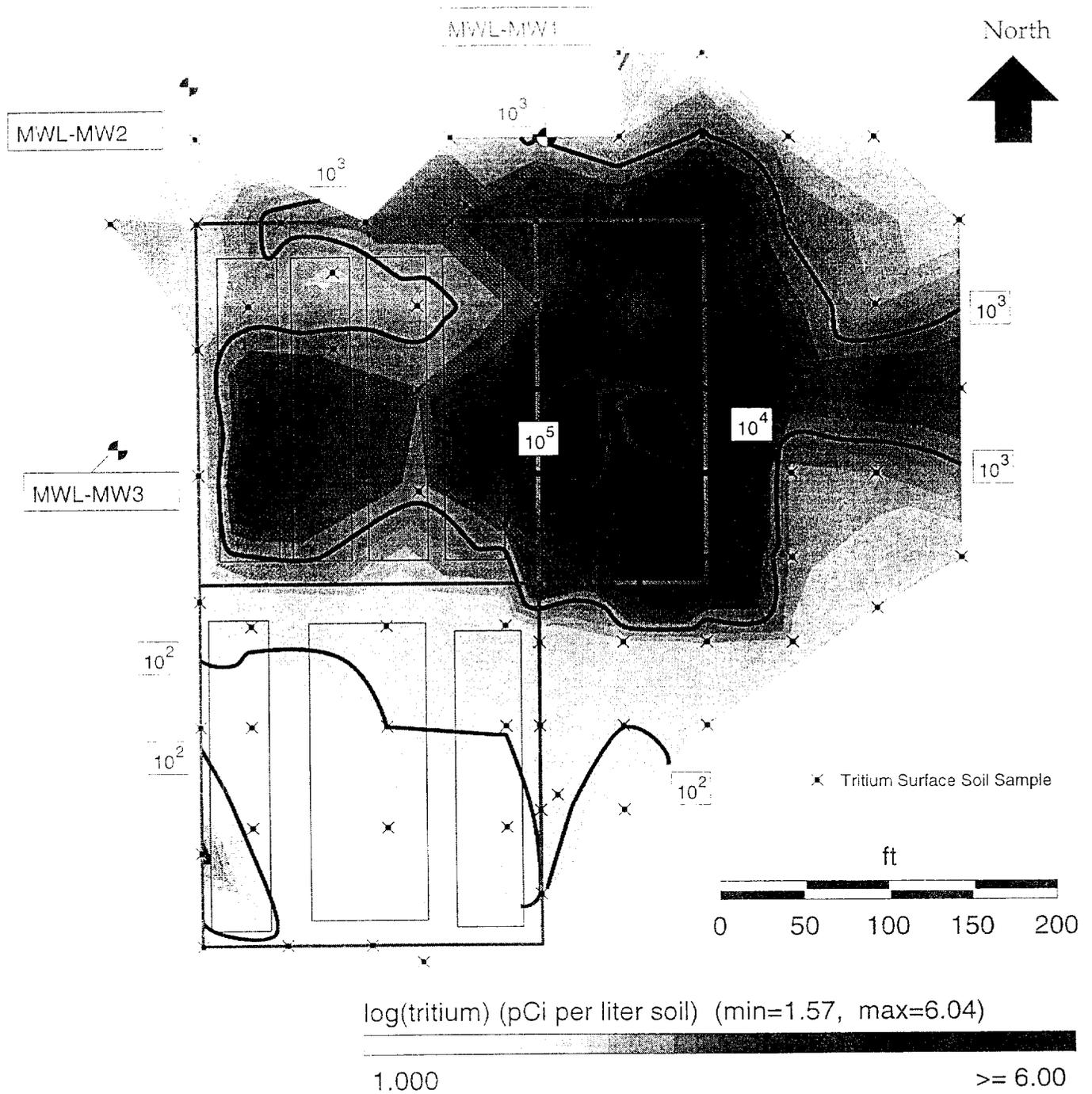


Figure 10 Spatial Distribution of Surface Soil Tritium Results Measured in pCi per Liter Soil (logarithm)

