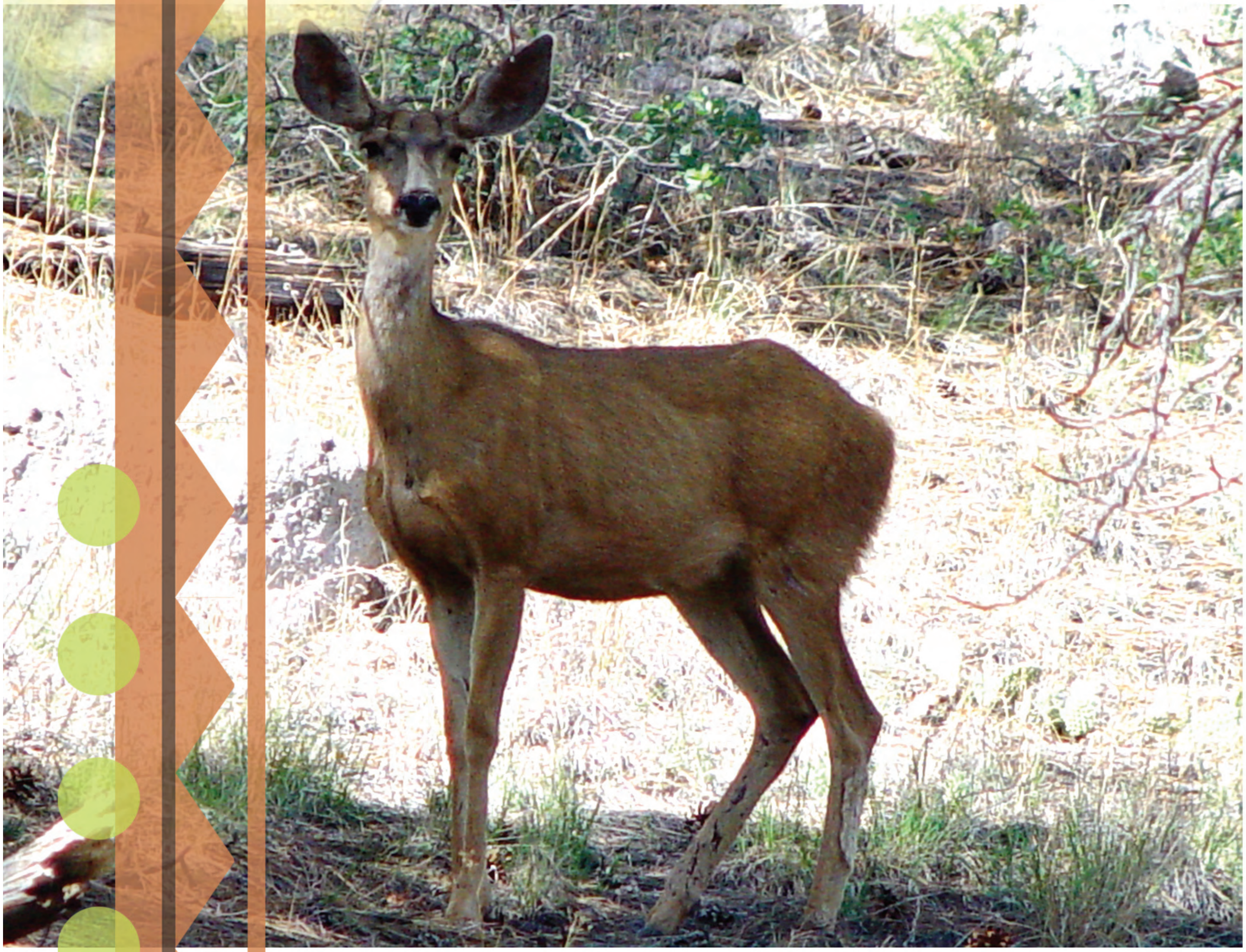
3. RADIOLOGICAL DOSE ASSESSMENT



3. RADIOLOGICAL DOSE ASSESSMENT

contributing authors:
William Eisele, Andrew Green, Keith Jacobson, and Michael McNaughton

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A. INTRODUCTION

The purpose of this chapter is to determine if the doses to the public and to biota are below the limits of the federal government. This chapter also provides a measure of the significance of environmental radioactivity in the context of its importance to humans and biota. In this respect, the human dose assessment provides a different perspective from the biota dose assessment. The human dose is received near the publicly accessible boundaries, whereas the biota dose is potentially received throughout the interior of the Los Alamos National Laboratory (LANL or the Laboratory), usually at locations rarely visited by humans.

As defined by the DOE Standard (DOE 2002), biota are divided into plants and animals. Plants receive the highest dose because they live their whole lives in one location. Animals range over a wider area, which usually minimizes their dose. Humans receive the lowest dose because they limit their time in areas with residual radioactivity, and they typically do not eat the vegetation or drink the water in those areas. Therefore, locations with no significant human dose may have higher biota dose.

B. HUMAN DOSE ASSESSMENT

1. Overview of Radiological Dose Equivalents

Radiological dose equivalents presented here are calculated using standard methods specified in DOE 1988a, 1988b, 1991; EPA 1988, 1993, 1997; and NRC 1977. The "effective dose equivalent," referred to here as "dose," is calculated using radiation weighting factors and tissue weighting factors to adjust for the various types of radiation and the various tissues in the body receiving the radiation. The final result, measured in millirem (mrem), is a measure of the overall dose to an individual, whether from external radiation or contact with radioactive material. For example, 1 mrem of direct gamma radiation is effectively equivalent to 1 mrem from inhalation of plutonium.

Federal government standards limit the dose that the public may receive from Laboratory operations. The DOE (DOE 1993) public dose limit to any individual is 100 mrem/year received from all pathways (i.e., all ways in which people can be exposed to radiation, such as inhalation, ingestion, and direct radiation). The dose received from airborne emissions of radionuclides is further restricted by the Environmental Protection Agency's (EPA's) dose standard of 10 mrem/year (40 CFR 61, EPA 1986). These doses are in addition to exposures from natural background, consumer products, and medical sources. Doses from community drinking water supplies are also limited according to the Clean Water Act, either by established maximum contaminant levels (MCLs) for some radionuclides, or by dose (4 mrem/year for man-made radionuclides, beta/photon emitters) (EPA 2000).

2. Public Dose Calculations

a. Scope

The objective of our public dose calculations is to report incremental (above-background) doses caused by LANL operations. Therefore, we don't include dose contributions from radionuclides present in our natural environment or from radioactive fallout.

Annual radiation doses to the public are evaluated for three principal exposure pathways: inhalation, ingestion, and direct (or external) radiation. We calculate doses for the following cases:

- The entire population within 80 km of the Laboratory;
- The maximally exposed individual (MEI) who is not on LANL/DOE property;
- Residents in Los Alamos and White Rock.

b. General Considerations

We begin with environmental measurements and convert these measurements to dose using the standard methods specified above.

As discussed in Section B.4, the dose rate from naturally occurring radioactivity is approximately 400 mrem/year (additional man-made sources of radiation raise the total background dose to about 500 mrem/year). It is extremely difficult to measure doses from LANL that are less than 0.1 percent (one one-thousandth) of natural doses. As the dose rates become smaller, the estimates become less certain and less significant. Generally, we conclude that a dose rate less than 0.1 mrem/year is essentially zero.

i. Direct Radiation Exposure. Direct radiation from gamma photons or neutrons is measured at about 100 locations near LANL (Chapter 4, Section C). Direct radiation doses above natural background are observed near Technical Area (TA) -54.

To receive a measurable dose, a member of the public must be within a few hundred meters of the source of external radiation. At distances more than 1 km, the decrease in radiation dose rate with increasing distance from the radiation source (inverse-square law), combined with scattering and attenuation or shielding in the air, reduces the dose to much less than 0.1 mrem/year, which cannot be distinguished from natural background radiation. This means the only significant doses from direct radiation are near TA-54 (section B.3.b of this chapter).

To estimate the dose to the public, we combine the measurements of gamma and neutron dose with an occupancy factor. The measurements reported in Chapter 4 would apply to an individual who is at a particular location continuously (i.e., 24 hours/day and 365 days/year). We follow standard guidance and assume continuous occupancy for residences and places of business. For all other locations, we multiply the measured dose by an occupancy factor of 1/16 (NCRP 1976).

ii. Airborne Radioactivity (Inhalation Pathway). At distances more than a few hundred meters from LANL sources, the dose to the public is almost entirely from airborne radioactive material. Whenever possible, we use the direct measurements of airborne radioactivity concentrations measured by the Ambient Air Sampling Network (AIRNET), and reported in Chapter 4, Section A. Where local concentrations are too small to measure, we calculate the doses using the standard model CAP88, an atmospheric dispersion and dose calculation computer code that combines stack radionuclide emissions information with meteorological data to estimate where the released radioactive material went and the dose from that radioactive material.

In particular, some of the radionuclide emissions from the Los Alamos Neutron Science Center (LANSCE) are not measured by AIRNET. These emissions are measured at the stacks (Chapter 4, Section B), and the resulting doses are calculated with CAP88 (Chapter 3, Section B.3.b). These doses decrease steeply with distance because the radioactive half-lives are short (e.g., the annual dose is 6.46 mrem at East Gate from LANSCE, 1 km to the north of LANSCE, and 0.079 mrem at an average Los Alamos residence, about 4 km to the west-northwest of LANSCE).

iii. Water (Ingestion Pathway). The majority of radionuclides detected in ground water samples collected from known or potential drinking water sources (e.g., Los Alamos County drinking water supply wells and natural springs) during 2005 resulted from the presence of natural radioactivity in these sources. These radionuclides include natural uranium and its decay products, such as radium-226. Tritium was the only radionuclide detected in these ground water samples that could possibly be attributed to Laboratory operations. The highest concentration of tritium from known or potential drinking water sources (349 pCi/L) was measured in a sample from an alluvial spring in Upper Los Alamos Canyon, which is not a recognized drinking water supply. This concentration is far below the EPA MCL of 20,000 pCi/L; this results in a dose less than 0.1 mrem/year. The highest concentration of tritium detected in a Los Alamos County drinking water supply well was 33 pCi/L in a sample collected from the Otowi-1 well located in Pueblo Canyon (this well was out of service much of the year).

iv. Soil (Direct Exposure Pathway). We report measurements of radionuclide concentrations in surface soil in Chapter 7. As described in Chapter 7, Section C.1, soil samples were collected on the perimeter of Pueblo de San Ildefonso land within Mortandad Canyon downwind of Area G. No samples had radionuclide concentrations above the Regional Statistical Reference Levels (RSRLs). RSRLs represent background radionuclide concentrations plus three standard deviations in media, such as soil, sediments, and crops, collected or harvested in regional areas far from the influence of the Laboratory averaged over a period of five years. Therefore, the soil concentrations measured in 2005 are essentially indistinguishable from regional background, and the resulting dose from soil (external gamma exposure, dust inhalation, and soil ingestion) at the sample location would be less than 0.1 mrem/year. As the strontium-90 and cesium-137 soil concentrations at the sample location are less than the RSRLs for both radionuclides, it is probable that all or almost all of the strontium-90 and cesium-137 are from global fallout and not from LANL. The tritium mainly comes from three sources: cosmic rays, nuclear weapons testing, and LANL; however, the dose from tritium in soil is virtually nonexistent at the Pueblo de San Ildefonso sample site. Similarly, the measured transuranics (plutonium-238, -239/240, and americium-241) may include a small contribution from LANL, but the dose from these radionuclides is much less than 0.1 mrem/year. Finally, the isotopic mixture of uranium is consistent with natural uranium. In summary, we conclude that the LANL contribution to the dose from soil is less than 0.1 mrem/year, and the majority of the radionuclides detected are primarily due to fallout.

v. Food (Ingestion Pathway). We report measurements of the radioactive content of foods in Chapter 8. During 2005, predator and bottom-feeding fish were caught at Abiquiu and Cochiti Reservoirs. Purslane, a wild edible plant, was also collected on the perimeter of Pueblo de San Ildefonso within Mortandad Canyon, downwind of Area G. No other foodstuffs were collected during 2005.

Fish caught at Abiquiu Reservoir serve as a background population essentially removed from the influence of the Laboratory because the reservoir is upstream of the Laboratory. Cochiti Reservoir is downstream of the Laboratory and fish caught there are potentially impacted by Laboratory operations. Therefore, the concentrations of radionuclides in fish caught at Abiquiu Reservoir are subtracted from the concentrations of radionuclides in fish caught at Cochiti Reservoir (LANL 2006). Review of these background-subtracted radionuclide concentrations indicates that the dose received from consuming predator and bottom-feeding fish caught at Cochiti Reservoir would be much less than 0.1 mrem per year. Refer to Supplemental Tables S8-1 and S8-2 for specific radionuclide concentration values.

The concentration of strontium-90 in three samples of purslane collected from Pueblo de San Ildefonso lands in Mortandad Canyon were high compared with domestic edible plant RSRLs. Refer to Supplemental Table S8-3 for specific radionuclide concentration values. The total dose received from consuming a pound of purslane would be much less than 0.01 mrem. Assuming consumption of approximately 30 pounds (expected consumption of produce from a contaminated area in accordance with LANL 2000) of purslane per year, a dose of approximately 0.1 mrem would be received.

We conclude that the LANL contribution to the dose from consuming foodstuffs is small relative to the all-pathways dose limit of 100 mrem/year and would be on the order of 0.1 mrem/year if wild foodstuffs were collected and consumed from the perimeter of Pueblo de San Ildefonso land within Mortandad Canyon.

vi. Release of Items. The Laboratory releases miscellaneous surplus items of salvageable office and scientific equipment to the general public. The requirements for release of such items are found in LANL 2002. It is a Laboratory goal to not knowingly release any items with residual radioactivity. All items destined for release from known or potentially contaminated areas are screened for radioactive contamination. Items from a known or potentially contaminated area that cannot be completely surveyed are not released. Therefore, there is no known additional dose to the general public through the release of items for uncontrolled use by the general public.

3. Dose Calculations and Results

a. Population within 80 Kilometers

We used the local population distribution to calculate the dose from 2005 Laboratory operations to the population within 80 km (50 miles) of LANL. Approximately 280,000 persons live within an 80-km radius of the Laboratory. We used county population estimates provided by the University of New Mexico Bureau of Business and Economic Research. These statistics are available at http://www.unm.edu/~bber/.

The collective dose from Laboratory operations is the sum of the estimated doses for each member of the public within an 80-km radius of LANL. For example, if two persons each receive 3 mrem, the collective dose is 6 person-mrem. This dose results from airborne radioactive emissions. Other potential sources, such as direct radiation, are essentially zero. We calculated the collective dose by modeling the transport of radioactive air emissions using CAP88.

The 2005 collective population dose attributable to Laboratory operations to persons living within 80 km of the Laboratory was 2.46 person-rem, which is significantly higher than the dose of 0.90 person-rem reported for 2004. Tritium contributed about 17 percent of the dose, and short-lived air activation products such as carbon-11, nitrogen-13, and oxygen-15 from LANSCE contributed about 83 percent of the dose. The increase in the 2005 collective population dose was attributable to a longer beam operation time at LANSCE (over twice that of 2004) and a malfunction in the LANSCE air emissions control system as described below in section 3.b. LANSCE has historically been the major contributor to the population dose. Until 2005, population doses for the past 12 years had declined from a high of about 4 person-rem in 1994 to less than 1 person-rem in 2004 (Figure 3-1). The collective population dose is expected to decrease in 2006 to the 2004 level. No observable health effects in the local population are expected from this dose.

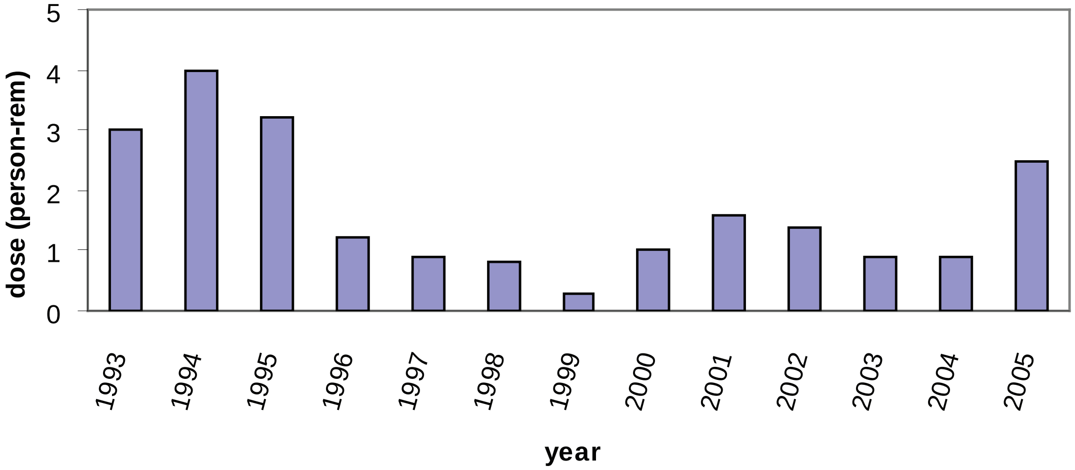

Figure 3-1. **Annual collective dose (person-rem) to the population within 80 km of LANL. This represents the total dose received by the total population (about 280,000) within 90 km.**

b. Maximally Exposed Individual

The MEI is a hypothetical member of the public who, while not on DOE/LANL property, received the greatest dose from LANL operations. During 2005, there were two potential MEI locations: one location was at East Gate along State Road 502 entering the east side of Los Alamos County; the other is the boundary between LANL TA-54 and the Pueblo de San Ildefonso Sacred Area, north of Area G.

East Gate is normally the location of greatest exposure because of its proximity to LANSCE and the prevailing wind direction. During LANSCE operations, short-lived positron emitters, such as carbon-11, nitrogen-13, and oxygen-15, are released from the stacks and diffuse from the buildings. These emitters release photon radiation as they decay, producing a potential radiation dose. We modeled the dose from LANSCE and from the LANL stacks using CAP88. The CAP88-modeled doses (Jacobson 2006) were approximately 6.31 mrem from LANSCE and 0.11 mrem from other LANL stacks and diffuse emissions sources. We added 0.039 mrem from the radionuclides measured at the Eastgate AIRNET station, though this dose is primarily from tritium, most of which was in the CAP88 modeled doses. Therefore, the total dose at East Gate was approximately 6.46 mrem.

Emissions of radioactive gases from LANSCE stacks were greatly elevated during 2005, relative to emissions in 2004. This is due to two factors. First, the beam operation time in 2005 was much longer: almost 10 months in 2005 versus four months in 2004. Second, there was a cracked valve in the air emissions control system, which holds up the short-lived gas emissions and allows for radioactive decay before they are released. This malfunction was repaired in late November 2005 and the rate of emissions returned to 2004 rates after this repair. We expect 2006 emissions to return to the 1–2 mrem range because of the repair and due to additional emissions controls implemented in 2005 that will compensate for any increased beam operations time.

The second location evaluated as the potential MEI is the boundary of the Pueblo de San Ildefonso Sacred Area north of Area G. Transuranic waste at Area G awaiting shipment to the Waste Isolation Pilot Plant (WIPP) emits neutrons. The measured neutron dose at the boundary was 16 mrem. After subtracting a 2-mrem neutron background value and applying the standard occupancy factor of 1/16 (NCRP 1976), the individual neutron dose was 14/16 = 0.88 mrem. A gamma photon dose was not calculated for this location because the low-energy photons emitted from the transuranic waste are absorbed in the intervening air layer between Area G and the Sacred Area. To estimate the contributions from airborne radionuclides at this location, we modeled the dose contribution from the LANL stacks as 0.040 mrem/16 = 0.003 mrem. We then added the maximum dose derived from measurements at the AIRNET stations along the northern boundary of Area G (0.18 mrem) and applied the occupancy factor of 1/16 to obtain a dose of 0.011 mrem. Thus, we conclude the dose at this location was approximately 0.9 mrem, which is less than the MEI dose at East Gate.

The MEI dose of 6.46 mrem is below the 10 mrem/year EPA airborne emissions dose limit for the public (40 CFR 61, EPA 1986), and based on previous studies, it will cause no observable health effects.

Until 2005, the MEI dose for the past 12 years had declined from a high of nearly 8 mrem in 1994 to less than 2 mrem in 2004 (Figure 3-2). LANSCE is the major contributor to the MEI dose. Generally, the year-to-year fluctuations are the result of variations in the number of hours that LANSCE runs, whereas the overall downward trend is the result of efforts to reduce the LANSCE emissions by installing delay lines and fixing small leaks. In comparison, the total annual dose from sources other than LANL is approximately 500 mrem.

An on-site MEI location had been evaluated in previous years, but because of increased security restrictions preventing access by members of the public to many of the technical areas and the relocation of significant external radiation sources, an on-site MEI is no longer applicable.

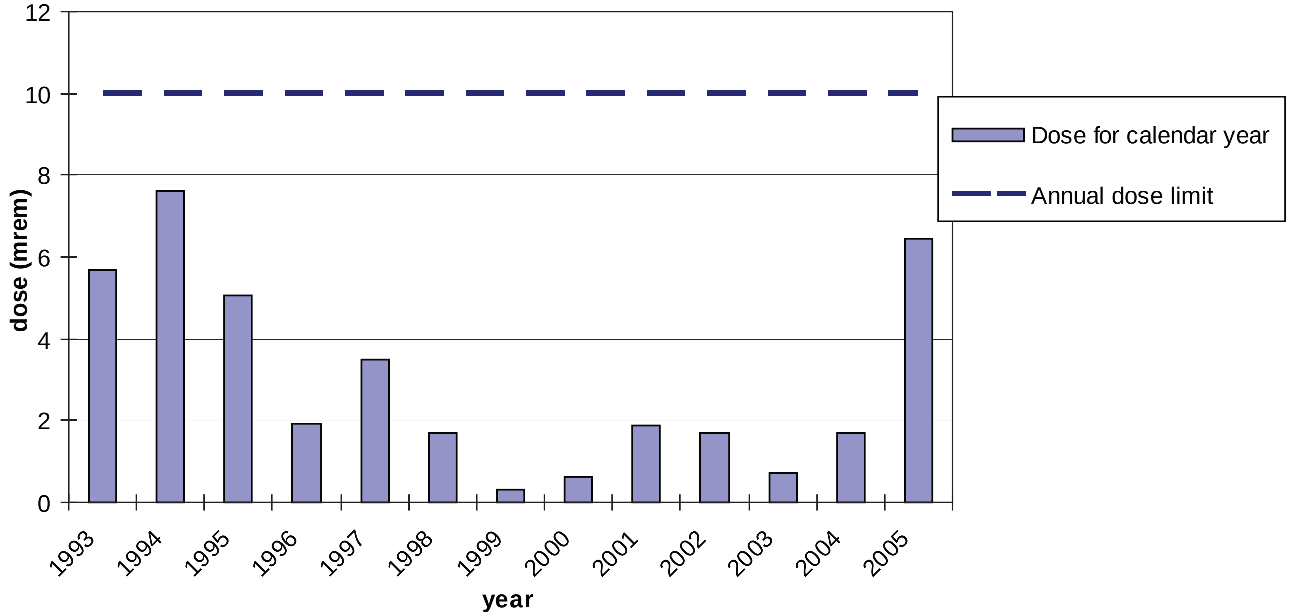

Figure 3-2. **Annual dose (mrem) to the maximally exposed individual off-site over the past 13 years.**

c. Doses in Los Alamos and White Rock

We used AIRNET data (reported in Chapter 4, Section A) to calculate an annual dose at each of the AIRNET stations for the perimeter stations that represent the Los Alamos resident and the White Rock resident. We then converted the AIRNET concentrations to doses using the factors in EPA 1986 and added the dose contributions from LANSCE (calculated using CAP88 for these Los Alamos and White Rock perimeter AIRNET station locations). Averaging the summed AIRNET and CAP88 doses provided the representative Los Alamos resident and the White Rock resident air pathway doses.

i. Los Alamos. During 2005, the measurable contributions to the dose at an average Los Alamos residence were 0.013 mrem from tritium and 0.079 mrem from LANSCE. Other radionuclides contributed about 0.021 mrem, amounting to a total of 0.11 mrem.

ii. White Rock. During 2005, the measurable contributions to the dose at an average White Rock residence were 0.013 mrem from tritium and 0.041 mrem from LANSCE. Other radionuclides contributed less than 0.01 mrem, amounting to a total of 0.06 mrem.

The contributions from direct radiation, food, water, and soil are discussed in Chapter 3, Section B.2; each contribution was too small to measure. In summary, the total annual dose to an average Los Alamos/White Rock resident from all pathways was about 0.1 mrem. No observable health effects are expected from this dose.

4. Estimation of Radiation Dose Equivalents for Naturally Occurring Radiation

In this section, we discuss the LANL contribution relative to natural radiation and radioactive materials in the environment (NCRP 1975, 1987a, 1987b).

External radiation comes from two sources that are approximately equal: cosmic radiation from space and terrestrial gamma radiation from naturally occurring radionuclides. Doses from cosmic radiation range from 50 mrem/year at lower elevations near the Rio Grande to about 90 mrem/year in the Jemez mountains west of Los Alamos. Doses from terrestrial radiation range from about 50 to 150 mrem/year, depending on the amounts of natural uranium, thorium, and potassium in the soil.

The largest dose from radioactive material is from the inhalation of naturally occurring radon and its decay products, which contribute about 200 mrem/year. An additional 40 mrem/year results from naturally occurring radioactive materials in the body, primarily potassium-40, which is present in all food and in all living cells.

In addition, members of the US population receive an average dose of 50 mrem/year from medical and dental uses of radiation, 10 mrem/year from man-made products such as stone or adobe walls, and less than 1 mrem/year from global fallout from nuclear-weapons tests (NCRP 1987a). Therefore, the total annual dose from sources other than LANL is approximately 500 mrem. The estimated LANL-attributable 2005 dose to the MEI, 6.46 mrem, is less than 2 percent of this dose.

5. Effect to an Individual from Laboratory Operations

Health effects from radiation exposure have been observed in humans at doses in excess of 10 rem (10,000 mrem). However, doses to the public from LANL operations are much smaller. According to the 1996 Position Statement of the Health Physics Society (HPS 1996), "Below 10 rem, risks of health effects are either too small to be observed or are nonexistent." Therefore, the doses reported here and summarized in Table 3-1 are not expected to cause observable health effects.

Table 3-1
LANL Radiological Dose for Calendar Year 2005

Pathway	Dose to Maximally Exposed Individual mrem (mSv)	% of DOE 100 mrem/year Limit	Estimated Population Dose person-rem (person-Sv)	Population within 80 km	Estimated Background Radiation Population Dose (person-rem)
Air	6.46 ($6.46x10^{-2}$)	7%	2.46 ($2.5x10^{-2}$)	~280,000	~56,000[a]
Water	<0.1 ($<1.0x10^{-3}$)	<0.1%	0	~280,000	~1,300[b]
Other Pathways	<0.1 ($<1.0x10^{-3}$)	<0.1%	0	~280,000	~76,000[c]
All Pathways	6.46 ($6.46x10^{-2}$)	7%	2.46 ($2.5x10^{-2}$)	~280,000	~133,300

[a] Based on 200 mrem/year from inhalation of radon and its decay products (see section B.4)

[b] Based on U-234 and U-238 concentrations detected in White Rock Canyon and Buckman Field water supply samples

[c] Based on approximately 270 mrem/year total from cosmic radiation (70 mrem/year), terrestrial radiation (100 mrem/year), K-40 (40 mrem/year), medical and dental uses of radiation (50 mrem/year), and man-made products (10 mrem/year) (see section B.4)

C. BIOTA DOSE ASSESSMENT

1. Biota Dose Assessment Approach

a. Overview

The biota dose assessment methods are described in detail in the DOE Standard (DOE 2002) and in the computer program RESRAD-BIOTA (http://web.ead.anl.gov/resrad/home2/biota.cfm). The DOE methods are general in nature and allow specific parameters to be adjusted according to local conditions because the calculations apply to all types of biota and all types of ecosystems. The site-specific methods used at LANL are specified in the quality assurance project plan for Biota Dose Assessment (available at http://www.lanl.gov/community/environment/air/), and McNaughton 2005 describes in detail the application of these methods to specific locations at LANL.

It is not possible to assess the dose to every animal and every plant at LANL. Therefore, we calculate the dose to selected plants and animals following the guidance of the DOE Standard (DOE 2002) and the environmental restoration program (LANL 2004). Trees of the pine family (pinaceae) are representatives for plants because they are radiosensitive (UNSCEAR 1996) and because their deep roots tap into buried contamination (Foxx 1984a, b; Tierney 1987). Deer mice are representatives for animals because of their relatively small home range, which means the maximally exposed mouse spends a large fraction of its time in the most contaminated location. These plants and animals are common and widespread at LANL and in the region.

b. Biota Dose Limits

The DOE biota dose limits (DOE 2002) are applied to biota populations rather than to individual plants and animals because it is the goal of DOE to protect populations, especially with respect to preventing the impairment of reproductive capability within the population. For animals, we use the population area for deer mice of 3 ha (30,000 m^2) (Ryti 2004; LANL 2004). We also average the dose to plants over this same area.