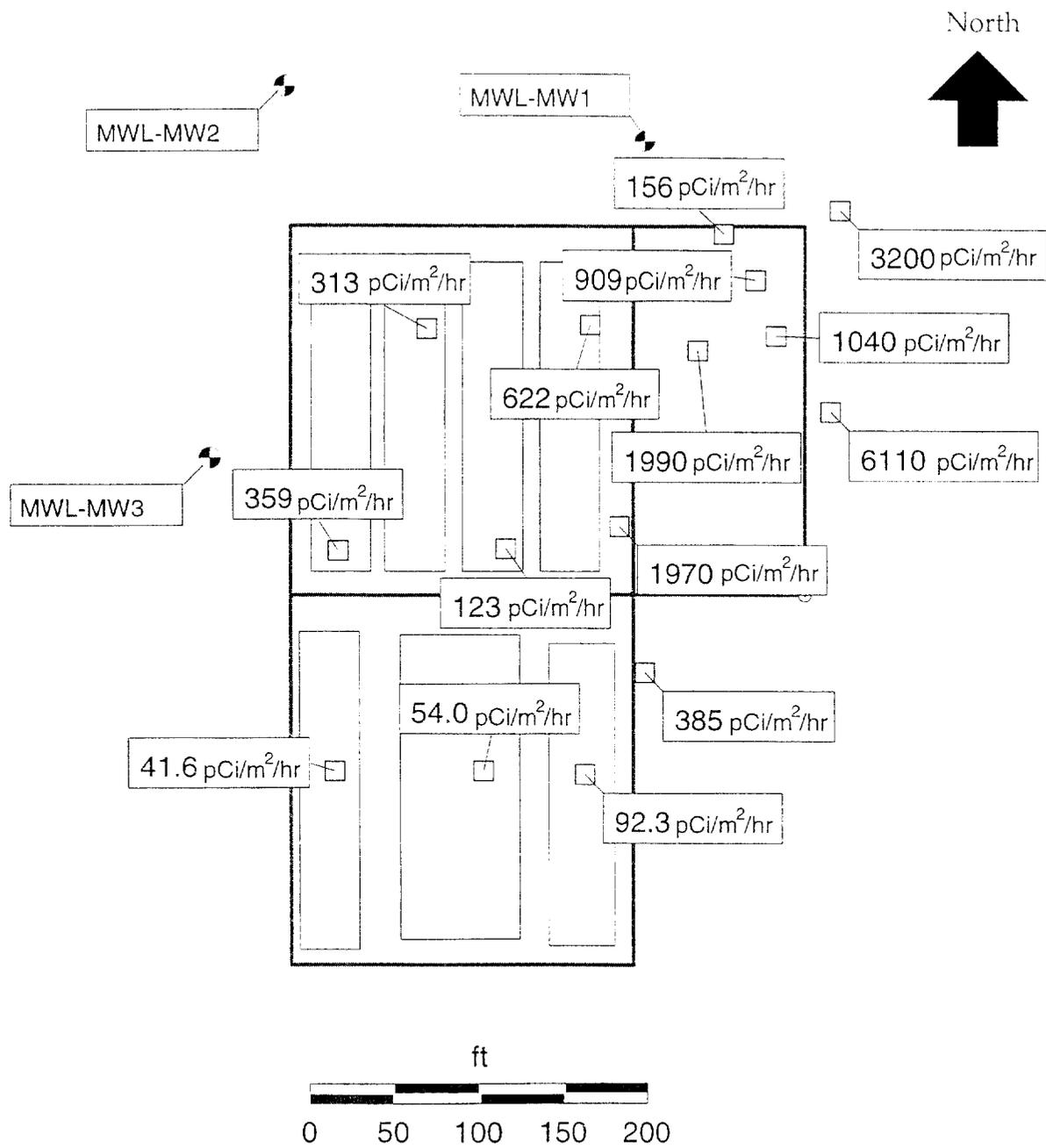


Figure 11 1992 Soil Tritium Flux Sampling Results

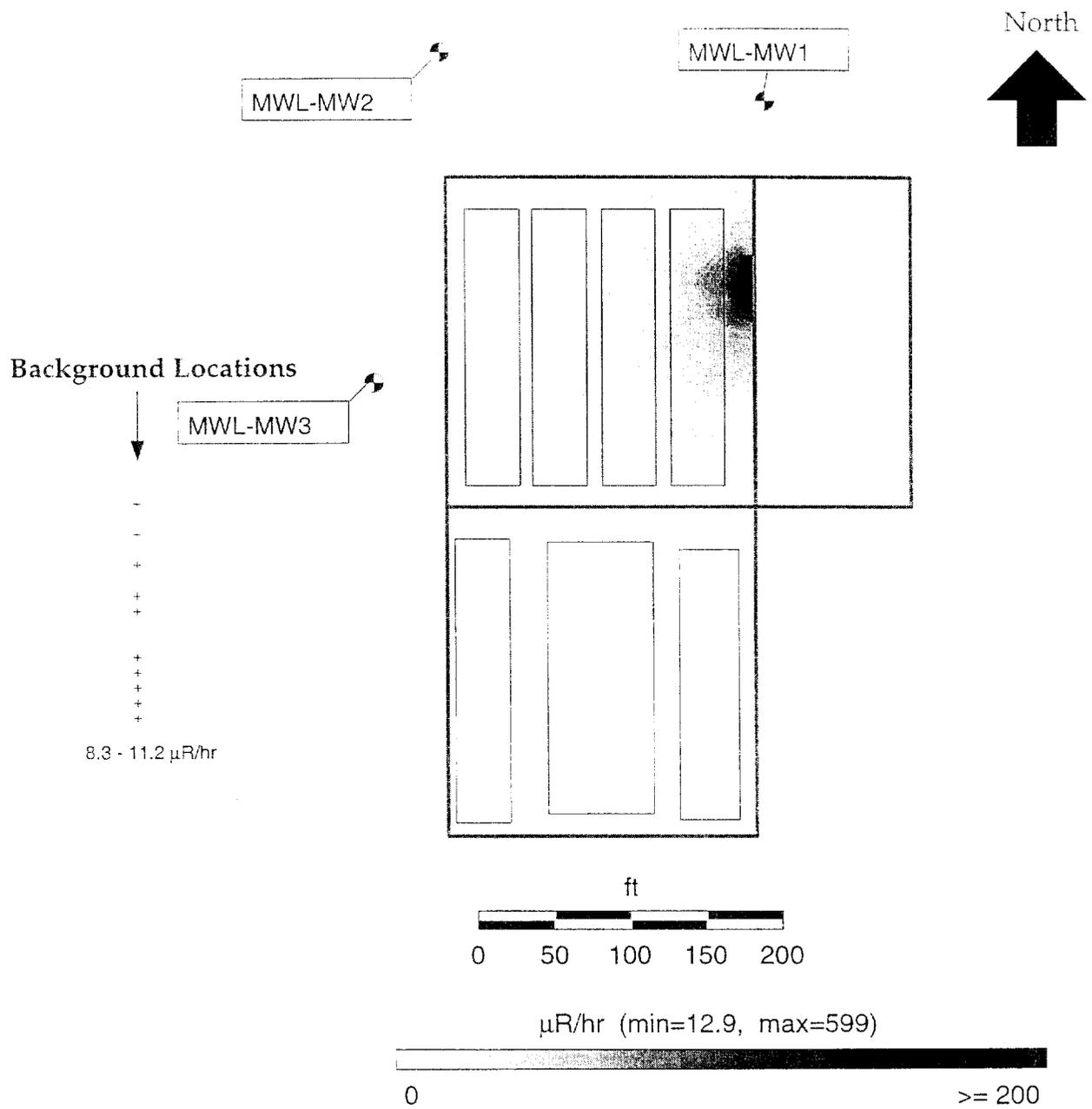


Figure 12 1992 Radiation Walk-Over Survey Results

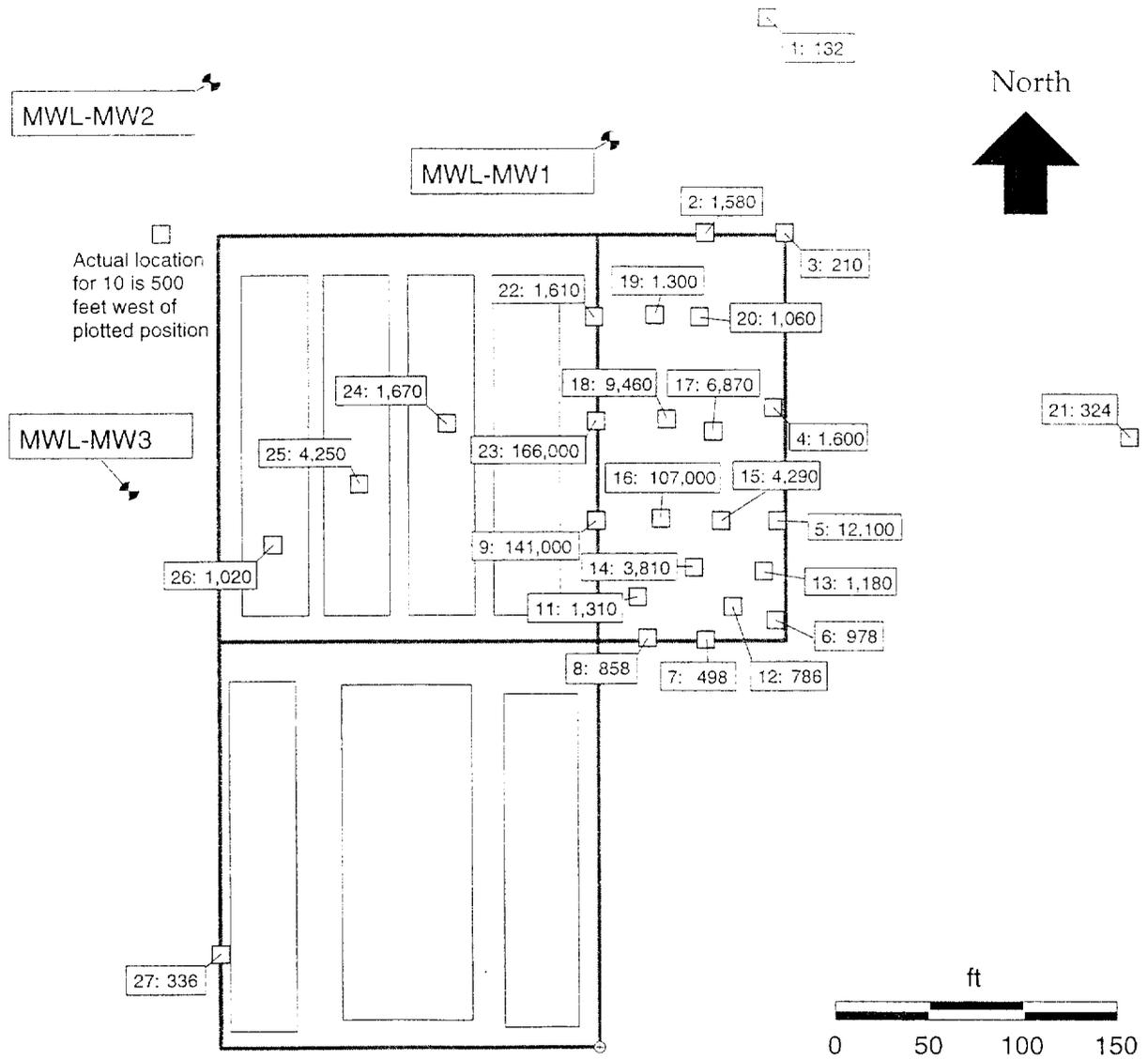


Figure 13 1993 Tritium Flux Measurements Results (pCi/m²/hr)

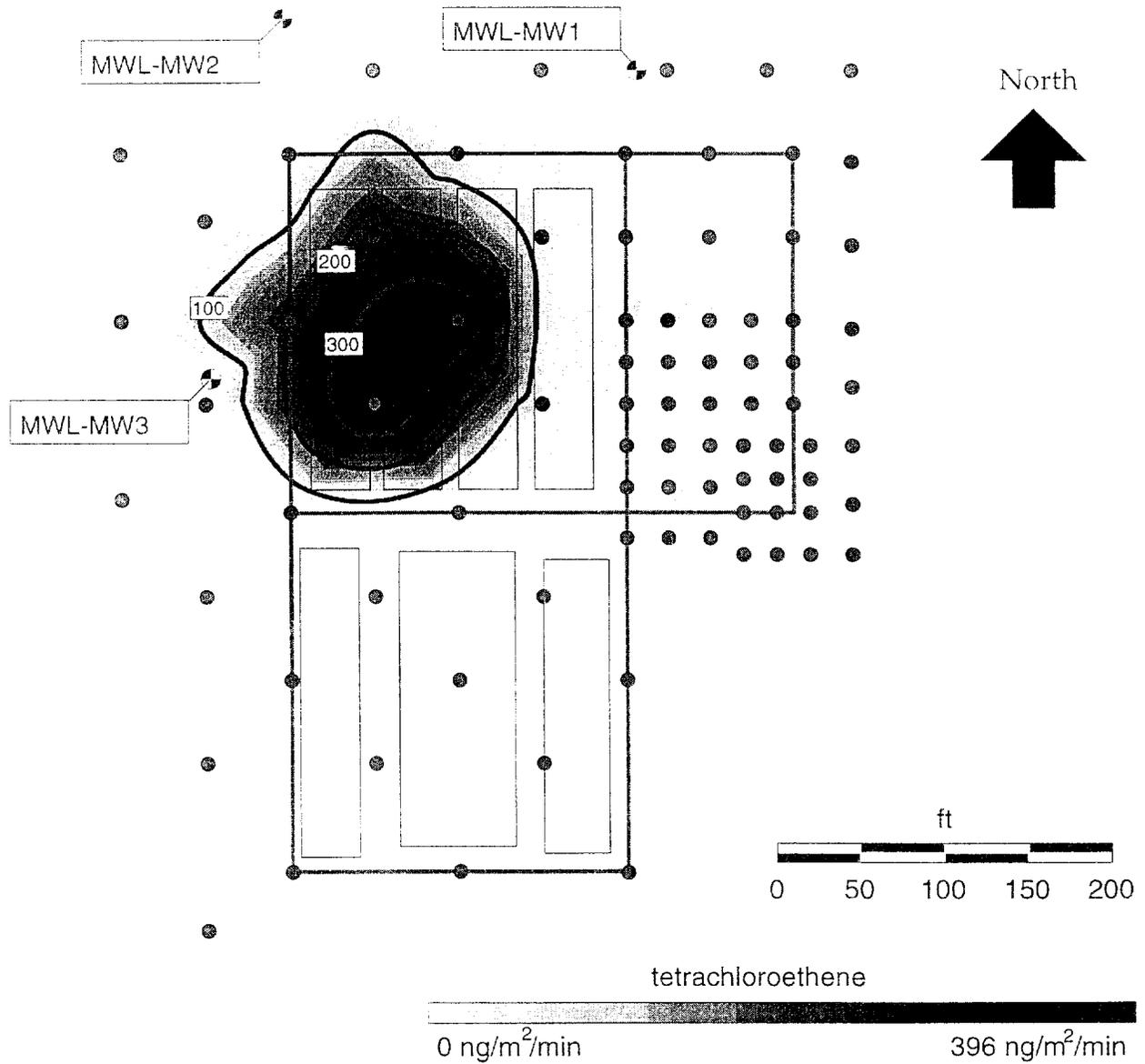


Figure 14 Distribution of Tetrachloroethene Flux Values Based on Passive Soil Gas Survey