The DOE dose limits to biota populations are:

- Terrestrial animals: 100 mrad/day
- Terrestrial plants: 1,000 mrad/day
- Aquatic animals: 1,000 mrad/day

c. Methods

To ensure that the assessment is comprehensive, we begin with an initial screening (DOE 2002) that compares the maximum radionuclide concentrations in soil, sediment, and water with the DOE “Biota Concentration Guides” (BCGs). The DOE Standard (DOE 2002) states: “An important point is that exceeding the BCGs should not force a mandatory decision regarding remediation of the evaluation area, but rather is an indication that further investigation is likely necessary.” If the BCGs are exceeded, a site-specific assessment is conducted that uses average concentrations and incorporates site-specific bioaccumulation factors. Following the guidance of the DOE Standard (DOE 2002), we do not include external-radiation dose from experimental facilities such as the Dual Axis Radiographic HydroTest (DARHT) facility and LANSCE. To provide further refinement of the screening process, we screen on a radionuclide-by-radionuclide basis and compare each radionuclide concentration to the appropriate BCG. If the concentration exceeds 10 percent of the BCG (or biota dose limit) for any one radionuclide, a full-scale screening is performed using the sum of the fractions approach.

2. Biota Dose Results

Vegetation samples were collected at TA-54 in 2005. Tritium above the RSRL was detected in some overstory and understory vegetation collected near the tritium shafts in the south section of TA-54. Plutonium-238 and plutonium-239 were also detected above the RSRL in vegetation collected from the north and northeastern sections of TA-54. However, none of these concentrations exceeded the 0.1 rad/day biota dose screening level for terrestrial plants. Refer to Chapter 8, section B.4.b.i. (page 223), for more information.

Similarly, uranium-238 above the baseline statistical reference level (BSRL) was detected in some overstory and understory vegetation at the DARHT facility (TA-15). (Note: BSRLs are essentially the same as RSRLs and represent background levels prior to the initiation of operations at the facility.) Again, these concentrations did not exceed the 0.1 rad/day screening level for terrestrial plants. Refer to Chapter 8, section B.4.c.i. (page 224), for more information.

During 2005, honey bees were collected from five hives located just northeast of the DARHT facility at LANL. The only radionuclides detected in these bees above the BSRL were isotopes of uranium, especially uranium-238. The concentrations of uranium in these bees did not exceed the biota dose screening level of 0.01 rad/day for terrestrial animals. Refer to Chapter 8, section B.4.c.ii. (page 224), for more information.

Surface waters in canyons potentially affected by the Laboratory were also collected in 2005 and analyzed for radionuclides. Specifically, these samples were collected in Pueblo Canyon above Acid Canyon, Lower Pueblo Canyon, DP Canyon below TA-21, LA Canyon at Skate Rink, LA Canyon between DP and SR-4, LA Canyon at Rio Grande, Mortandad Canyon below Effluent Canyon, and Pajarito Canyon above SR-4. The time-weighted sum of ratios for estimated annual average surface water concentrations of radionuclides in these major canyons were well below the aquatic animal BCGs (no greater than 11 percent or 0.11 rad/day). Refer to Chapter 6, Table 6-2, for more information regarding specific radionuclide concentrations and associated BCG ratios.

Data quality objective evaluation determined that soil, vegetation, and other related samples may be collected on a three-year frequency because data from previous years showed no upward trends or exceedances of DOE limits. Because of this evaluation, other non-foodstuff biota (e.g., pine trees and deer mice) and media such as soil were not collected in 2005 for purposes of assessing biota dose. A full suite of biota doses will be reported next year for 2006.

D. REFERENCES

DOE 1988a: US Department of Energy, "External dose conversion factors for calculating dose to the public," US Department of Energy report DOE/EP-0070 (July 1988).

DOE 1988b: US Department of Energy, "Internal dose conversion factors for calculating dose to the public," US Department of Energy report DOE/EP-0071 (July 1988).

DOE 1991: US Department of Energy, "Environmental regulatory guide for radiological effluent monitoring and environmental surveillance," US Department of Energy report DOE/EH-0173T (January 1991).

DOE 1993: US Department of Energy, "Radiation protection of the public and the environment," US Department of Energy Order DOE 5400.5 (January 1993).

DOE 2002: US Department of Energy, "A graded approach for evaluating radiation dose to aquatic and terrestrial biota," US Department of Energy Technical Standard 1153-2002 (August 2000). [Available at http://www.eh.doe.gov/techstds/standard/std1153/Frontmatter.pdf]

EPA 1986: US Environmental Protection Agency, "National emission standards for hazardous air pollutants," Code of Federal Regulations, Title 40, Part 61 (1986).

EPA 1988: Environmental Protection Agency, "Limiting values of radionuclide intake and air concentration and dose conversion factors for inhalation, submersion, and ingestion," EPA-520/1-88-020, Federal Guidance Report No. 11 (September 1988).

EPA 1993: Environmental Protection Agency, "External Exposure to Radionuclides in the Air, Water, and Soil," EPA-402-R-93-081, Federal Guidance Report No. 12 (September 1993).

EPA 1997: Environmental Protection Agency, "Exposure factors handbook," EPA/600/C-99/001 (August 1997).

EPA 2000: US Environmental Protection Agency, "Primary drinking water regulations; radionuclides; final rule," Code of Federal Regulations, Title 40, Parts 9, 141, and 142 (December 2000).

Foxx 1984a: T. S. Foxx, G. D. Tierney, and J. M. Williams, "Rooting depths of plants on low-level waste disposal sites," Los Alamos National Laboratory report LA-10253-MS (1984).

Foxx 1984b: T. S. Foxx, G. D. Tierney, and J. M. Williams, "Rooting depths of plants relative to biological and environmental factors," Los Alamos National Laboratory report LA-10254-MS (1984).

HPS 1996: Health Physics Society, "Radiation risk in perspective," Health Physics Society Position Statement, HPS Newsletter (March 1996).

Jacobson 2003: Keith Jacobson, Scot Johnson, and Jeremy Rishel, "Facility-Wide Air Quality Impact Analysis," LA-UR-03-3983 (July 2003).

Jacobson 2006: K. W. Jacobson, "US DOE Report: 2006 LANL radionuclide air emissions," Los Alamos National Laboratory report LA-14298 (2006).

LANL 2000: R. J. Mirenda, L. F. Soholt, "Standard Human Health Risk Assessment Scenarios, Revision 2," Los Alamos National Laboratory document LA-UR-00-4084 (September 1, 2000).

LANL 2004: "Screening-level ecological risk assessment methods, Revision 2," Los Alamos National Laboratory document LA-UR-04-8246, ER2004-0519 (2004).

LIR 2002: Laboratory Implementation Requirement LIR-402-700-01.2, "Occupational Radiation Protection Requirements," Revision 2 (2002).

McNaughton 2005: "Biota dose assessment at LANL," Los Alamos National Laboratory document LA-UR-05-4699.

NCRP 1975: National Council on Radiation Protection and Measurements, "Natural background radiation in the United States," National Council on Radiation Protection and Measurements report 45 (November 1975).

NCRP 1976: National Council on Radiation Protection and Measurements, "Structural shielding and evaluation for medical use of x-rays and gamma rays of energies up to 10 MeV, recommendations of the National Council on Radiation Protection and Measurements," National Council on Radiation Protection and Measurements report 49 (1976).

NCRP 1987a: National Council on Radiation Protection and Measurements, "Ionizing radiation exposure of the population of the United States," National Council on Radiation Protection and Measurements report 93 (September 1987).

NCRP 1987b: National Council on Radiation Protection and Measurements, "Exposure of the population in the United States and Canada from natural background radiation," National Council on Radiation Protection and Measurements report 94 (December 1987).

NRC 1977: Nuclear Regulatory Commission, "Calculation of annual doses to man from routine releases of reactor effluents for the purpose of evaluating compliance with 10 CFR 50, Appendix I," Nuclear Regulatory Commission Report, Regulatory Guide 1.109 (October 1977).

Ryti 2004: R. T. Ryti, J. Markwiese, R. Mirenda, L. Soholt, "Preliminary remediation goals for terrestrial wildlife," Human and Ecological Risk Assessment 10: 437–450 (2004).

Tierney 1987: G. D. Tierney and T. S. Foxx, "Root lengths of plants on Los Alamos National Laboratory Lands," Los Alamos National Laboratory report LA-10865-MS (1987).

UNSCEAR 1996: United Nations Scientific Committee on the Effects of Atomic Radiation, 1996 Report to the General Assembly, "Sources and effects of ionizing radiation," United Nations, New York (ISBN 92-1-142219-1) (1996).

4. AIR SURVEILLANCE

contributing authors:
David Fuehne, Erin Dempsey, Andrew Green, Scot Johnson, Michael McNaughton, Terrance Morgan

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A. AMBIENT AIR SAMPLING

1. Introduction

The radiological air sampling network, referred to as AIRNET, measures environmental levels of airborne radionuclides, such as plutonium, americium, uranium, tritium, and activation products, that may be released from Los Alamos National Laboratory (LANL or the Laboratory) operations. Natural atmospheric and fallout radioactivity levels fluctuate and affect measurements made by LANL's air sampling program. Most of the regional airborne radioactivity comes from the following sources: (1) fallout from past atmospheric nuclear weapons tests conducted by several countries, (2) natural radioactive constituents in particulate matter, such as uranium and thorium, (3) terrestrial radon diffusion out of the earth and its subsequent decay products, and (4) material formation from interactions with cosmic radiation, such as natural tritiated water vapor produced by interactions of cosmic radiation and common atmospheric gases. Table 4-1 summarizes regional levels of radioactivity in the atmosphere for the past 5 years, which can be useful in interpreting current air sampling data.

Particulate matter in the atmosphere is primarily caused by aerosolized soil. Windy, dry days can increase soil entrainment, but precipitation, such as rain or snow, can wash particulate matter out of the air. Consequently, changing meteorological conditions often cause large daily and seasonal fluctuations in airborne radioactivity concentrations. Natural events can also have major impacts: the 2000 Cerro Grande fire dramatically increased short-term ambient concentrations of particulate matter (ESP 2001).

Air quality group personnel compared ambient air concentrations, as calculated from the AIRNET sample measurements, with environmental compliance standards for publicly accessible locations or with workplace exposure standards for on-site locations. We usually compare annual concentrations in areas accessible to the public with the 10-mrem equivalent concentration established by the Environmental Protection Agency (EPA) (EPA 1989). Concentrations in controlled access areas are usually compared with Department of Energy (DOE) Derived Air Concentrations (DACs) for workplace exposure (DOE 1988a) because access to these areas is generally limited to workers with a need to be in the controlled area.

Table 4-1
Average Background Concentrations of Radioactivity in the Regional[a] Atmosphere

			Annual Averages[c]				
	Units	EPA Concentration Limit[b]	2001	2002	2003	2004	2005
Alpha	fCi/m^3	NA[d]	0.8	0.8	0.8	1.1	0.9
Beta	fCi/m^3	NA	13.9	13.3	13.7	18.3	16.3
Tritium[e]	pCi/m^3	1500	0.0	-0.1	-0.1	0.1	0.1
Pu-238	aCi/m^3	2100	0.0	0.0	-0.1	0.09	0.0
Pu-239	aCi/m^3	2000	0.1	0.3	-0.1	-0.07	0.1
Am-241	aCi/m^3	1900	-0.2	0.3	-0.7	-0.47	0.1
U-234	aCi/m^3	7700	17.9	21.7	20.9	17.4	12.4
U-235	aCi/m^3	7100	1.3	2.4	1.8	1.17	1.2
U-238	aCi/m^3	8300	17.7	21.8	20.1	17.0	13.2

[a] Data from regional air sampling stations operated by LANL during the last 5 years (locations can vary by year).

[b] Each EPA Concentration Limit is from 10 CFR 40 and corresponds to 10 mrem/yr

[c] Gross alpha and beta annual averages are calculated from gross air concentrations. All other annual averages are calculated from net air concentrations.

[d] Not available.

[e] Tritium annual averages have been corrected for the tritium lost to bound water in the silica gel.

2. Air Monitoring Network

During 2005, LANL operated 50 environmental air samplers to sample radionuclides by collecting water vapor and particulate matter. AIRNET sampling locations (Figures 4-1 through 4-3) are categorized as regional, pueblo, perimeter, waste site Technical Area 54 (TA-54), or other on-site locations.

3. Sampling Procedures, Data Management, and Quality Assurance

a. Sampling Procedures

Generally, each AIRNET sampler continuously collects particulate matter and water-vapor samples for approximately two weeks per sample. Particulate matter is collected on 47-mm polypropylene filters at airflow rates of about 0.11 m^3 per minute. These filters are analyzed for various radionuclides.

Vertically mounted canisters that contain about 135 g of silica gel, with an airflow rate of about 0.0002 m^3 per minute, are used to collect water vapor samples. We dry this silica gel in a drying oven to remove most residual water before using in the field. The gel is a desiccant that removes moisture from the sampled air. After use in the field, the gel is removed from the canister and shipped to the analytical laboratory where the moisture is distilled, condensed, and collected as a liquid. This liquid is analyzed for the presence of tritium. The AIRNET quality assurance project plan and the numerous procedures through which the plan is implemented provide details about the sample collection, sample management, chemical analysis, and data management activities.

b. Data Management

In the field, personnel recorded the sampling data on a palm-held microcomputer, including timer readings, volumetric airflow rates at the start and stop of the sampling period, and comments pertaining to these data. These data are transferred to an electronic table format within the AIRNET database.

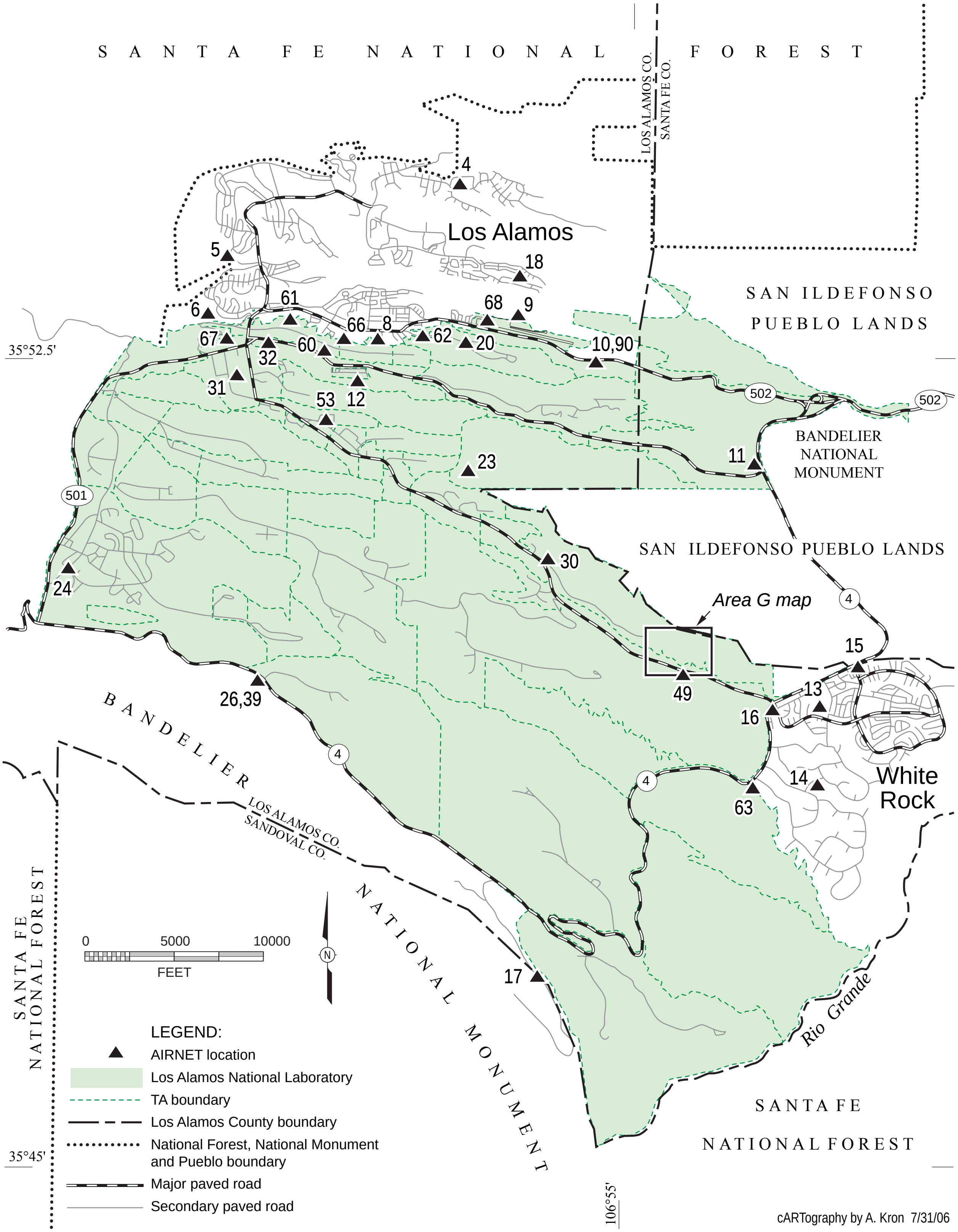

Figure 4-1. Off-site perimeter and on-site LANL AIRNET locations.

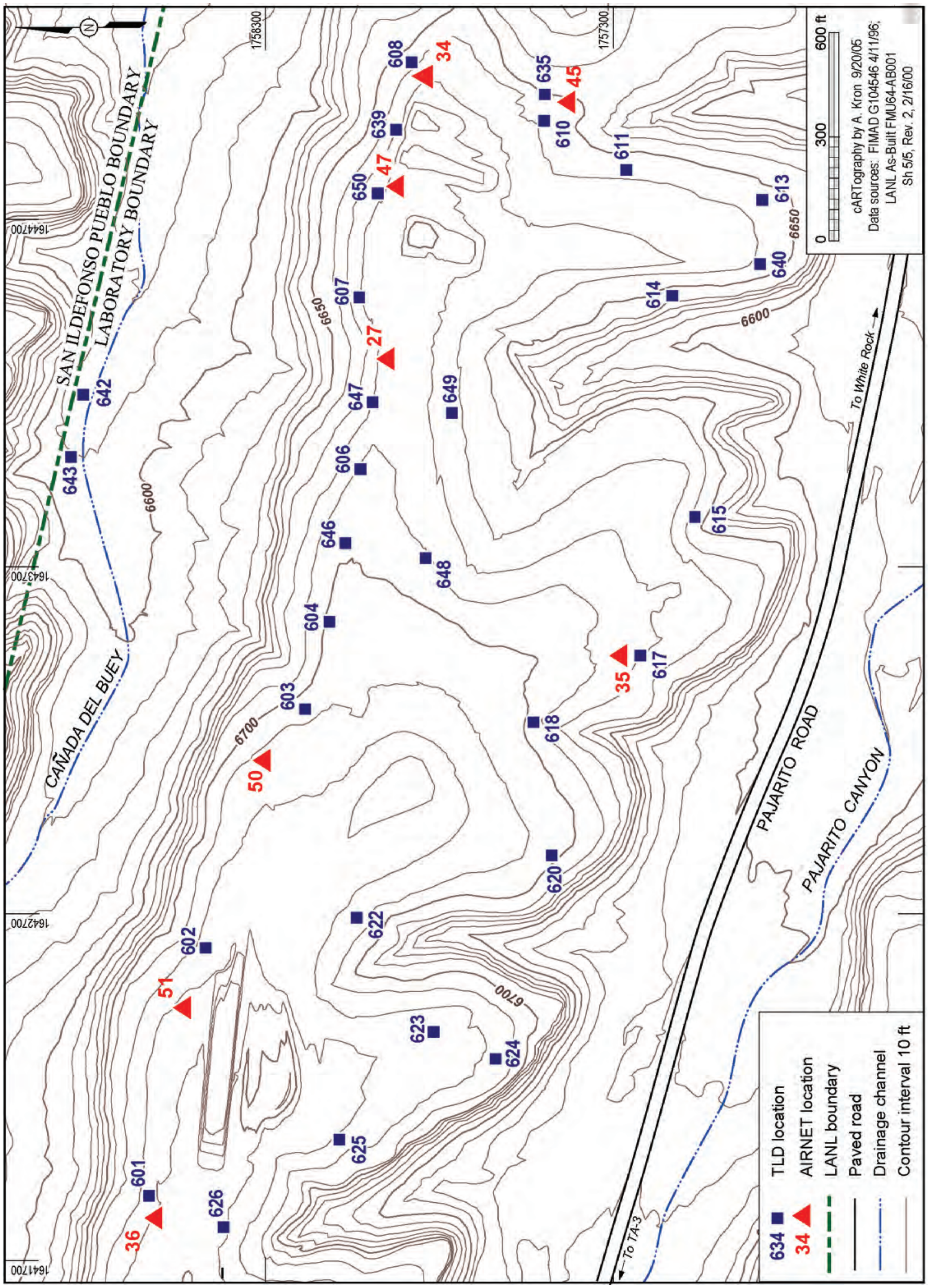

Figure 4-2. AIRNET and thermoluminescent dosimeter locations at TA-54, Area G.

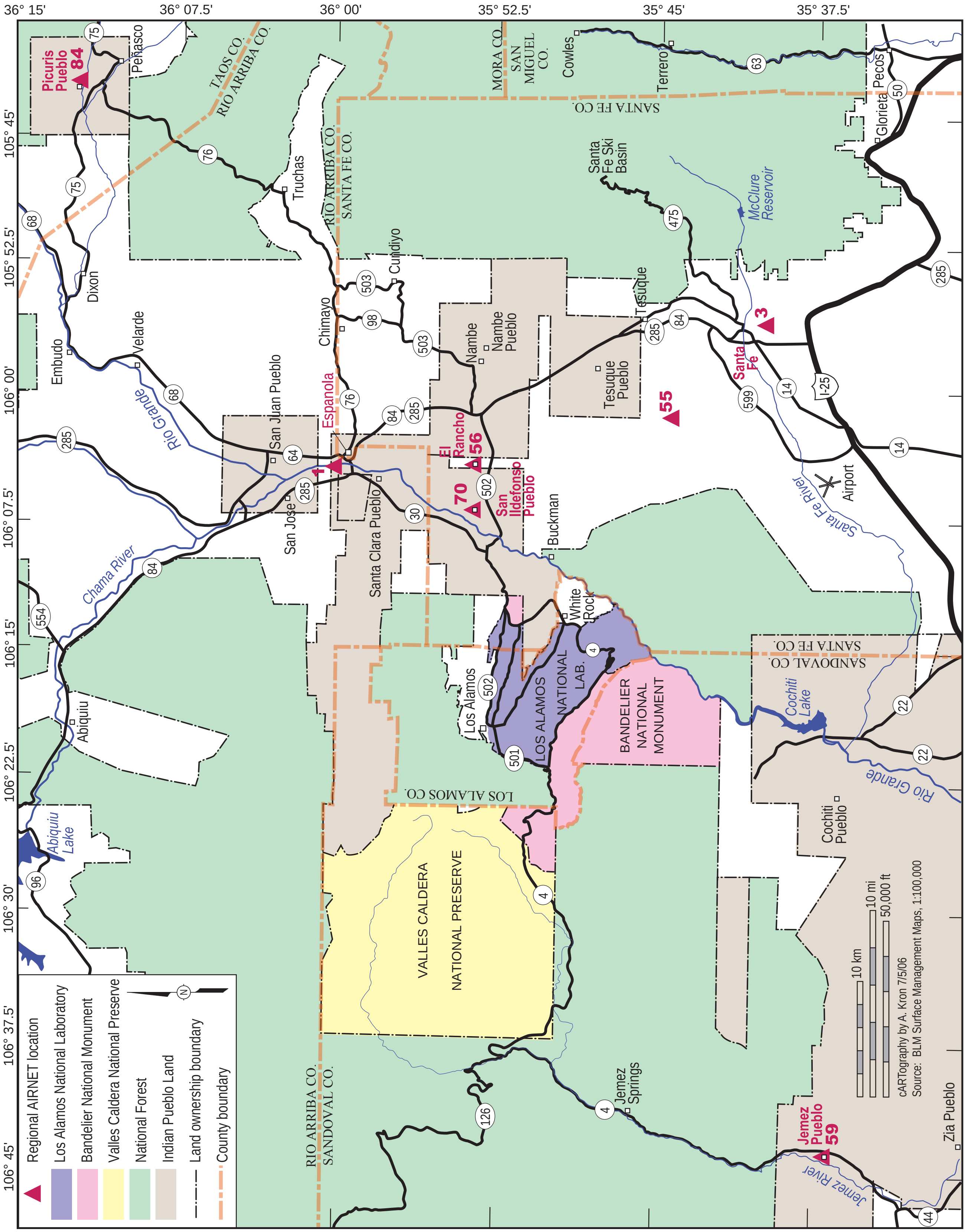

Figure 4-3. Regional and pueblo AIRNET locations.

c. Analytical Chemistry

A commercial laboratory analyzed each particulate-matter filter for gross alpha and gross beta activities. These filters were also grouped by region across sites, designated as “clumps,” and analyzed for gamma-emitting radionuclides. During 2005, clumps usually ranged from six to nine filters. To prepare a quarterly composite for isotopic gamma analyses for each AIRNET station, half-filters from the six or seven sampling periods at each site were combined during the quarter. Analysts dissolved these composites, separated them chemically, and then analyzed them for isotopes of americium, plutonium, and uranium using alpha spectroscopy. After a two-week collection period, water was distilled from the silica gel that had been used to collect water vapor in the field. A commercial laboratory used liquid scintillation spectrometry to analyze this distillate for tritium. All analytical procedures met the requirements of Title 40 Code of Federal Regulations (CFR) Part 61, Appendix B. The AIRNET quality assurance project plan provided a summary of the target minimum detectable activity for the biweekly and quarterly samples.

d. Laboratory Quality Control Samples

For 2005, the air sampling team and the analytical laboratories maintained a program of blank, spike, duplicate, and replicate analyses. This program provided information on the quality of the data received from analytical laboratories. These data were reviewed by technical staff and experienced chemists to ensure the sample data met all quality assurance requirements for the AIRNET program.

4. Ambient Air Concentrations

a. Explanation of Reported Concentrations

Tables 4-2 through 4-12 summarize the 2005 ambient air concentrations calculated from the field and analytical data. In the Data Supplement, Tables S4-1 through S4-9 provide data from individual sites. The number of measurements is normally equal to the number of samples analyzed. Measurements containing measurable amounts of the material of interest are those in which the value is greater than three times the standard deviation (s = standard deviation, or sigma) of the measurement’s uncertainty. The minimum detectable amounts are the levels that the instrumentation could detect under ideal conditions. All AIRNET concentrations and doses are total measurements without any type of regional background subtractions. However, the air concentrations include corrections for radioactivity from the filter material and the analytical process. The net concentrations are usually somewhat lower because small amounts of radioactivity are present in the filter material, the acids used to dissolve the filter, and the tracers added to determine recovery efficiencies. The net uncertainties include the variation added by correcting for the blank measurements.

Table 4-2
Airborne Long-lived Gross Alpha Concentrations for 2005 — Group Summaries

Station Grouping	Number of Biweekly Samples	Number of samples exceeding uncertainty >2s	>3s	95% Confidence Mean (fCi/m^3)	Interval[a] (fCi/m^3)	Maximum Annual Concentration Station	(fCi/m^3)
Regional	103	103	103	0.93	±0.09	01	1.04
Pueblo	76	76	76	0.92	±0.09	59	1.06
Perimeter	573	573	573	0.80	±0.03	18	1.54
Waste Site	208	208	208	0.84	±0.04	36	0.94
On-site	138	138	138	0.79	±0.06	20	0.90

[a] 95% confidence intervals are calculated using all calculated sample concentrations from every site within the group.

Table 4-3
Airborne Long-lived Gross Beta Concentrations for 2005 — Group Summaries

Station Grouping	Number of Biweekly Samples	Number of samples exceeding uncertainty		95% Confidence		Maximum Annual Concentration	
		>2s	>3s	Mean (fCi/m^3)	Interval[a] (fCi/m^3)	Station	(fCi/m^3)
Regional	103	103	103	16.3	±0.9	01	17.7
Pueblo	76	76	76	15.5	±1.0	70	16.7
Perimeter	573	573	573	14.9	±0.3	18	22.0
Waste Site	208	208	208	14.8	±0.5	50	16.0
On-site	138	138	138	14.9	±0.6	53	17.4

[a] 95% confidence intervals are calculated using all calculated sample concentrations from every site within the group.

Table 4-4
Airborne Tritium as Tritiated Water Concentrations for 2005 — Group Summaries

Station Grouping	Number of Biweekly Samples	Number of samples exceeding uncertainty		95% Confidence		Maximum Annual Concentration	
		>2s	>3s	Mean (pCi/m^3)	Interval[a] (pCi/m^3)	Station	(pCi/m^3)
Regional[b]	99	11	7	0.1	±0.25	03	0.4
Pueblo[b]	73	8	5	0.2	±0.30	59	0.3
Perimeter[b]	550	267	169	2.8	±0.26	39	8.3
Waste Site	199	178	160	127	±84	35	940
On-site	133	88	66	6.9	±4.6	25	62

[a] 95% confidence intervals are calculated using all calculated sample concentrations from every site within the group.