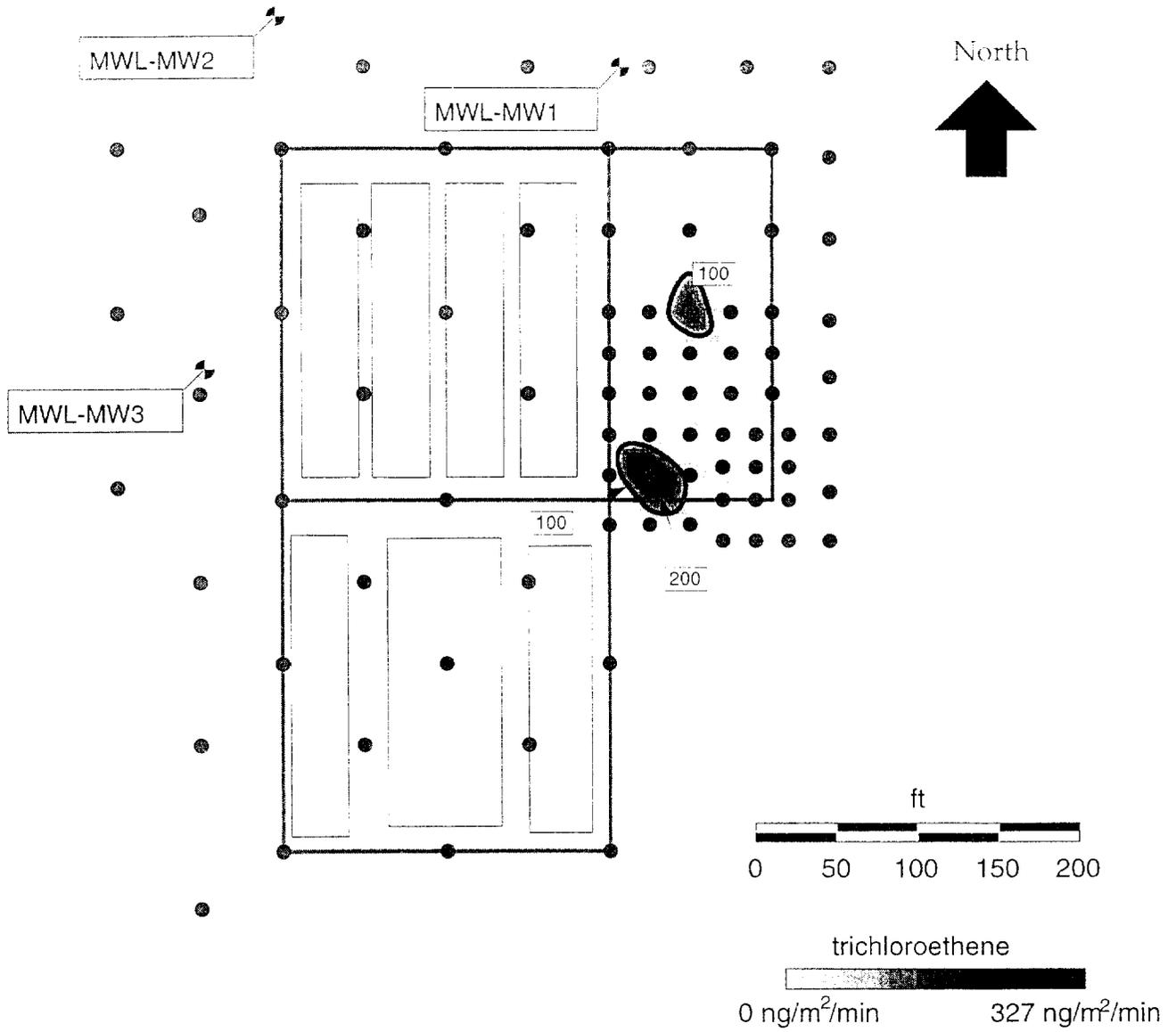


Figure 15 Distribution of Trichloroethene Flux Values Based on Passive Soil Gas Survey