[b] EPA 40 CFR Concentration Limit is 1,500 pCi/m^3.

Table 4-5
Airborne Plutonium-238 Concentrations for 2005 — Group Summaries

Station Grouping	Number of Biweekly Samples	Number of samples exceeding uncertainty		95% Confidence		Maximum Annual Concentration	
		>2s	>3s	Mean (aCi/m^3)	Interval[a] (aCi/m^3)	Station	(aCi/m^3)
Regional[b]	16	0	0	-0.01	±0.31	03	0.3
Pueblo[b]	12	1	0	0.01	±0.56	70	0.3
Perimeter[b]	87	0	0	-0.07	±0.12	14	0.4
Waste Site	32	1	0	0.07	±0.31	50	0.7
On-site	22	0	0	0.03	±0.28	24	0.6

[a] 95% confidence intervals are calculated using all calculated sample concentrations from every site within the group.

[b] EPA 40 CFR Concentration Limit is 2,100 aCi/m^3.

Table 4-6
Airborne Plutonium-239,240 Concentrations for 2005 — Group Summaries

Station Grouping	Number of Biweekly Samples	Number of samples exceeding uncertainty		95% Confidence		Maximum Annual Concentration	
		>2s	>3s	Mean (aCi/m^3)	Interval[a] (aCi/m^3)	Station	(aCi/m^3)
Regional[b]	16	0	0	0.09	±0.28	56	0.3
Pueblo[b]	12	1	0	0.04	±0.44	70	0.4
Perimeter[b]	87	14	5	1.04	±0.97	66	15.9
Waste Site	32	14	5	2.77	±2.79	36	11.7
On-site	22	4	2	8.86	±12.36	20	47.4

[a] 95% confidence intervals are calculated using all calculated sample concentrations from every site within the group.

[b] EPA 40 CFR Concentration Limit is 2,000 aCi/m^3.

Table 4-7
Airborne Americium-241 Concentrations for 2005 — Group Summaries

Station Grouping	Number of Biweekly Samples	Number of samples exceeding uncertainty		95% Confidence		Maximum Annual Concentration	
		>2s	>3s	Mean (aCi/m^3)	Interval[a] (aCi/m^3)	Station	(aCi/m^3)
Regional[b]	16	2	0	0.07	±0.51	01	0.7
Pueblo[b]	12	1	0	-0.10	±0.43	70	0.0
Perimeter[b]	87	9	1	0.02	±0.21	68	1.1
Waste Site	32	7	0	0.25	±0.34	51	0.9
On-site	22	4	3	0.48	±1.25	20	4.5

[a] 95% confidence intervals are calculated using all calculated sample concentrations from every site within the group.

[b] EPA 40 CFR Concentration Limit is 1,900 aCi/m^3.

Table 4-8
Airborne Uranium-234 Concentrations for 2005 — Group Summaries

Station Grouping	Number of Biweekly Samples	Number of samples exceeding uncertainty		95% Confidence		Maximum Annual Concentration	
		>2s	>3s	Mean (aCi/m^3)	Interval[a] (aCi/m^3)	Station	(aCi/m^3)
Regional[b]	16	16	16	12.4	±3.5	03	20.3
Pueblo[b]	12	12	11	15.4	±7.7	59	27.3
Perimeter[b]	87	86	80	7.1	±1.9	32	39.5
Waste Site	32	31	30	13.9	±5.0	50	31.4
On-site	22	20	20	16.1	±15.9	20	59.0

[a] 95% confidence intervals are calculated using all calculated sample concentrations from every site within the group.

[b] EPA 40 CFR Concentration Limit is 7,700 aCi/m^3.

Table 4-9
Airborne Uranium-235 Concentrations for 2005 — Group Summaries

Station Grouping	Number of Biweekly Samples	Number of samples exceeding uncertainty >2s	Number of samples exceeding uncertainty >3s	95% Confidence Mean (aCi/m^3)	95% Confidence Interval[a] (aCi/m^3)	Maximum Annual Concentration Station	Maximum Annual Concentration (aCi/m^3)
Regional[b]	16	7	1	1.20	±0.55	56	2.0
Pueblo[b]	12	3	2	1.11	±0.88	59	2.6
Perimeter[b]	87	18	3	0.33	±0.26	32	3.1
Waste Site	32	7	2	0.75	±0.53	50	2.4
On-site	22	8	2	1.20	±1.08	20	4.5

[a] 95% confidence intervals are calculated using all calculated sample concentrations from every site within the group.

[b] EPA 40 CFR Concentration Limit is 7,100 aCi/m^3.

Table 4-10
Airborne Uranium-238 Concentrations for 2005 — Group Summaries

Station Grouping	Number of Biweekly Samples	Number of samples exceeding uncertainty >2s	Number of samples exceeding uncertainty >3s	95% Confidence Mean (aCi/m^3)	95% Confidence Interval[a] (aCi/m^3)	Maximum Annual Concentration Station	Maximum Annual Concentration (aCi/m^3)
Regional[b]	16	16	16	13.2	±3.4	03	19.8
Pueblo[b]	12	12	11	16.5	±7.3	59	29.1
Perimeter[b]	87	86	75	8.9	±2.2	32	44.9
Waste Site	32	32	29	13.6	±4.5	50	27.4
On-site	22	21	20	13.8	±6.6	20	28.9

[a] 95% confidence intervals are calculated using all calculated sample concentrations from every site within the group.

[b] EPA 40 CFR Concentration Limit is 8,300 aCi/m^3.

Table 4-11
Airborne Gamma-emitting Radionuclides Potentially Released by LANL Operations

Nuclide	Number of Biweekly Samples	Number of samples > MDA[a]	Mean Concentration (fCi/m^3)	Measured MDA as % of required MDA[b]
As-73	160	0	2.11	0.38
As-74	159	0	.005	0.004
Cd-109	160	0	-.006	0
Co-57	160	0	.004	0.006
Co-60	160	0	-.02	0
Cs-134	158	0	-.02	0
Cs-137	160	0	-.03	0
Mn-54	160	0	-.0001	0
Na-22	160	0	.01	0.9
Rb-83	160	0	-.001	0
Rb-86	160	0	-.003	0
Ru-103	160	0	-.015	0
Se-75	160	0	-.01	0
Zn-65	160	0	-.06	0

[a] Minimum detectable activity.

[b] Required MDA is for 0.5 mrem annual dose.

Table 4-12
Airborne Concentrations of Gamma-emitting Radionuclides That Occur Naturally in Measurable Quantities

Nuclide	Number of Biweekly Samples	Number of samples > MDA[a]	Mean[b] Concentration (fCi/m^3)
Be-7	160	160	94
Pb-210	160	0	31

[a] Minimum detectable activity.

[b] Measurements less than the MDA are not included in the average.

All data in this AIRNET section, whether in the tables or the text, that are expressed as a value plus or minus (±) another value represent a 95 percent confidence interval. Because these confidence intervals are calculated with data from multiple sites and throughout the year, they include not only random measurement and analytical errors but also seasonal and spatial variations. As such, the calculated 95 percent confidence intervals are overestimated for the average concentrations and probably represent confidence intervals that approach 100 percent. All ambient concentrations are activity concentrations per actual cubic meter of sampled air. Some values in the tables are negative. See Appendix B for an explanation of negative values.

Air concentrations greater than their 3s uncertainties are used to identify samples of interest or detected concentrations. Other multiples of uncertainties could be used, but 3s is consistent with the widely accepted practice of using 3s control limits for statistical quality control charts (Duncan 1986, Gilbert 1987). It also eliminates most of the false positives or detections that occur about 5 percent of the time at 2s, but less than 0.3 percent of the time at 3s.

b. Gross Alpha and Gross Beta Radioactivity

We use gross alpha and gross beta analyses primarily to: (1) evaluate general radiological air quality, (2) identify potential trends, and (3) detect sampling problems. If the gross analytical results appear to be elevated, then analyses for specific radionuclides may be performed to investigate a potential problem, such as an unplanned release.

The National Council on Radiation Protection and Measurements (NCRP) estimated the national average concentration of long-lived gross alpha activity in air to be two femtocuries (fCi)/m^3. Polonium-210, a decay product of radon, and other naturally occurring radionuclides are the primary sources of alpha activity (NCRP 1975, NCRP 1987). The NCRP also estimated national average concentration levels of long-lived gross beta activity in air to be 20 fCi/m^3. The presence of lead-210 and bismuth-210, also decay products of radon, and other naturally occurring radionuclides are the primary sources of this activity.

In 2005, we collected and analyzed approximately 1,100 air samples for gross alpha and gross beta activity. The annual mean for all of the stations is about half of the NCRP's estimated average for gross alpha concentrations (Table 4-2). At least two factors contribute to these lower concentrations: (1) the use of actual sampled air volumes instead of standard temperature and pressure volumes, and (2) the burial of alpha emitters in the filter that are not measured by front-face counting. Gross alpha activity is dependent on variations in natural conditions, such as atmospheric pressure, atmospheric mixing, temperature, and soil moisture.

Table 4-3 shows gross beta concentrations within and around LANL. These data show variability similar to the gross alpha concentrations. The annual average is below the NCRP-estimated national average, but the gross beta measurements include little if any lead-210 because of its low-energy beta emission. We calculate the gross beta measurements on the actual sampled air volumes instead of standard temperature and pressure volumes. The primary source of measured gross beta activity in the particulate matter samples is the bismuth-210 in the radon-222 decay chain.

Figures 4-4 and 4-5 show the temporal variability of gross alpha and beta activities in air, respectively. Variability among sites within AIRNET is usually much less than variability over time. For example, in winter, at lower elevations around LANL, the radon may be trapped below an inversion layer, resulting in higher levels of radon near the ground, and therefore higher gross alpha and beta count rates.

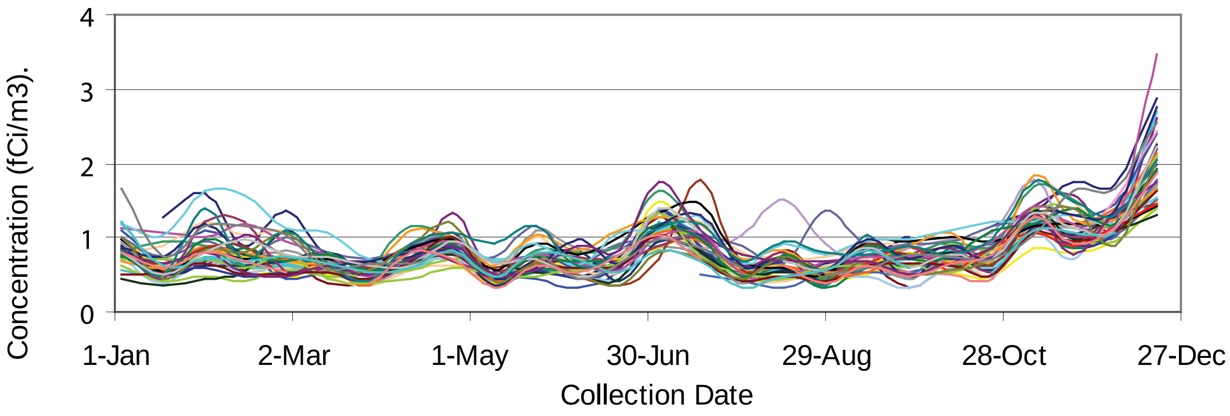

Figure 4-4. **Gross alpha measurements (fCi/m3) for all sampling sites by date collected.**

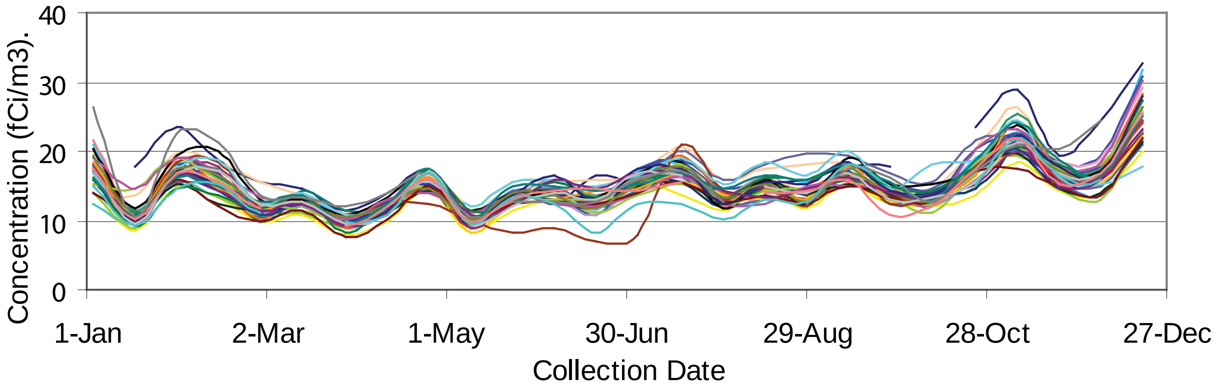

Figure 4-5. **Gross beta measurements (fCi/m3) for all sampling sites by date collected.**

c. Tritium

Tritium is present in the environment primarily as the result of nuclear weapons tests and natural production by cosmogenic processes (Eisenbud and Gesell 1997). We measure the tritium in water (HTO or tritiated water) because the dose impact is about 14,000 times higher than if it were hydrogen gas (HT or tritium) (DOE 1988b).

Water-vapor concentrations in the air and tritium concentrations in the water vapor were used to calculate ambient levels of tritium. Corrections for blanks, bound water in the silica gel, and isotopic distillation effects are included in this calculation (ESP 2002).

The annual concentrations of tritium for 2005 at the regional and pueblo stations were not significantly greater than zero (Table 4-4). The average concentration of tritium for the perimeter samplers was significantly greater than zero, as were the average concentrations for the on-site groups. The highest concentrations were measured at the TA-54 waste site in Area G. These data indicate that LANL release very low but measurable amounts of tritium. All annual mean concentrations at all sampling sites were well below the applicable EPA and DOE guidelines.

Figure 4-6 shows the measured stack emissions at TA-21 and also maximum and average off-site AIRNET measurements in nearby and generally downwind east Los Alamos.

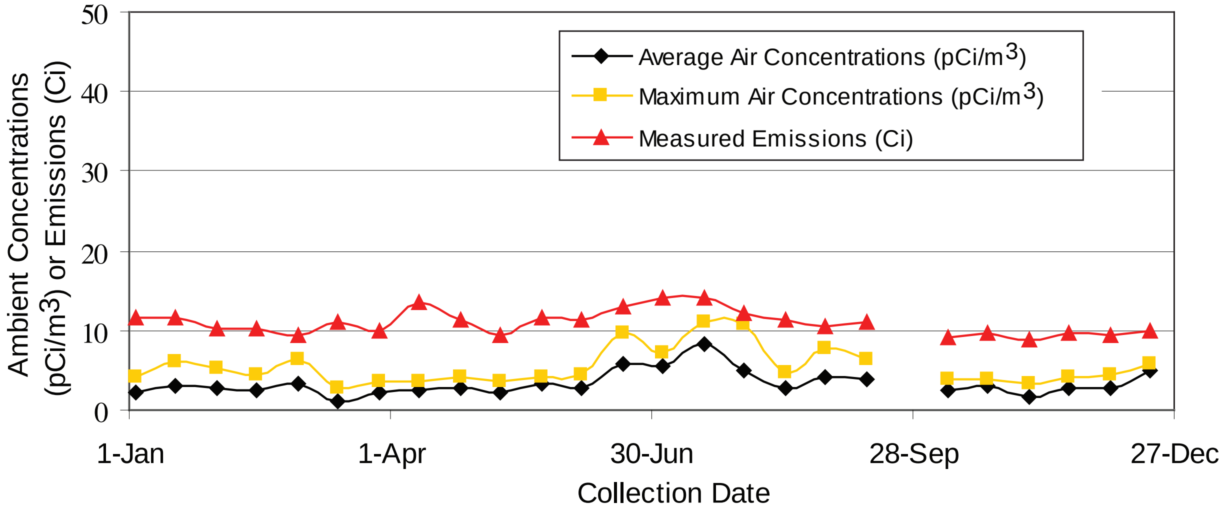

Figure 4-6. **Tritium oxide stack emissions at TA-21 and ambient concentrations in east Los Alamos.**

The highest off-site annual tritium concentration in 2005, 8.3 picocuries (pCi)/m^3 at station 39, was near TA-16, a known source of tritium. This concentration is equivalent to about 0.5 percent of the EPA public dose limit of 1,500 pCi/m^3. Emissions from TA-16 seldom caused concentrations to exceed investigation levels as described in section A.5 of this chapter (investigation levels are set at values of 5-yr averages plus 3s). We measured elevated tritium concentrations at a number of on-site stations, with the highest annual concentration (940 pCi/m^3) at TA-54, Area G. This annual mean concentration, 950 pCi/m^3, is well below the applicable limits for worker exposure of 20,000,000 pCi/m^3 and is measured at a location near shafts containing tritium-contaminated waste.

d. Plutonium

While plutonium occurs naturally at extremely low concentrations from cosmic radiation and spontaneous fission (Eisenbud and Gesell 1997), this element is not naturally present in measurable quantities in the ambient air. All measurable sources in air are from plutonium research-and-development activities, nuclear-weapons production and testing, the nuclear fuel cycle, and other related activities. With few exceptions, worldwide fallout from atmospheric testing of nuclear explosives is the primary source of plutonium in ambient air.

Table 4-5 summarizes the plutonium-238 data for 2005. No concentrations of plutonium-238 more than 3s from zero were measured at any station in any quarter. The highest quarterly concentration was 2.2 ±2.8 aCi/m^3, which, because the uncertainty exceeds the value, is consistent with zero.

No detectable concentrations of plutonium-239, 240 greater than 3s were found at any of the regional or pueblo samplers (Table 4-6). Five perimeter quarterly concentrations were above their 3s uncertainties, three of which were collected at station 66 (Los Alamos Lodge-South). The annual mean concentration at this location was 16 aCi/m^3, or about 1 percent of the EPA public dose limit. These higher ambient concentrations are from historical activities at LANL's old main Technical Area (TA-1) that deposited plutonium on the hillside below the Los Alamos Lodge. The other two perimeter concentrations above 3s were measured at station 68 near the Los Alamos Airport and are due to remediation work at TA-21.

The on-site station at TA-21 (station 20) exceeded 3s for its quarterly concentrations for two quarters – also due to the work at TA-21. Finally, five quarterly concentrations at Area G exceeded 3s. All on-site and waste site concentrations were substantially below 1 percent of the DOE DAC for workplace exposure.

e. Americium-241

As with the plutonium isotopes, americium is present in very low concentrations in the environment. No detected concentrations of americium-241 were measured at any of the regional or pueblo sampling stations (Table 4-7).

One perimeter (at station 11) and three on-site quarterly samples (all at station 20, see section above on plutonium) with a concentration of americium-241 greater than 3s were measured. Both the off-site and on-site concentrations were significantly less than 1 percent of the public and worker limits, respectively.

f. Uranium

Three isotopes of uranium are normally found in nature: uranium-234, uranium-235, and uranium-238. In natural uranium, relative isotopic abundances are constant and well characterized. Uranium-238 and uranium-234 are essentially in radioactive equilibrium, with a measured uranium-238 to uranium-234 isotopic activity ratio of 0.993 (as calculated from Walker et al., 1989). Comparisons of isotopic concentrations are used to estimate LANL contributions because known LANL emissions in the past 50 years are not of natural uranium, but enriched (EU–enriched in uranium-234 and -235) or depleted (DU–depleted of uranium-234 and -235).

All annual mean concentrations of the three uranium isotopes were well below 1 percent of the applicable EPA and DOE guidelines (Tables 4-8 through 4-10). The highest annual uranium concentrations were at locations with high dust levels from local soil disturbances, such as dirt roads at the Los Alamos County Landfill and LANL's TA-54, Area G. The regional and pueblo groupings had higher average concentrations of uranium isotopes than the perimeter group because of increased particulate matter concentrations associated with unpaved roads, unpaved parking lots, and other soil disturbances, such as construction activities and grazing, but not any known man-made sources of uranium.

During 2005, five samples downwind of the firing sites detected DU, as shown in Figure 4-7. Firing sites use DU in tests and so there is DU dust in the surrounding areas. These excess uranium-238 concentrations were identified by statistically comparing the uranium-234 and uranium-238 concentrations. If the concentrations in a sample were more than 3s apart, the sample was considered to have significant concentrations of EU or DU (see Section A.6). We measured one instance of EU during 2005 at station 20 near the remediation work at TA-21. EU remaining from Manhattan era work is expected in this area.

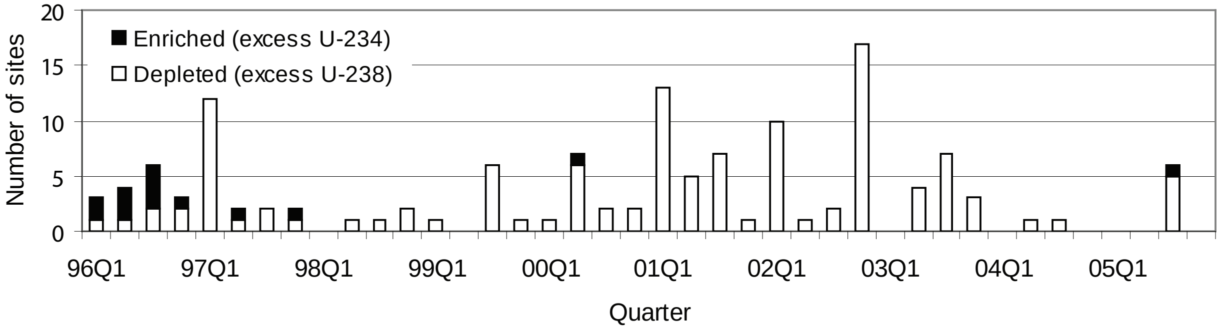

Figure 4-7. **AIRNET sites with excess isotopic uranium.**

g. Gamma Spectroscopy Measurements

In 2005, the air sampling team requested gamma spectroscopy measurements (Tables 4-11 and 4-12) on biweekly filters grouped across sites for a single sampling period, which are identified as "clumps." We investigated the measurement of any analyte (listed in Table 4-11) above its minimum detectable amount, but we did not investigate detectable quantities of beryllium-7, potassium-40, and lead-210, which are natural radionuclides normally present in measurable concentrations. Any other measurable concentration was highly unlikely unless an actual release occurred. In 2005, beryllium-7 was routinely detected.

5. Investigation of Elevated Air Concentrations

Two action levels have been established to determine the potential occurrence of an unplanned release: "investigation" and "alert." "Investigation" levels are based on historical measurements and are designed to indicate that an air concentration is higher than expected. These levels are set at values equal to a 5-yr rolling average plus 3s. "Alert" levels are based on dose and require a more thorough, immediate follow-up.

When a measured air concentration exceeds an action level, the air quality group verifies that the calculations were done correctly and that the sampled air concentrations are likely to be representative, i.e., that no cross contamination has taken place. Next, we work with personnel from the appropriate operations to assess potential sources and possible mitigation for the elevated concentrations. In 2005, no air sampling values exceeded alert action levels.

Some investigations were related to elevated tritium concentrations; others were of elevated uranium levels caused by wind. A number of investigations, discussed in the previous sections, were caused by the remediation work at TA-21.

a. El Rancho Plutonium-238 Investigation Concluded

An analytically rejected and unexpected value was noted at the El Rancho station in 2004. As part of the investigation into this occurrence, we reevaluated all plutonium measurements over the last two years. In 2003, an unexpected detection of plutonium at the same station had been rejected. We initiated a more thorough investigation: a re-analysis of samples from the same time periods at the same location, as well as a suite of swipes taken on the AIRNET housing. All negative results confirmed our suspicion that there was no real plutonium contamination at this site.

6. Long-Term Trends

a. Uranium

Even though the annual and quarterly concentrations of uranium isotopes vary, peak concentrations for all three isotopes occur during the second quarter of each year (Figure 4-8). For years, the uranium-238 concentrations have been consistently higher than the uranium-234 concentrations, indicating the presence of DU. Figure 4-7 shows that DU has been detected regularly.

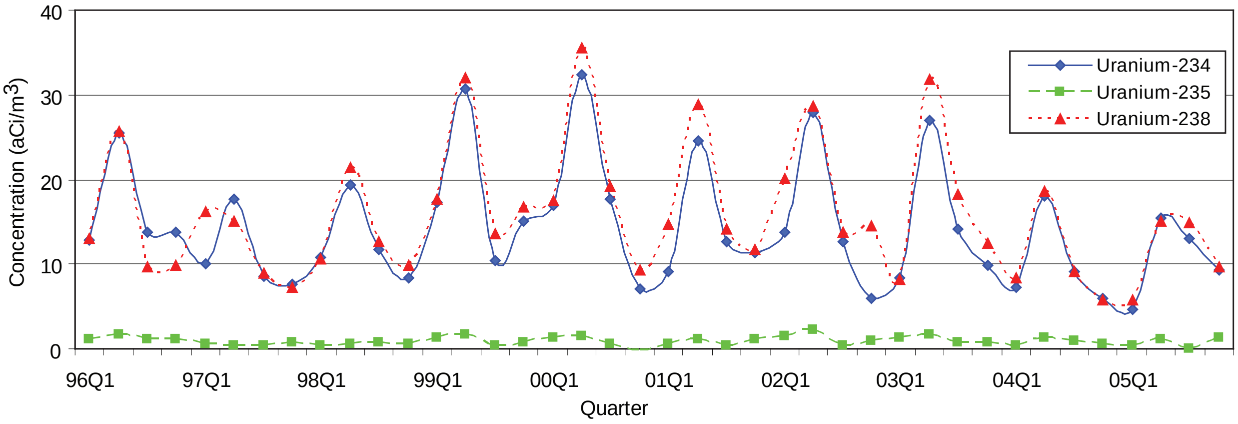

Figure 4-8. AIRNET quarterly uranium concentrations (network-wide excluding site at TA-36).

All of the samples with DU were collected on Laboratory property or within Los Alamos County. From 1995 to 2000, 15 quarterly composite samples with DU were collected off-site. From 2001–2003, 23 off site DU samples were collected—a notable increase since the 2000 Cerro Grande fire. The ongoing drought in the years following the fire has kept DU and other dust ready for resuspension. However, in 2004, rainfall was substantially above the levels of preceding years, and no DU was detected off-site. In 2005 rainfall was low again; one EU and five DU detections were reported. Off-site concentrations of DU are comparable to, or less than, historical natural uranium concentrations.

b. Plutonium and Americium

Only two quarterly measurements during the last nine years for the regional and pueblo samples were above their 3s analytical uncertainties. However, on-site measurements of plutonium-238, plutonium-239, and americium-241 are clearly higher for the TA-21 and TA-54, Area G, sampling stations, where about one-third of the measurements are detected concentrations of these radionuclides. Perimeter samplers are somewhere in between, with occasional samples having detected concentrations. Figures 4-9, 4-10, and 4-11 are graphs of the annual concentrations by isotope and general station locations. The remediation activities at TA-21 are the cause for the increase in the on-site americium-241 and plutonium-239 annual averages.

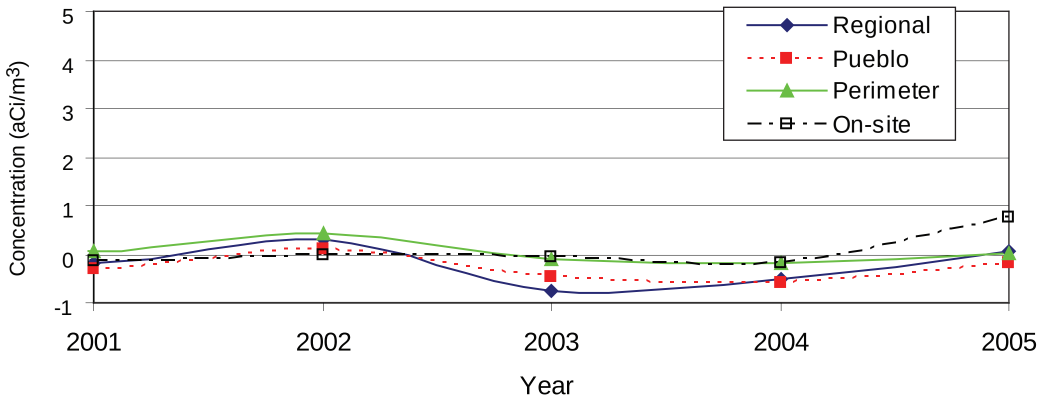

Figure 4-9. Am-241 concentration trends.