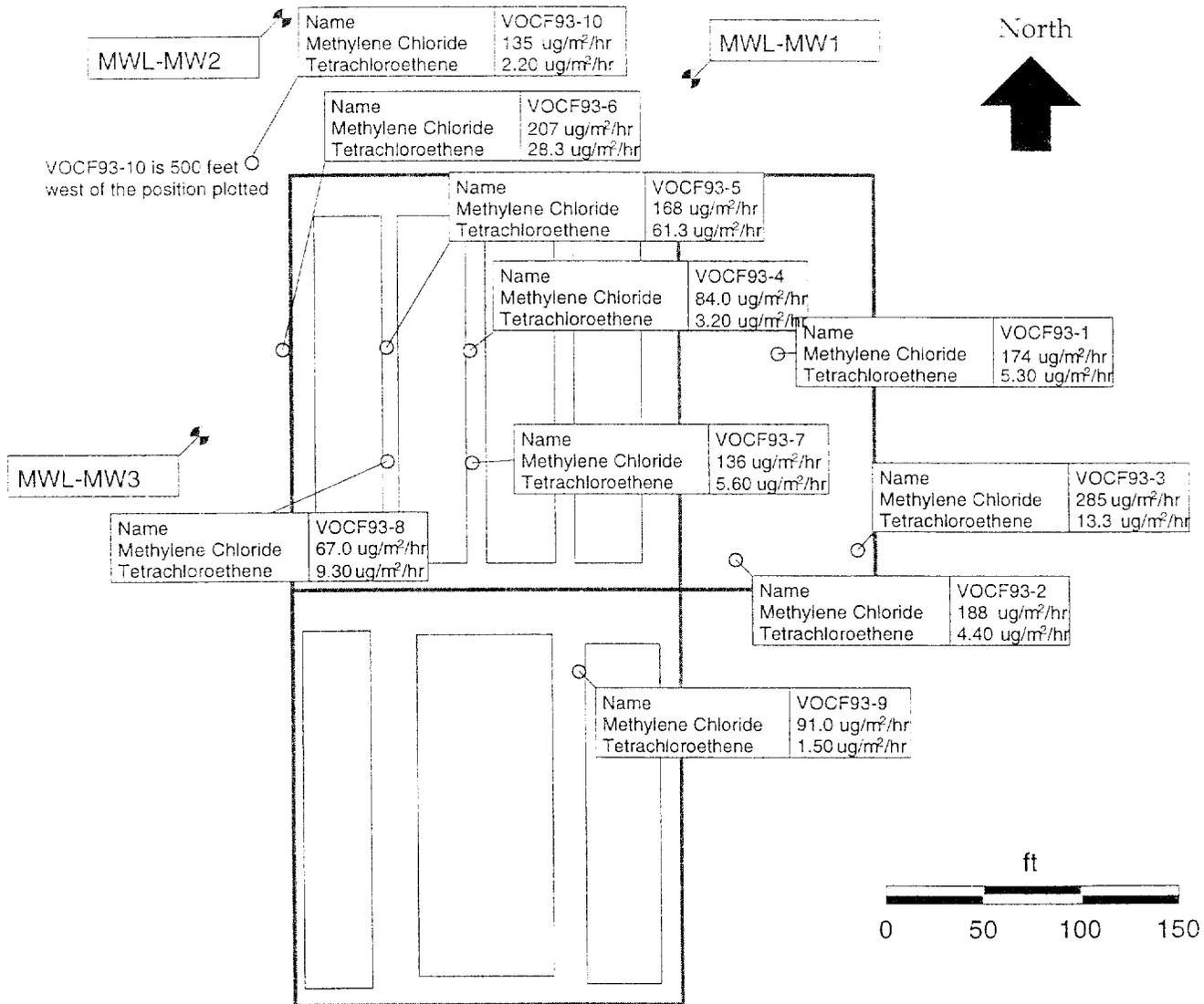


Figure 16 1993 VOC Flux Measurement Locations and Results

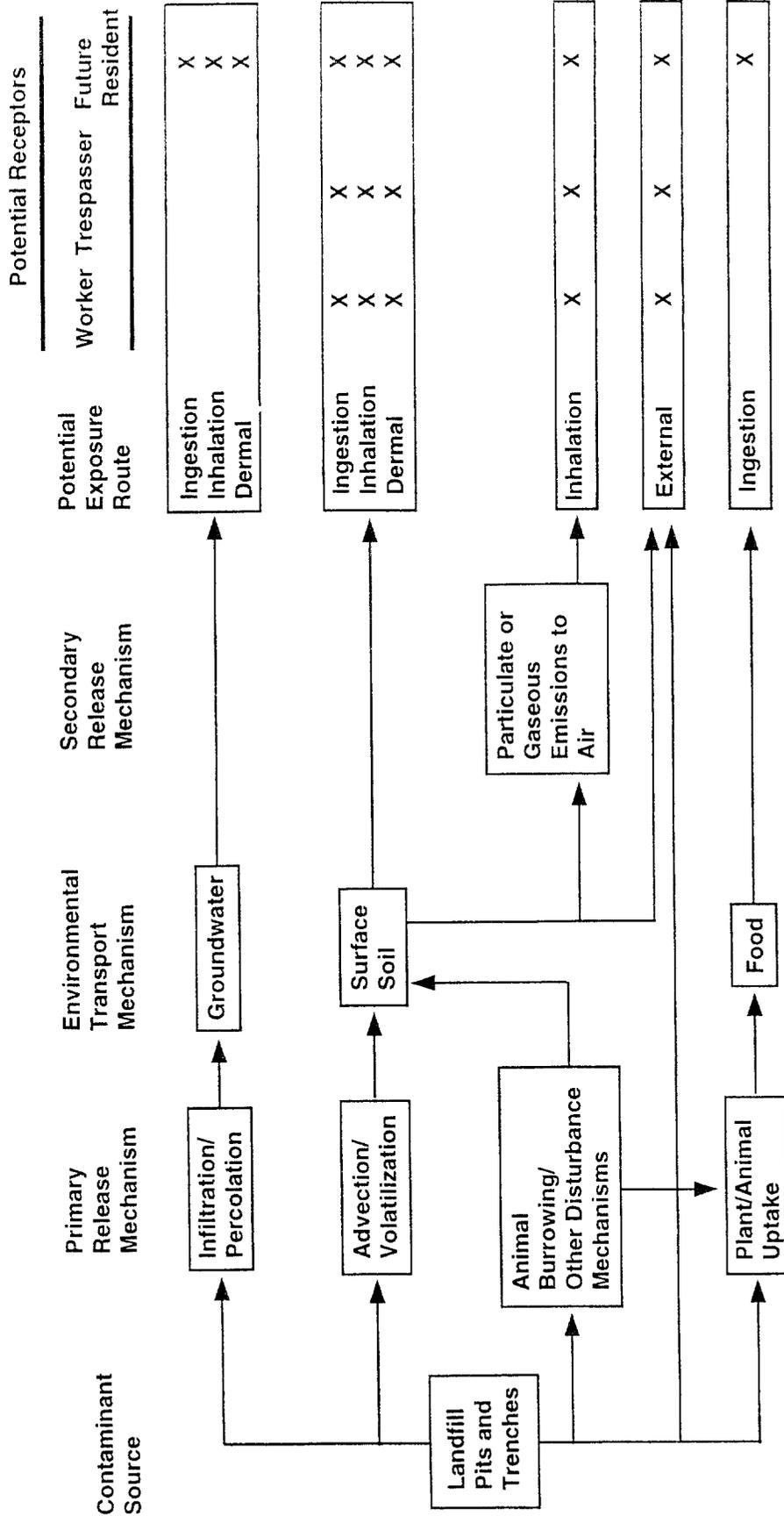


Figure 17 Conceptual Human Health Risk Model for the MWL

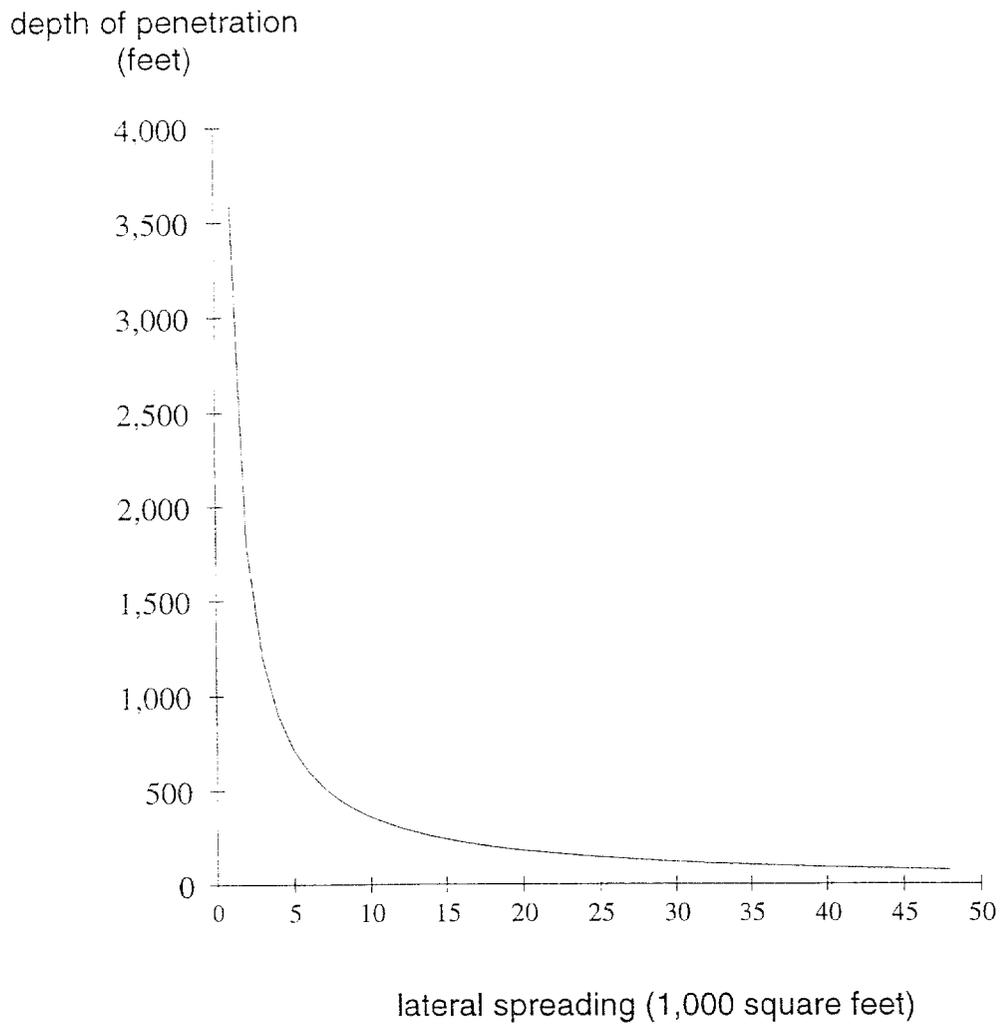


Figure 18 Relationship Between Depth of Penetration and Lateral Spreading for Reactor Water in First Tier Screen

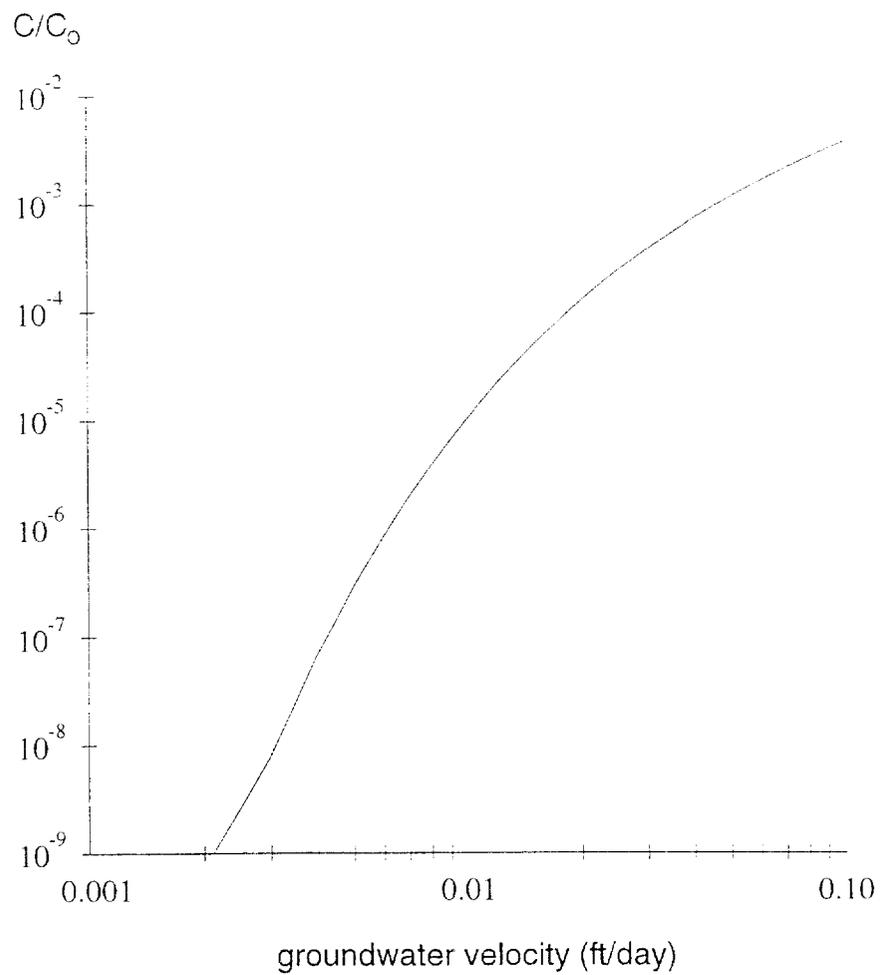


Figure 19 Maximum Tritium Concentration Observed at Water Table as a Function of Assumed Ground Water Velocity

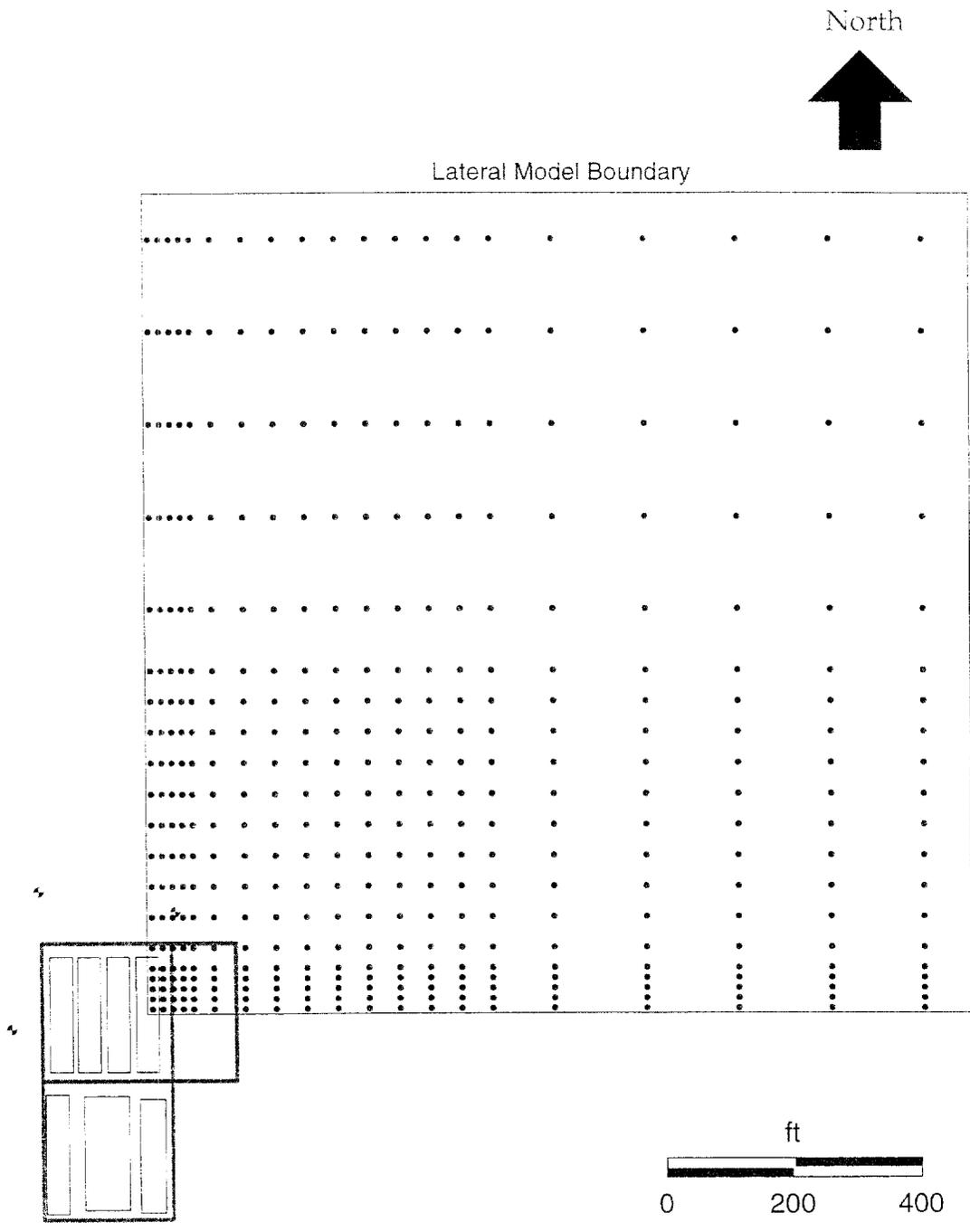


Figure 20 Lateral Location of TRACR3D Cell Centers

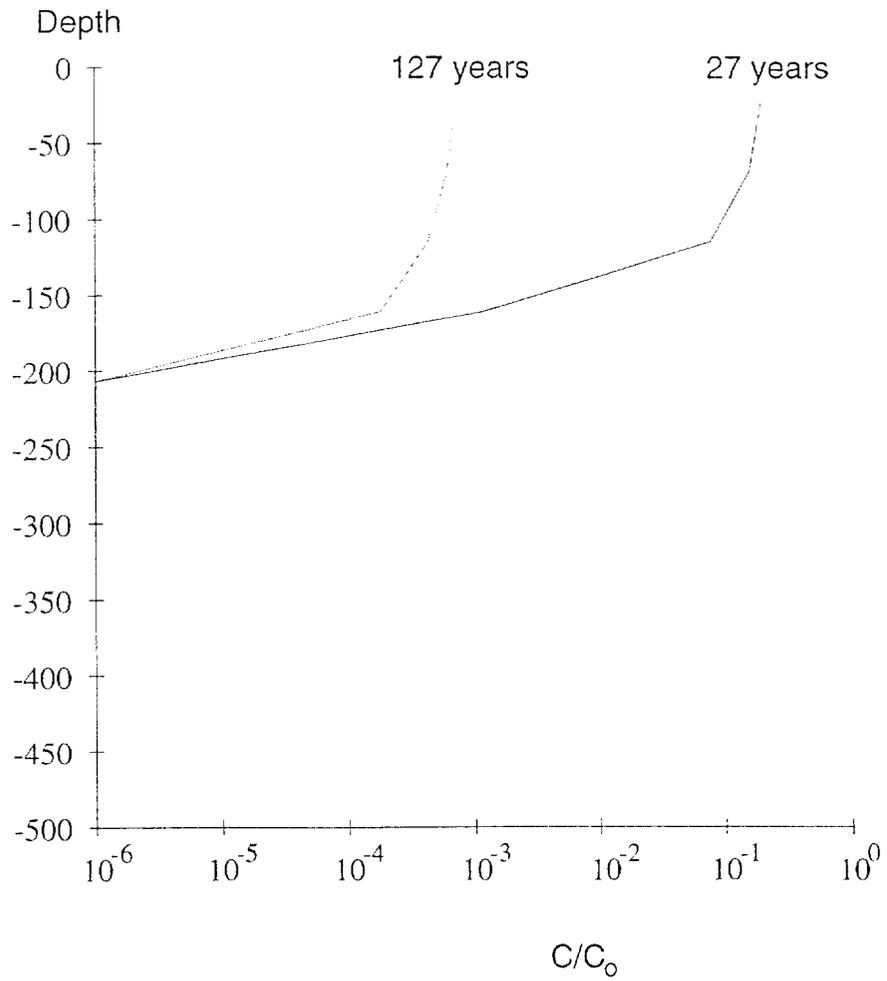


Figure 21 Vertical Distribution of Tritium After 27 and 127 Years

Appendix A Methodology for 1D Analytical Solution

The concentration of tritium at the water table beneath the MWL can be estimated by solving the following, general purpose partial differential equation used to describe the time dependent fate and transport of a reactive compound moving vertically along a one-dimensional path while undergoing sorption, dispersion, volatilization, and radioactive decay (Jury et al. 1983; Jury et al. 1990):

$$\frac{\partial C}{\partial t} = \frac{D}{R} \frac{\partial^2 C}{\partial z^2} - \frac{V}{R} \frac{\partial C}{\partial z} - \lambda C \quad (4)$$

where:

- C = total concentration of tritium for all phases in the soil;
- D = effective diffusion/dispersion coefficient;
- R = retardation for the contaminant;
- V = volumetric soil-water flux; and
- λ = first-order rate constant for radioactive decay.

C, the total tritium concentration for all phases, is composed of:

$$C = \rho_b C_s + \phi_w C_l + a C_g \quad (5)$$

where:

- a = air-filled porosity of the porous medium;
- C_g = gaseous phase concentration;
- C_l = liquid phase concentration;
- C_s = sorbed phase concentration;
- ρ_b = bulk density of the porous medium, and
- ϕ_w = water-filled porosity of the porous medium.

D, the effective diffusion/dispersion coefficient, is also composed of two parts:

$$D = D_l + D_g \quad (6)$$

where:

- D_l = liquid diffusion/dispersion coefficient, and
- D_g = gaseous phase diffusion/dispersion coefficient.

R, the retardation coefficient, is defined as:

$$R = \rho_b K_d + \phi_w + a K_h \quad (7)$$

where:

- $K_d =$ mass distribution coefficient between sorbed solid phase and liquid phase, and
- $K_h =$ dimensionless Henry's constant.

The first-order rate constant for radioactive decay, λ , is related to the half-life of tritium by the expression:

$$\lambda = \frac{\ln(2)}{\tau_{1/2}} \quad (8)$$

where $\tau_{1/2}$ is tritium's radioactive half-life, 12.3 years.

To calculate the gaseous diffusion coefficient, D_g , from the pure air diffusion coefficient, D_g^a , the Millington and Quirk (1961) expression is used:

$$D_g = \frac{a^{10/3} D_g^a K_h}{\phi^2} \quad (9)$$

The liquid diffusion/dispersion coefficient, D_l , is assumed to be advection dominated (diffusion is small compared to dispersion) and scale dependent:

$$D_l = \alpha_1 V \quad (10)$$

where:

- $\alpha_1 =$ 0.1L
- $L =$ distance from point of release to water table, and
- $V =$ volumetric soil water flux.

For the vadose zone, the volumetric soil water flux is, in general, time dependent and a complex function of the moisture content of the soil. For simplicity, the Green-Amp theory (Green and Ampt 1911) is often invoked, and for long-time infiltration events, it is often assumed to be equal to the saturated hydraulic conductivity of the least permeable soil horizon (Freeze and Cherry 1979).

Equation (4) is subject to two boundary conditions: (1) as the depth of the soil goes to infinity, the tritium concentration goes to zero; and (2) at the land surface, the concentration behaves as a unit-step function in time (Hildebrand 1976). The initial concentration, $C(z=0, t=0)$, is given by the concentration of tritium in the disposed water. In addition to the initial tritium concentration at the land surface, the length of the time the initial concentration is applied is required. This time is obtained from the infiltration time of the ponded reactor water in trench D (approximately 30 days).

The solution to equation (4) for the specified boundary conditions can be obtained by using standard Laplace transform methodologies (Ditkin and Prudnikov 1967). In closed form, the solution

can be written as follows:

$$\begin{aligned} \frac{C}{C_0} = & \frac{C_0}{2} \left(e^{-\frac{RZ^2}{4Dt}} \operatorname{erfc} \left(\frac{1}{2} \sqrt{\frac{RZ^2}{Dt}} - \sqrt{\left(\frac{V^2}{4DR} - \frac{\lambda}{R} \right) t} \right) - e^{-\frac{RZ^2}{4D(t-\Delta t)}} \operatorname{erfc} \left(\frac{1}{2} \sqrt{\frac{RZ^2}{D(t-\Delta t)}} - \sqrt{\left(\frac{V^2}{4DR} - \frac{\lambda}{R} \right) (t-\Delta t)} \right) \right) \\ & - \frac{C_0}{2} H(t - \Delta t) \left(e^{-\frac{RZ^2}{4D(t-\Delta t)}} \operatorname{erfc} \left(\frac{1}{2} \sqrt{\frac{RZ^2}{D(t-\Delta t)}} - \sqrt{\left(\frac{V^2}{4DR} - \frac{\lambda}{R} \right) (t-\Delta t)} \right) - e^{-\frac{RZ^2}{4D(t-\Delta t)}} \operatorname{erfc} \left(\frac{1}{2} \sqrt{\frac{RZ^2}{D(t-\Delta t)}} - \sqrt{\left(\frac{V^2}{4DR} - \frac{\lambda}{R} \right) (t-\Delta t)} \right) \right) \end{aligned} \quad (11)$$

where H is the Heaviside function (Hildebrand 1976), such that

$$\begin{aligned} H(t - \Delta t) &= 0 \text{ for } t < \Delta t \\ &= 1 \text{ for } t \geq \Delta t \end{aligned} \quad (12)$$

and erfc is the complementary error function (Hildebrand 1976).