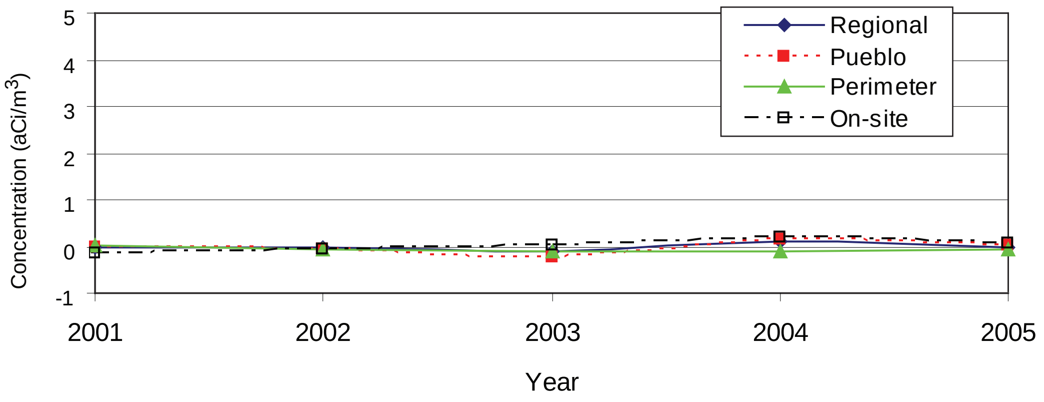

Figure 4-10. Pu-238 concentration trends.

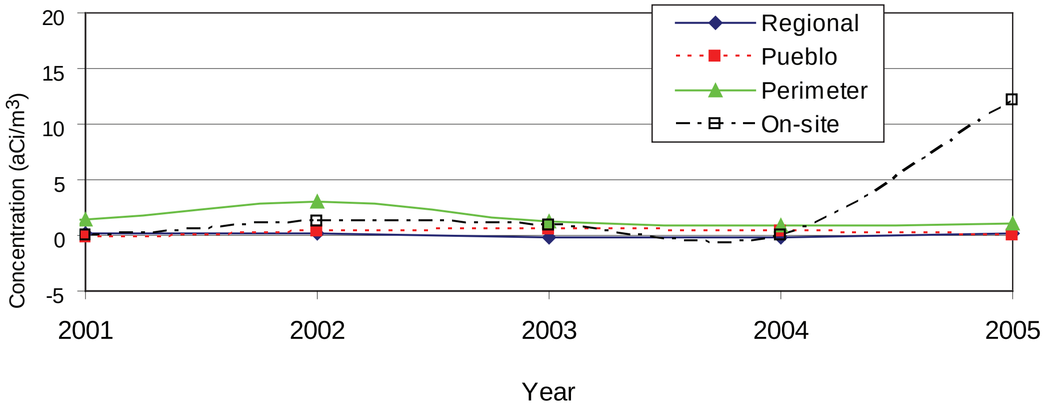

Figure 4-11. Pu-239,240 concentration trends.

Annual average concentrations for plutonium-239 and americium-241 are above zero for the TA-54, Area G sampling stations. Concentrations at the TA-54 samplers have been low for several years, except for the soil-screening operation in 2002 (Figure 4-12) (ESP 2002). The average concentrations for the other sample groupings vary but remain near zero, with occasional samples and/or locations having detected concentrations.

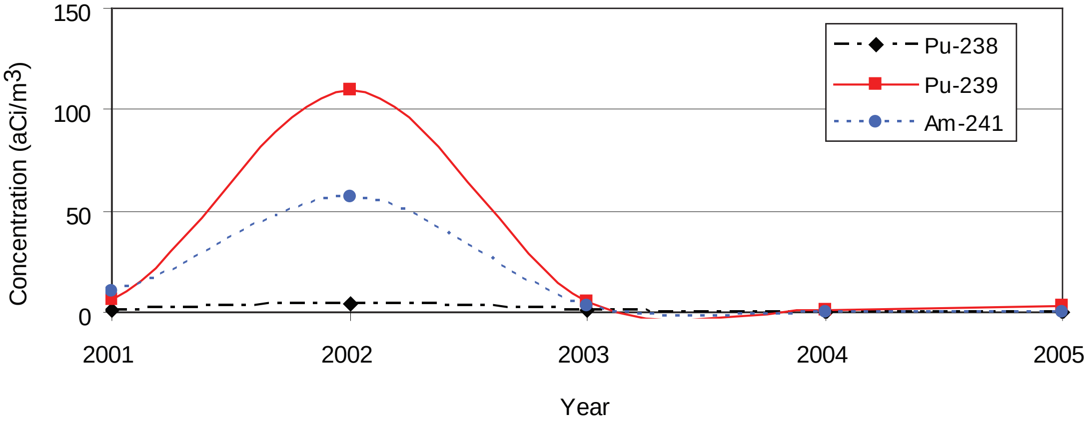

Figure 4-12. Americium and plutonium concentration trends for TA-54, Area G.

c. Tritium

Unlike other radionuclides, tritium concentrations are strongly influenced by current operations and emissions with no distinctive trends over this period. The trend in concentrations at Area G has been down over the last five years (Figure 4-13). With fewer decommissioning and decontamination activities at TA-21 during 2005, we currently see lower ambient values nearby.

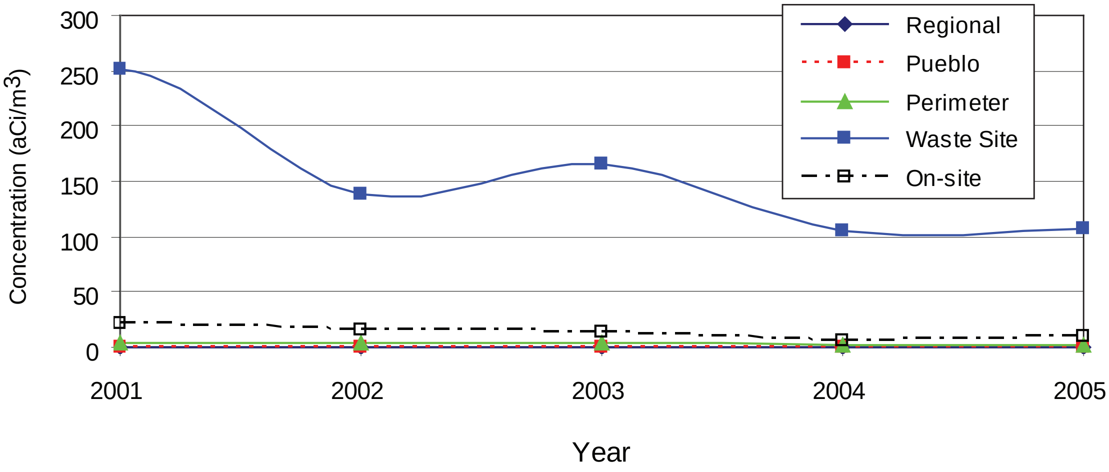

Figure 4-13. Tritium concentration trends.

B. STACK SAMPLING FOR RADIONUCLIDES

1. Introduction

Radioactive materials are an integral part of many activities at LANL. Some operations involving these materials may be vented to the environment through a stack or other forced air release point. Limits and requirements for these emissions are put forth in the Clean Air Act, specifically the National Emission Standards for Hazardous

Air Pollutants (Radionuclides), referred to as Rad-NESHAP. Under Rad-NESHAP regulations, the LANL site is limited to 10 millirem per year to the maximally exposed off-site receptor. Members of the Rad-NESHAP team at LANL evaluate Laboratory operations to determine impacts on the public and the environment. If this evaluation shows that emissions from a stack may potentially result in a member of the public receiving as much as 0.1 mrem in a year, LANL must sample the stack in accordance with Title 40 CFR 61, Subpart H, "National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities" (EPA 1989). During 2005, we identified 27 stacks meeting this criterion. One additional sampling system is in place to meet DOE requirements for nuclear facilities prescribed in their respective technical or operational safety requirements. Where sampling is not required, emissions are estimated using engineering calculations and radionuclide materials usage information. The 2005 Rad-NESHAP compliance report contains a complete description of radionuclide emissions from LANL (RN 2005).

2. Sampling Methodology

In 2005, we continuously sampled 28 stacks for the emission of radioactive material to the ambient air. LANL categorizes its radioactive stack emissions into one of four types: (1) particulate matter, (2) vaporous activation products, (3) tritium, and (4) gaseous mixed activation products (GMAP). For each of these emission types, LANL employs the appropriate sampling method, as described below.

Emissions of radioactive particulate matter generated by operations at facilities, such as the Chemistry and Metallurgy Research Building and the TA-55 Plutonium Facility, are sampled using a glass-fiber filter. A continuous sample of stack air is pulled through a filter that captures small particles of radioactive material. These samples are collected weekly and shipped to an off-site analytical laboratory. This laboratory uses gross alpha/beta counting and gamma spectroscopy to identify any increase in emissions and to identify short-lived radioactive materials. Every six months, the laboratory composites these samples and analyzes them to determine the total activity of materials, such as uranium-234, -235, and -238, plutonium-238 and -239,240, and americium-241. These isotopic data are used to calculate emissions from each stack for the six-month period.

A charcoal cartridge samples emissions of vapors, such as bromine-82, and highly volatile compounds, such as selenium-75, generated by operations at the Los Alamos Neutron Science Center (LANSCE) and hot cell activities at the Chemistry and Metallurgy Research Building and TA-48. A continuous sample of stack air is pulled through a charcoal cartridge that adsorbs vaporous emissions of radionuclides. This charcoal cartridge is mounted downstream of a glass-fiber filter (discussed above) that removes any particulates from this sample media. Gamma spectroscopy determines the amount and identity of the radionuclide(s) present in the cartridge.

We measure tritium emissions from LANL's tritium facilities with a collection device known as a bubbler. This device enables LANL to determine not only the total amount of tritium released but also whether it is in the elemental (HT) or oxide (HTO) form. The bubbler pulls a continuous sample of air from the stack, which is then "bubbled" through three sequential vials containing ethylene glycol. The ethylene glycol collects the water vapor from the sample of air, including any tritium that may be part of a water molecule (HTO). "Bubbling" through these three vials removes essentially all HTO from the air, leaving only elemental tritium. The air is passed through a palladium catalyst that converts the elemental tritium to HTO. The sample is pulled through three additional vials containing ethylene glycol, which collect the newly formed HTO. Liquid scintillation counting determines the amount of HTO and HT by analyzing the ethylene glycol for the presence of tritium.

In previous years, stacks at LANSCE were monitored for tritium. After an historical evaluation of HTO emissions from LANSCE in 2001, we discontinued sampling tritium following the July 2001 report period based on the low historical emissions of HTO from TA-53 and the low relative contribution of tritium to the off-site dose from TA-53 emissions. Emissions of tritium reported in 2005 from LANSCE are based on 2001 tritium generation rates.

We measure GMAP emissions from LANSCE activities using real-time monitoring data. A sample of stack air is pulled through an ionization chamber that measures the total amount of radioactivity in the sample. Gamma spectroscopy and decay curves were used to identify specific radioisotopes.

3. Sampling Procedures and Data Analysis

a. Sampling and Analysis

Analytical methods used comply with EPA requirements (40 CFR 61, Appendix B, Method 114). See Section F in this chapter for the results of analytical quality assurance measurements. General discussions on the sampling and analysis methods for each of LANL's emissions follow.

b. Particulate Matter Emissions

We removed and replaced the glass-fiber filters that sample facilities with significant potential for radioactive particulate emissions weekly and shipped them to an off-site analytical laboratory. Prior to shipping, each sample was screened with a hand-held instrument to determine if there were any unusually high levels of alpha or beta radioactivity. The laboratory performed analyses for the presence of alpha and beta radioactivity after the sample had been allowed to decay for approximately one week. In addition to alpha and beta analyses, the laboratory performed gamma spectroscopy analysis to identify specific isotopes in the sample.

The glass-fiber filters were composited every six months for radiochemical analysis because gross alpha/beta counting cannot identify specific radionuclides. We used the data from these composite analyses to quantify emissions of radionuclides, such as the isotopes of uranium and plutonium. The Rad-NESHAP team compared the results of the isotopic analysis with gross activity measurements to ensure that the requested analyses (e.g., uranium-234, -235, and -238; and plutonium-238 and -239,240, etc.) identified all significant activity in the composites.

For particulate filters from the LANSCE accelerator facility, the analytical laboratory only performs gamma spectroscopy analyses based on the anticipated suite of emissions from this facility.

c. Vaporous Activation Products Emissions

We removed and replaced the charcoal cartridges that sample facilities with the potential for significant vaporous activation products emissions weekly. Samples were shipped to the off-site analytical laboratory where gamma spectroscopy identified and quantified the presence of vaporous radioactive isotopes.

d. Tritium Emissions

Tritium bubbler samples, used to sample facilities with the potential for significant elemental and oxide tritium emissions, were collected and transported weekly to LANL's Health Physics Analytical Laboratory. The Health Physics Analytical Laboratory added an aliquot of each sample to a liquid scintillation fluid and determined the amount of tritium in each vial by liquid scintillation counting.

e. GMAP Emissions

Continuous monitoring was used, rather than sample collection with off-line analysis, to record and report GMAP emissions for two reasons. First, the nature of the emissions is such that standard filter paper and charcoal filters will not collect the radionuclides of interest. Second, the half-lives of these radionuclides are so short that the activity would decay away during transit before any sample could be analyzed off-line. The GMAP monitoring system includes a flow-through ionization chamber in series with a gamma spectroscopy system. Total GMAP emissions were measured with the ionization chamber. The real-time current this ionization chamber measured was recorded on a strip chart, and the total amount of charge collected in the chamber over the entire beam operating cycle was integrated on a daily basis. The gamma spectroscopy system analyzed the composition of these GMAP emissions. Using decay curves and energy spectra to identify the various radionuclides, we determined the relative composition of the emissions. Decay curves were typically taken one to three times per week based on accelerator operational parameters. When major ventilation configuration changes were made at LANSCE, new decay curves and energy spectra were recorded.

4. Analytical Results

Measurements of LANL stack emissions during 2005 totaled approximately 19,100 Ci. Of this total, tritium emissions composed approximately 704 Ci, and air activation products from LANSCE stacks contributed nearly 18,400 Ci. Combined airborne emissions of materials, such as plutonium, uranium, americium, and thorium, were less than 0.00002 Ci. Emissions of particulate/vapor activation products (P/VAP) were less than 0.02 Ci.

Table 4-13 provides detailed emissions data for LANL buildings with sampled stacks.

Table 4-14 provides a detailed listing of the constituent radionuclides in the groupings of GMAP and P/VAP.

Table 4-15 presents the half-lives of the radionuclides typically emitted by LANL. During 2005, LANSCE facility (TA-53) non-point source emissions of activated air comprised approximately 530 Ci carbon-11 and 22 Ci argon-41. TA-18, usually a source of non-point emissions, had no operations in 2005.