For this study, a numerical procedure was implemented to calculate the maximum tritium concentration at the water table using Equation 8, as well as the concentration at the water table after a duration equal to the elapsed time since the disposal. Because equation (11) calculates the total concentration for all three phases of tritium, equation (11) is solved for the aqueous phase to give the liquid concentration at the water table.

Appendix B

External Gamma Radiation Survey Data, 1992

#	year	year	counts	$\mu\text{R/hr}$	#	year	year	counts	$\mu\text{R/hr}$	#	year	year	counts	$\mu\text{R/hr}$	#	year	year	counts	$\mu\text{R/hr}$
1	10	10	7159	14.318	57	170	30	22571	45.142	113	130	60	15494	30.988	169	90	90	10424	20.846
2	20	10	7728	15.456	58	180	30	24682	49.364	114	140	60	16949	33.898	170	100	90	12524	25.048
3	30	10	8051	16.102	59	190	30	25200	50.4	115	150	60	19516	39.032	171	110	90	12799	25.58
4	40	10	8639	17.278	60	200	30	27487	54.974	116	160	60	20968	50.136	172	120	90	14548	29.09
5	50	10	9183	18.366	61	10	40	6696	13.392	117	170	60	33363	66.726	173	130	90	15268	30.536
6	60	10	11330	22.66	62	20	40	7861	15.722	118	180	60	41025	82.05	174	140	90	17329	34.658
7	70	10	9084	18.168	63	30	40	7813	15.626	119	190	60	57980	115.96	175	150	90	22141	44.282
8	80	10	9949	19.898	64	40	40	8691	17.382	120	200	60	173504	347.008	176	160	90	27688	55.376
9	90	10	10434	20.868	65	50	40	8732	17.464	121	10	70	7157	14.314	177	170	90	32199	64.218
10	100	10	11328	22.656	66	60	40	9115	18.23	122	20	70	7817	15.634	178	180	90	37467	74.934
11	110	10	10970	21.94	67	70	40	9578	19.156	123	30	70	8737	17.474	179	190	90	49186	98.372
12	120	10	12316	24.632	68	80	40	8909	17.818	124	40	70	8651	17.302	180	200	90	60799	121.598
13	130	10	12795	25.59	69	90	40	9873	19.746	125	50	70	9483	18.966	181	10	100	6978	13.956
14	140	10	13528	27.056	70	100	40	10190	20.38	126	60	70	10067	20.134	182	20	100	7752	15.504
15	150	10	14216	28.432	71	110	40	12401	24.802	127	70	70	10385	20.77	183	30	100	8335	16.67
16	160	10	14585	29.17	72	120	40	13840	27.68	128	80	70	10241	20.482	184	40	100	8533	17.066
17	170	10	16825	33.65	73	130	40	14657	29.314	129	90	70	10703	21.406	185	50	100	9106	18.212
18	180	10	16041	32.082	74	140	40	13526	27.052	130	100	70	12731	25.462	186	60	100	9131	18.262
19	190	10	16849	33.698	75	150	40	16495	32.99	131	110	70	13271	26.542	187	70	100	9777	19.554
20	200	10	16937	33.874	76	160	40	18413	36.826	132	120	70	14482	28.964	188	80	100	9626	19.252
21	10	20	6472	12.944	77	170	40	20157	40.314	133	130	70	16064	32.128	189	90	100	8931	17.862
22	20	20	7165	14.33	78	180	40	28326	56.652	134	140	70	17743	35.486	190	100	100	12641	25.282
23	30	20	7143	14.286	79	190	40	24452	48.904	135	150	70	23555	47.11	191	110	100	12961	25.922
24	40	20	7825	15.65	80	200	40	34145	68.29	136	160	70	29414	58.828	192	120	100	14148	28.296
25	50	20	8282	16.564	81	10	50	6899	13.798	137	170	70	36539	73.078	193	130	100	13178	26.356
26	60	20	8642	17.284	82	20	50	7798	15.596	138	180	70	46603	93.206	194	140	100	14498	28.996
27	70	20	9256	18.512	83	30	50	8771	17.542	139	190	70	76217	152.434	195	150	100	19031	38.062
28	80	20	9563	19.126	84	40	50	8583	17.166	140	200	70	299496	598.992	196	160	100	19858	39.716
29	90	20	9926	19.852	85	50	50	9090	18.18	141	10	80	6861	13.722	197	170	100	22609	45.218
30	100	20	11376	22.752	86	60	50	9410	18.82	142	20	80	7858	15.716	198	180	100	27092	54.184
31	110	20	11124	22.248	87	70	50	9768	19.536	143	30	80	7906	15.812	199	190	100	30974	61.948
32	120	20	11432	22.864	88	80	50	10282	20.564	144	40	80	8355	16.71	200	200	100	32163	64.326
33	130	20	12921	25.842	89	90	50	10015	20.03	145	50	80	8964	17.928	201	10	110	7142	14.284
34	140	20	13752	27.504	90	100	50	12670	25.34	146	60	80	9080	18.16	202	20	110	8113	16.226
35	150	20	15541	31.082	91	110	50	12967	25.934	147	70	80	9626	19.252	203	30	110	8255	16.51
36	160	20	14881	29.762	92	120	50	13637	27.274	148	80	80	9711	19.422	204	40	110	8423	16.846
37	170	20	15285	30.57	93	130	50	16037	32.074	149	90	80	10448	20.896	205	50	110	8610	17.22
38	180	20	18719	37.438	94	140	50	16641	33.282	150	100	80	12115	24.23	206	60	110	9066	18.132
39	190	20	17883	35.766	95	150	50	20513	41.026	151	110	80	12615	25.23	207	70	110	9486	18.972
40	200	20	21439	42.878	96	160	50	26504	53.008	152	120	80	14201	28.402	208	80	110	9549	19.098
41	10	30	6591	13.182	97	170	50	28968	57.936	153	130	80	15420	30.84	209	90	110	8976	17.952
42	20	30	7932	15.864	98	180	50	33822	67.644	154	140	80	17567	35.134	210	100	110	11954	23.908
43	30	30	8354	16.708	99	190	50	42129	84.258	155	150	80	21553	43.106	211	110	110	12907	25.814
44	40	30	8589	17.178	100	200	50	31413	62.826	156	160	80	26418	52.836	212	120	110	14027	28.054
45	50	30	8596	17.192	101	10	60	6836	13.672	157	170	80	31731	63.462	213	130	110	13804	27.608
46	60	30	9154	18.308	102	20	60	7468	14.936	158	180	80	36164	72.328	214	140	110	16481	32.962
47	70	30	9571	19.142	103	30	60	8209	16.418	159	190	80	58070	116.14	215	150	110	17976	35.952
48	80	30	10222	20.444	104	40	60	8874	17.748	160	200	80	99072	198.144	216	160	110	22377	44.754
49	90	30	10489	20.978	105	50	60	8773	17.546	161	10	90	7111	14.222	217	170	110	25389	50.778
50	100	30	11217	22.434	106	60	60	9535	19.07	162	20	90	7678	15.356	218	180	110	26640	53.28
51	110	30	12479	24.958	107	70	60	10160	20.32	163	30	90	7471	14.942	219	190	110	29154	58.308
52	120	30	13400	26.8	108	80	60	10365	20.73	164	40	90	8852	17.704	220	200	110	25838	51.676
53	130	30	15168	30.336	109	90	60	9978	19.956	165	50	90	9039	18.078	221	10	120	7157	14.314
54	140	30	16073	32.146	110	100	60	13105	26.21	166	60	90	9583	19.166	222	20	120	7353	14.706
55	150	30	18031	36.062	111	110	60	13618	27.236	167	70	90	9765	19.53	223	30	120	7904	15.808
56	160	30	20962	41.924	112	120	60	14578	29.156	168	80	90	9859	19.718	224	40	120	7652	15.304

Appendix B (cont.)
External Gamma Radiation Survey Data, 1992

#	X-coor	Y-coor	counts	$\mu\text{R/hr}$	#	X-coor	Y-coor	counts	$\mu\text{R/hr}$	#	X-coor	Y-coor	counts	$\mu\text{R/hr}$	#	X-coor	Y-coor	counts	$\mu\text{R/hr}$
225	50	120	8361	16.722	277	170	140	16380	32.76	329	90	170	8445	16.89	381	10	200	6695	13.39
226	60	120	8563	17.126	278	180	140	17479	34.958	330	100	170	10588	21.176	382	20	200	6937	13.866
227	70	120	9012	18.024	279	190	140	16651	33.302	331	110	170	9867	19.734	383	30	200	7018	14.036
228	80	120	9428	18.856	280	200	140	15819	31.638	332	120	170	10590	21.18	384	40	200	6953	13.906
229	90	120	9357	18.714	281	10	150	7043	14.086	333	130	170	10689	21.378	385	50	200	7376	14.752
230	100	120	10294	20.588	282	20	150	7735	15.47	334	140	170	11308	22.616	386	60	200	7890	15.78
231	110	120	12537	25.074	283	30	150	7977	15.954	335	150	170	12098	24.196	387	70	200	7491	14.982
232	120	120	13159	26.318	284	40	150	8204	16.408	336	160	170	12697	25.394	388	80	200	7902	15.804
233	130	120	13276	26.552	285	50	150	7892	15.784	337	170	170	12897	25.794	389	90	200	8299	16.598
234	140	120	14831	29.662	286	60	150	8120	16.24	338	180	170	13782	27.564	390	100	200	8136	16.272
235	150	120	12758	25.516	287	70	150	8464	16.928	339	190	170	13596	27.192	391	110	200	8720	17.44
236	160	120	15871	31.742	288	80	150	8839	17.678	340	200	170	11870	23.74	392	120	200	9048	18.096
237	170	120	18116	36.232	289	90	150	8860	17.72	341	10	180	7231	14.462	393	130	200	9195	18.39
238	180	120	20762	41.524	290	100	150	9961	19.922	342	20	180	7168	14.336	394	140	200	9603	19.206
239	190	120	20820	41.64	291	110	150	10484	20.968	343	30	180	7236	14.472	395	150	200	9439	18.878
240	200	120	22935	45.87	292	120	150	10904	21.808	344	40	180	7342	14.684	396	160	200	9590	19.18
241	10	130	6924	13.848	293	130	150	11136	22.272	345	50	180	7628	15.256	397	170	200	9514	19.028
242	20	130	7625	15.25	294	140	150	12256	24.512	346	60	180	8183	16.366	398	180	200	9808	19.616
243	30	130	8152	16.304	295	150	150	12067	24.134	347	70	180	8137	16.274	399	190	200	8608	17.216
244	40	130	8501	17.002	296	160	150	13587	27.174	348	80	180	7873	15.746	400	200	200	9572	19.144
245	50	130	8500	17	297	170	150	14379	28.758	349	90	180	8174	16.348	401	10	210	7254	14.508
246	60	130	9355	18.71	298	180	150	15698	31.396	350	100	180	9072	18.144	402	20	210	7310	14.62
247	70	130	9523	19.046	299	190	150	15111	30.222	351	110	180	8686	17.372	403	30	210	6851	13.702
248	80	130	9657	19.314	300	200	150	14331	28.662	352	120	180	9793	19.586	404	40	210	7073	14.146
249	90	130	9291	18.582	301	10	160	6881	13.762	353	130	180	9496	18.992	405	50	210	7229	14.458
250	100	130	11736	23.472	302	20	160	7250	14.5	354	140	180	10408	20.816	406	60	210	7350	14.7
251	110	130	12273	24.546	303	30	160	7864	15.728	355	150	180	10445	20.89	407	70	210	7725	15.45
252	120	130	12890	25.78	304	40	160	7659	15.318	356	160	180	11272	22.544	408	80	210	8003	16.006
253	130	130	12864	25.728	305	50	160	7678	15.356	357	170	180	10651	21.302	409	90	210	8138	16.276
254	140	130	14049	28.098	306	60	160	7744	15.488	358	180	180	11562	23.124	410	100	210	8941	17.882
255	150	130	15218	30.436	307	70	160	8360	16.72	359	190	180	10946	21.892	411	110	210	9339	18.678
256	160	130	18552	37.104	308	80	160	8261	16.522	360	200	180	10588	21.176	412	120	210	9452	18.904
257	170	130	19078	38.156	309	90	160	8014	16.028	361	10	190	6681	13.362	413	130	210	9849	19.698
258	180	130	18575	37.15	310	100	160	9506	19.012	362	20	190	7523	15.046	414	140	210	10696	21.392
259	190	130	21803	43.606	311	110	160	9111	18.222	363	30	190	7617	15.234	415	150	210	9308	18.616
260	200	130	18345	36.69	312	120	160	9745	19.49	364	40	190	7681	15.362	416	160	210	8916	17.832
261	10	140	7310	14.62	313	130	160	10753	21.506	365	50	190	8110	16.22	417	170	210	9149	18.298
262	20	140	7674	15.348	314	140	160	10780	21.56	366	60	190	8500	17	418	180	210	9906	19.812
263	30	140	7920	15.84	315	150	160	11031	22.062	367	70	190	8427	16.854	419	190	210	9265	18.53
264	40	140	8088	16.176	316	160	160	12693	25.386	368	80	190	8676	17.352	420	200	210	9287	18.574
265	50	140	8441	16.882	317	170	160	11809	23.618	369	90	190	9408	18.816	B1	-200	310	4167	8.334
266	60	140	8860	17.72	318	180	160	11546	23.092	370	100	190	8854	17.708	B2	-200	320	5186	10.372
267	70	140	8896	17.792	319	190	160	12818	25.636	371	110	190	8707	17.414	B3	-200	330	5510	11.02
268	80	140	9110	18.22	320	200	160	12129	24.258	372	120	190	10004	20.008	B4	-200	340	5454	10.908
269	90	140	8869	17.738	321	10	170	7018	14.036	373	130	190	9764	19.528	B5	-200	350	5343	10.686
270	100	140	11195	22.39	322	20	170	7499	14.998	374	140	190	8930	17.86	B6	-200	280	5331	10.662
271	110	140	11339	22.678	323	30	170	7804	15.608	375	150	190	9976	19.952	B7	-200	270	5595	11.19
272	120	140	12197	24.394	324	40	170	7896	15.792	376	160	190	10225	20.45	B8	-200	250	5509	11.018
273	130	140	12654	25.308	325	50	170	8386	16.772	377	170	190	10148	20.296	B9	-200	230	5609	11.218
274	140	140	13795	27.59	326	60	170	8488	16.976	378	180	190	10763	21.526	B10	-200	210	5502	11.004
275	150	140	13737	27.474	327	70	170	8189	16.378	379	190	190	10467	20.934					
276	160	140	15073	30.146	328	80	170	8154	16.308	380	200	190	10052	20.104					

Radiation measured in counts per 30 seconds at 3 feet above ground surface with NaI.

Appendix C

Surface Soil Tritium Data for the Mixed Waste Landfill

Sample	Date	xcoord	ycoord	tritium per liter		Laboratory	tritium per liter of soil
				extracted water	soil moist.		
				pCi/L	%		pCi/L
ER92002130	07/12/93	300	-100	15435	1.8	TMA/Eberline	277.83
ER92002131	07/12/93	250	-100	75050	1.6	TMA/Eberline	1200.8
ER92002132	07/12/93	400	-50	10149	1.6	TMA/Eberline	162.384
ER92002133	07/12/93	400	-50	6080	0.51	ORNL	31.008
ER92002134	07/12/93	350	-50	22203	1.4	TMA/Eberline	310.842
ER92002135	07/12/93	300	-50	73304	1.5	TMA/Eberline	1099.56
ER92002136	07/12/93	250	-50	26611	1.9	TMA/Eberline	505.609
ER92002137	07/12/93	200	-50	42319	2.2	TMA/Eberline	931.018
ER92002138	07/12/93	150	-50	64878	2.2	TMA/Eberline	1427.32
ER92002139	07/12/93	150	-50	18000	0.96	ORNL	172.8
ER92002140	07/12/93	0	-50	6111	2.4	TMA/Eberline	146.664
ER92002141	07/12/93	450	0	9145	2.5	TMA/Eberline	228.625
ER92002142	07/12/93	350	0	46393	1.8	TMA/Eberline	835.074
ER92002143	07/12/93	300	0	544285	1.8	TMA/Eberline	9797.13
ER92002144	07/12/93	260	0	1038940	1.5	TMA/Eberline	15584.1
ER92002145	07/12/93	250	-10	74686	3.2	TMA/Eberline	2389.95
ER92002146	07/13/93	230	0	110000	3.8	TMA/Eberline	4180
ER92002147	07/13/93	200	0	130000	4.2	TMA/Eberline	5460
ER92002148	07/13/93	159	-10	20000	9.3	TMA/Eberline	1860
ER92002149	07/13/93	150	0	30000	6.9	TMA/Eberline	2070
ER92002150	07/13/93	100	-0	45000	4.5	TMA/Eberline	2025
ER92002151	07/13/93	50	0	17000	8.1	TMA/Eberline	1377
ER92002152	07/13/93	0	0	5900	6.1	TMA/Eberline	359.9
ER92002153	07/13/93	-50	0	4500	8.6	TMA/Eberline	387
ER92002154	07/13/93	-50	0	4770	5.9	ORNL	281.43
ER92002155	07/13/93	400	50	7600	6.7	TMA/Eberline	509.2
ER92002156	07/13/93	350	50	22000	8.4	TMA/Eberline	1848
ER92002157	07/13/93	300	50	96000	10.4	TMA/Eberline	9984
ER21009258	07/13/93	450	100	29000	12.7	TMA/Eberline	3683
ER92002159	07/13/93	350	100	22000	12.2	TMA/Eberline	2684
ER92002160	07/13/93	300	100	220000	7.8	TMA/Eberline	17160
ER92002161	07/13/93	400	150	17000	3.1	TMA/Eberline	527
ER92002162	07/13/93	350	150	18000	2	TMA/Eberline	360
ER92002163	07/13/93	350	150	19700	2.23	ORNL	439.31
ER92002164	07/13/93	300	150	1600000	4.1	TMA/Eberline	65600
ER92002165	07/14/93	450	200	3955	5.1	TMA/Eberline	201.705
ER92002166	07/14/93	350	200	10400	4.4	TMA/Eberline	457.6
ER92002167	07/14/93	300	200	557400	2.8	TMA/Eberline	15607.2
ER92002168	07/14/93	260	215	812111	4.2	TMA/Eberline	34108.7
ER92002169	07/14/93	230	215	52377	4	TMA/Eberline	2095.08
ER92002170	07/14/93	200	215	74476	5.1	TMA/Eberline	3798.28
ER92002171	07/14/93	400	230	4635	3.6	TMA/Eberline	166.86
ER92002172	07/14/93	350	250	9287	3.6	TMA/Eberline	334.332
ER92002173	07/14/93	300	250	9175	4.1	TMA/Eberline	376.175
ER92002174	07/14/93	250	250	12193	2.7	TMA/Eberline	329.211
ER92002175	07/14/93	200	250	12364	1.4	TMA/Eberline	173.096
ER92002176	07/14/93	300	300	5617	2.6	TMA/Eberline	146.042
ER92002177	07/14/93	300	300	3460	0.9	ORNL	31.14
ER92002178	07/14/93	250	300	2299	4.4	TMA/Eberline	101.156
ER92002179	07/14/93	210	341	3564	3.3	TMA/Eberline	117.612
ER92002180	07/14/93	200	300	4328	3.1	TMA/Eberline	134.168
ER92002181	07/14/93	250	350	1658	3.9	TMA/Eberline	64.662
ER92002182	07/14/93	200	350	5786	2.2	TMA/Eberline	127.292

Appendix C (cont.)
Surface Soil Tritium Data for the Mixed Waste Landfill

Sample	Date	scoor	vcoor	tritium per liter		Laboratory	tritium per liter of soil
				extracted water	soil moist.		
				pCi/L	%		pCi/L
ER92002183	07/14/93	200	400	3549	2.9	TMA/Eberline	102.921
ER92002184	07/14/93	130	440	2590	3.4	TMA/Eberline	88.06
ER92002185	07/14/93	100	430	1865	3.7	TMA/Eberline	69.005
ER92002186	07/14/93	100	430	1180	1.51	ORNL	17.518
ER92002187	07/14/93	50	430	2566	2.6	TMA/Eberline	66.715
ER92002188	07/14/93	0	430	1328	2.8	TMA/Eberline	37.184
ER92002189	07/14/93	0	375	45726	2.8	TMA/Eberline	1280.33
ER92002190	07/14/93	0	300	3198	1.9	TMA/Eberline	60.762
ER92002191	07/14/93	0	225	5291	2.9	TMA/Eberline	153.439
ER92002192	07/14/93	0	150	14760	2.1	TMA/Eberline	309.96
ER92002193	07/14/93	0	75	25217	1.8	TMA/Eberline	453.906
ER92002194	07/14/93	200	50	186994	1.1	TMA/Eberline	2056.93
ER92002195	07/14/93	130	50	27290	2.6	TMA/Eberline	709.54
ER92002196	07/14/93	80	30	30437	1.5	TMA/Eberline	456.555
ER92002197	07/14/93	30	50	28073	2.3	TMA/Eberline	645.679
ER92002198	07/14/93	180	75	73552	2.8	TMA/Eberline	2059.46
ER92002199	07/14/93	80	75	41023	3.2	TMA/Eberline	1312.74
ER92002200	07/14/93	200	100	2838760	2.1	TMA/Eberline	59614
ER92002201	07/15/93	130	100	75243	2.1	TMA/Eberline	1580.1
ER92002202	07/15/93	130	100	32200	0.58	ORNL	186.76
ER92002203	07/15/93	30	100	146512	2.4	TMA/Eberline	3516.29
ER92002204	07/15/93	180	130	640999	2.8	TMA/Eberline	17948
ER92002205	07/15/93	80	130	183436	2.4	TMA/Eberline	4402.46
ER92002206	07/15/93	200	150	19239700	1.5	TMA/Eberline	288595
ER92002207	07/15/93	180	180	88627	2	TMA/Eberline	1772.54
ER92002208	07/15/93	130	160	41109	2.9	TMA/Eberline	1192.16
ER92002209	07/15/93	30	160	241826	2.5	TMA/Eberline	6045.65
ER92002210	07/15/93	180	240	7626	2.6	TMA/Eberline	198.276
ER92002211	07/15/93	110	240	7229	2.2	TMA/Eberline	159.038
ER92002212	07/15/93	110	240	5410	2.15	ORNL	116.315
ER92002213	07/15/93	30	240	7208	1.9	TMA/Eberline	136.952
ER92002214	07/15/93	180	300	2846	3.8	TMA/Eberline	108.148
ER92002215	07/15/93	110	300	4008	2.5	TMA/Eberline	100.2
ER92002216	07/15/93	30	300	1519	2.5	TMA/Eberline	37.975
ER92002217	07/15/93	180	360	2155	2.2	TMA/Eberline	47.41
ER92002218	07/15/93	110	360	1757	2.5	TMA/Eberline	43.925
ER92002219	07/15/93	30	360	2688	2.1	TMA/Eberline	56.448
ER92004565	07/16/93	260	50	135943	2.5	TMA/Eberline	3398.57
ER92004566	07/16/93	230	50	498152	2.8	TMA/Eberline	13948.3
ER92004567	07/16/93	230	50	314000	0.89	ORNL	2794.6
ER92004568	07/16/93	260	100	3391820	3.2	TMA/Eberline	108538
ER92004569	07/16/93	230	100	7396750	2.3	TMA/Eberline	170125
ER92004570	07/16/93	260	150	885154	2.3	TMA/Eberline	20358.5
ER92004571	07/16/93	260	150	333000	1.1	ORNL	3663
ER92004572	07/16/93	230	150	9655080	2.1	TMA/Eberline	202757
ER92004573	07/16/93	250	105	1185840	2.8	TMA/Eberline	33203.6
ER92004574	07/16/93	245	110	2233250	2.5	TMA/Eberline	55831.2
ER92004575	07/16/93	255	110	39388400	2.8	TMA/Eberline	1102870
ER92004576	07/16/93	250	115	2970540	2.2	TMA/Eberline	65352

Appendix E
Tritium Data for Soil Cuttings from MWL-MW4

<u>Sample no.</u>	<u>Date Collected</u>	<u>Depth From</u> <u>(feet)</u>	<u>Depth To</u> <u>(feet)</u>	<u>tritium per liter</u> <u>extracted water</u> <u>(pCi/L)</u>	<u>%moisture</u> <u>content</u>
110293-08	11/02/93	0	8	5000	8.8
110293-11	11/02/93	0	8	110000	6.4
110293-09	11/02/93	0	8	8700	7.1
110293-10	11/02/93	0	8	49000	6.6
110293-03	11/02/93	0	35	7000	1.8
110293-05	11/02/93	35	50	620	1.6
110293-07	11/02/93	50	57	540	1.7
110293-06	11/02/93	57	70	700	1.8
110293-01	11/02/93	70	78	790	2.3
110293-04	11/02/93	78	93	430	3.2
110293-02	11/02/93	93	103	430	2.4
011810	12/21/93	103	120	520	2.2
011811	12/21/93	120	135	720	3.4
011812	12/21/93	135	139	590	3.1
011813	12/21/93	139	165	360	3.3
011814	12/21/93	165	170	390	2.7
011815	12/21/93	170	180	870	2.7
011816	12/21/93	180	192	670	4
011817	12/21/93	192	165	460	2.4
SNLA014501		200	211	510	
SNLA014502		211	223	350	
SNLA014503		223	238	250	
SNLA014504		238	246	140	
SNLA014505		246	250	320	
SNLA014507		259	269	370	
SNLA014508		269	277	290	
SNLA014509		277	284	230	
SNLA014510		284	290	100	
SNLA014511		290	298	390	
SNLA014512		298	312	390	
SNLA014513		312	320	310	
SNLA014514		320	327	450	
SNLA014515		327	342	240	
SNLA014516		342	352	260	
SNLA014517		352	360	480	

Appendix E (cont.)
Tritium Data for Soil Cuttings from MWL-MW4

<u>Sample no.</u>	<u>Date Collected</u>	<u>Depth From (feet)</u>	<u>Depth To (feet)</u>	<u>tritium per liter extracted water (pCi/L)</u>	<u>%moisture content</u>
SNLA014518		360	370	450	
SNLA014519		370	378	220	
SNLA014520		378	383	360	
SNLA014521		383	390	440	
SNLA014522		390	394	410	
SNLA014523		394	400	760	

Appendix F
Tritium Flux Monitoring Data, Fall 1993

<u>Sample</u>	<u>Flux</u> <u>(pCi/m²/hr)</u>
TF93-1	132
TF93-2	1580
TF93-3	210
TF93-4	1600
TF93-5	12100
TF93-6	978
TF93-7	498
TF93-8	858
TF93-9	141000
TF93-10	126
TF93-11	1310
TF93-12	786
TF93-13	1180
TF93-14	3810
TF93-15	4290
TF93-16	107000
TF93-17	6870
TF93-18	9460
TF93-19	1300
TF93-20	1060
TF93-21	324
TF93-22	1610
TF93-23	166000
TF93-24	1670
TF93-25	4250
TF93-26	1020
TF93-27	336

Appendix G
VOC Flux Monitoring Data for Fall, 1993

Sample	Methylene Chloride ($\mu\text{g}/\text{m}^2/\text{hr}$)	Trichloroethylene ($\mu\text{g}/\text{m}^2/\text{hr}$)	Tetrachloroethylene ($\mu\text{g}/\text{m}^2/\text{hr}$)	1,1,1-trichloroethane ($\mu\text{g}/\text{m}^2/\text{hr}$)	Benzene ($\mu\text{g}/\text{m}^2/\text{hr}$)	Toluene ($\mu\text{g}/\text{m}^2/\text{hr}$)	1,1,1,1-TETHC ($\mu\text{g}/\text{m}^2/\text{hr}$)
VOCF93-1	174	6.3	5.3	1.4	1.8	1	21.8
VOCF93-2	188	1.7	4.4	ND	0.9	ND	20.4
VOCF93-3	285	ND	13.3	0.8	0.9	1.6	45.4
VOCF93-4	84	ND	3.2	0.3	0.8	0.7	93.5
VOCF93-5	168	1.3	61.3	2.7	1.1	3.1	72.4
VOCF93-6	207	0.5	28.3	0.9	1.6	3.1	52.2
VOCF93-7	136	ND	5.6	ND	1.1	0.5	15.5
VOCF93-8	67	ND	9.3	6.3	1.2	0.7	30.4
VOCF93-9	91	ND	1.5	ND	0.5	ND	21
VOCF93-10	135	ND	2.2	ND	0.9	2.2	327