Table 4-13
Airborne Radioactive Emissions from LANL Buildings with Sampled Stacks in 2005 (Ci)

TA-Bldg	H-3[a]	Am-241	Pu[b]	U[c]	Th[d]	P/VAP[e]	GMAP[f]	Sr-90[g]
TA-03-029		1.32E-07	4.39E-06	9.84E-06	3.86E-07	2.17E-05		3.86E-07
TA-03-102				4.42E-09				
TA-16-205	3.70E+02							
TA-21-155	2.29E+02							
TA-21-209	6.12E+01							
TA-48-001				6.52E-09		3.01E-03		
TA-50-001								
TA-50-037								
TA-50-069		7.61E-10	5.30E-09		1.21E-09			
TA-53-003	6.72E-01						1.83E+00	
TA-53-007	7.20E+00					1.60E-02	1.84E+04	
TA-55-004	4.45E+01			1.57E-07	3.35E-08			
Total[h]	7.12E+02	1.32E-07	4.39E-06	1.00E-05	4.21E-07	1.90E-02	1.89E+04[i]	3.86E-07

[a] Includes both gaseous and oxide forms of tritium.

[b] Includes Pu-238, Pu-239, and Pu-240.

[c] Includes U-234, U-235, and U-238. Does NOT include radioactive progeny of U-238.

[d] Includes Th-228, Th-230, and Th-232.

[e] P/VAP–Particulate/vapor activation products (with measured radionuclides and short-lived radioactive progeny).

[f] GMAP–Gaseous mixed activation products.

[g] Strontium-90 values include yttrium-90 short-lived radioactive progeny.

[h] Some differences may occur because of rounding.

[i] Total for GMAP includes 555 curies released from diffuse sources at TA-53.

5. Long-Term Trends

Figures 4-14 through 4-17 present radioactive emissions from sampled LANL stacks. These figures illustrate trends in measured emissions for plutonium, uranium, tritium, and GMAP emissions, respectively. As the figures demonstrate, emissions from plutonium and uranium isotopes stayed relatively steady since 2000, varying slightly each year but staying in the low-microcurie range. Tritium emissions were about the same in 2005 as in 2004. GMAP emissions are quite high relative to recent years, and are explained more below. Note that with the suspension of work activity in July 2004, most operations ceased for long periods of time. Operations ramped up to full production in late 2004 and into 2005. One side effect of this work suspension was a drop in air emissions from these operations in 2004, as noted by the tritium, uranium, and plutonium emissions plots. For tritium, uranium, and plutonium emissions, the 2005 level is the anticipated steady-state level for the next few years.

Table 4-14
Detailed Listing of Activation Products Released from Sampled LANL Stacks in 2005 (Ci)

TA-Building	Nuclide	Emission
TA-03-0029	Ga-68	1.09E-05
TA-03-0029	Ge-68	1.09E-05
TA-48-0001	Ga-68	1.50E-03
TA-48-0001	Ge-68	1.50E-03
TA-48-0001	Se-75	1.42E-05
TA-53-0003	C-11	1.81E+00
TA-53-0003	Ar-41	2.26E-02
TA-53-0007	Ar-41	2.76E+01
TA-53-0007	As-73	1.05E-05
TA-53-0007	Be-7	6.96E-06
TA-53-0007	Br-76	3.23E-03
TA-53-0007	Br-77	2.41E-04
TA-53-0007	Br-82	3.56E-03
TA-53-0007	C-10	8.98E-01
TA-53-0007	C-11	1.56E+04
TA-53-0007	Hg-197	4.41E-03
TA-53-0007	Hg-197m	4.41E-03
TA-53-0007	N-13	4.36E+01
TA-53-0007	N-16	5.31E-01
TA-53-0007	Na-24	4.62E-05
TA-53-0007	O-14	2.33E+01
TA-53-0007	O-15	2.73E+03
TA-53-0007	Os-191	4.99E-05
TA-53-0007	Se-75	1.45E-05

Table 4-15
Radionuclide Half-Lives

Nuclide	Half-Life
H-3	12.3 yr
Be-7	53.4 d
C-10	19.3 s
C-11	20.5 min
N-13	10.0 min
N-16	7.13 s
O-14	70.6 s
O-15	122.2 s
Na-24	14.96 h
K-40	1,277,000,000 yr
Ar-41	1.83 h
Co-60	5.3 yr
Ga-68	1.1 d
Ge-68	271 d
As-73	80.3 d
Br-76	16 h
Br-77	2.4 d
Br-82	1.47 d
Se-75	119.8 d
Sr-90	28.6 yr
Cs-137	30.2 yr
Os-191	15.4 d
Hg-197	2.67 d
Hg-197m	23.8 h
U-234	244,500 yr
U-235	703,800,000 yr
U-238	4,468,000,000 yr
Pu-238	87.7 yr
Pu-239	24,131 yr
Pu-240	6,569 yr
Pu-241	14.4 yr
Am-241	432 yr

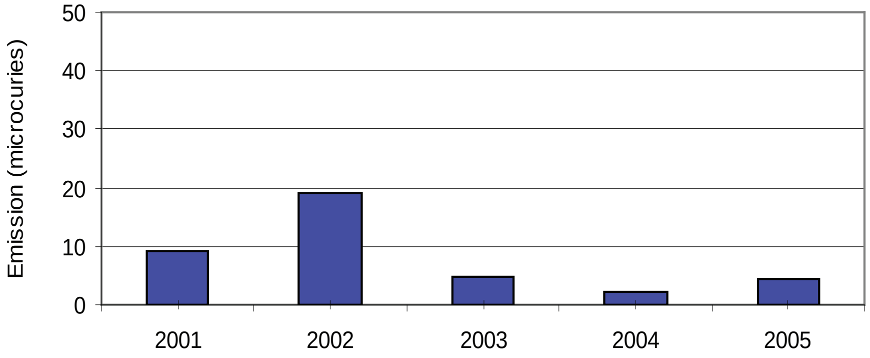

Figure 4-14. **Plutonium emissions from sampled LANL stacks.**

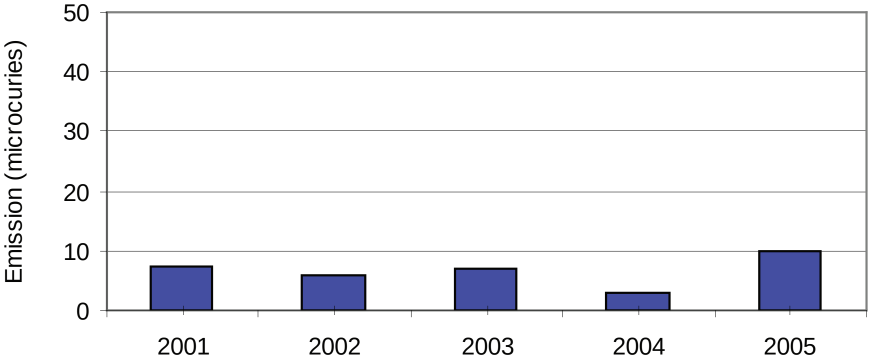

Figure 4-15. **Uranium emissions from sampled LANL stacks.**

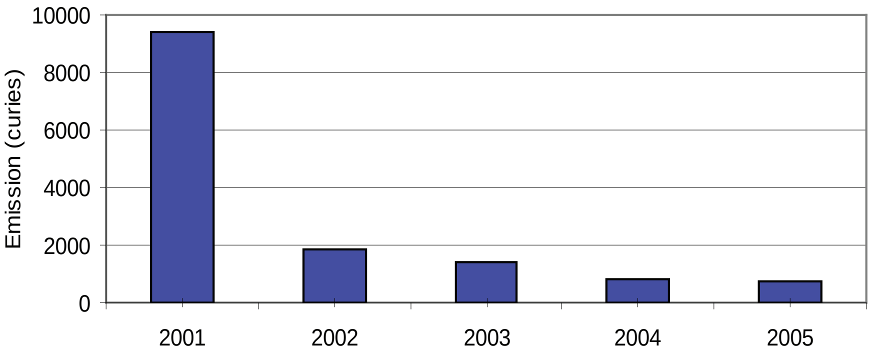

Figure 4-16. **Tritium emissions from sampled LANL stacks.**

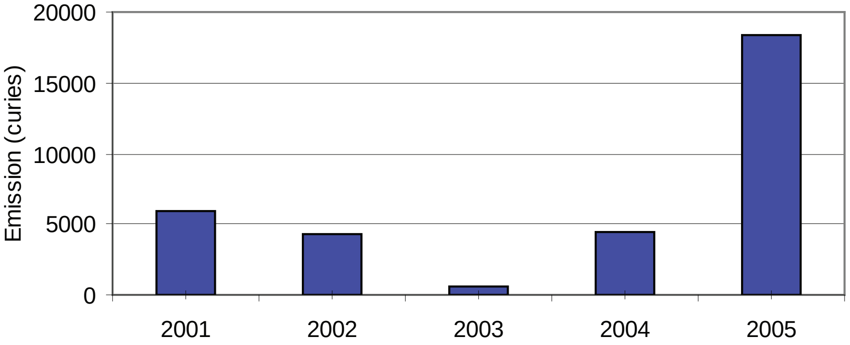

Figure 4-17. **GMAP Emissions from sampled LANL stacks.**

Site-wide tritium emissions are staying low due to the consolidation of most tritium operations at TA-16. In 2005, source removal activities were completed at building 21-155. Similar activities were ongoing at building 21-209 and should be completed in 2006. Continued emissions from these facilities result from off gassing of contaminated equipment remaining in the building. Monitoring will continue until the potential emissions levels from these buildings are fully characterized. As tritium-contaminated systems are dismantled and prepared for removal and disposal, increased releases of tritium are expected. However, overall long-term emissions from these facilities will decrease following decontamination and decommissioning.

The large spike in tritium emissions from 2001 is due to a single release of 7600 curies of tritium gas (HT) on January 31, 2001 (when the valve on a legacy waste bottle failed during handling and vented the contents). No such large-scale releases have occurred since that time. The release in 2001, as well as routine operational releases before and since that time, was well below regulatory limits.

In 2005, LANSCE operated in the same configuration as 2001–2004, with continuous beam operations to the 1L Target and the Lujan Neutron Scattering Center causing the majority of radioactive air emissions. Operations to the 1L Target took place from January through December, with a four-week maintenance outage in July. Emissions from this target area were greatly elevated over 2004 levels for a variety of reasons. First, the beam operation time was higher: almost 10 months of beam delivery in 2005 versus less than 4 months in 2004. Second, as the target coolant water filtration system became saturated over time, the buildup of pollutants in the water system increased the rate of radioactive gas generation over the course of the run cycle. Finally, a hairline crack in a valve at the inlet of the emissions controls system resulted in a significant portion of the radioactive gases bypassing this control system and venting straight to the stack.

The emissions control system at the LANSCE 1L Target is a “delay line,” which retains the short-lived activation products for a short time before release out the stack. This time interval allows decay of the short-lived radionuclides to non-radioactive components. The cracked valve at the delay line inlet was fixed in late November 2005. The result was an immediate drop in the emissions rate back to predicted levels. It is anticipated that emissions in 2006 will be similar to the 2002–2004 levels. The overall total emissions from 2005 remained below the Rad-NESAHP regulatory limits described above.

Figure 4-18 shows the individual contribution of each of these emission types to total LANL emissions. It clearly shows that GMAP emissions and tritium emissions make up the vast majority of radioactive stack emissions. This plot does not directly relate to off-site dose, because some radionuclides have a higher dose impact per curie released than others. GMAP and tritium remain the highest contributors to the total curies released. These gas-phase nuclides are not easily removed from an exhaust stack air stream by standard control techniques, such as filtration. GMAP and tritium emissions continue to fluctuate as the major emissions type; tritium cleanup operations and LANSCE operations vary from year to year. GMAP emissions remain the greatest source of off-site dose from the airborne pathway because of the close proximity of the LANSCE facility to the LANL site boundary.

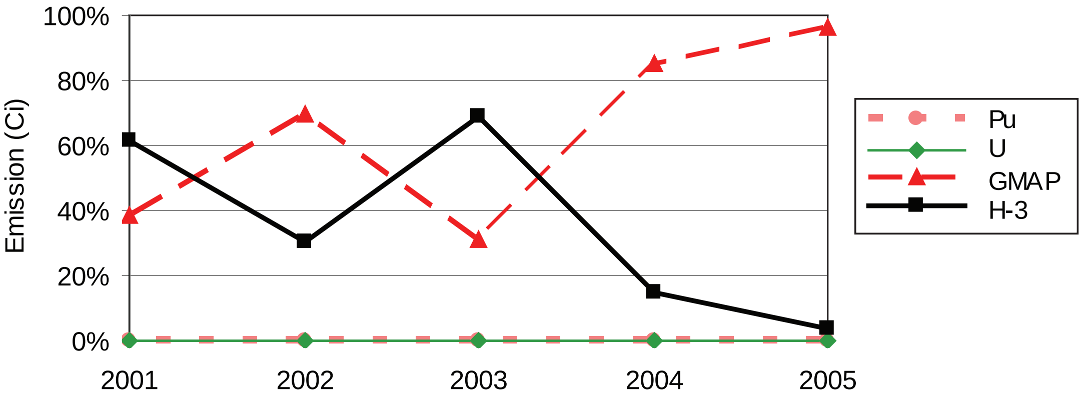

Figure 4-18. **Fraction of total annual stack emissions resulting from plutonium, uranium, tritium, and GMAP.**

C. GAMMA AND NEUTRON RADIATION MONITORING PROGRAM

1. Introduction

We monitor gamma and neutron radiation in the environment—that is, outside of the workplace—according to the criteria specified in McNaughton et al. (2000). Naturally occurring radiation originates from terrestrial and cosmic sources. It is extremely difficult to distinguish man-made sources from the natural background because the natural radiation doses are generally much larger than those from man-made sources. The dose rate from natural terrestrial and cosmic sources measured by the dosimeters (does not include radon and internal sources) varies from approximately 100 to 200 mrem/yr.

2. Monitoring Network

a. Dosimeter Locations

In an attempt to distinguish any impact from LANL operations on the public, we located 90 thermoluminescent dosimeter (TLD) stations around LANL and in surrounding communities (Figures 4-2 and 4-19).

b. Neutron Dosimeters

We monitor potential neutron doses with 52 albedo TLD stations. Albedo dosimeters are sensitive to neutrons and use a hydrogenous material that causes neutron backscatter to simulate the human body.

c. Neutron Background

Natural cosmic rays result in a neutron background dose of approximately 10 mrem/yr. However, at stations with no LANL contribution, the neutron dosimeters record a dose of approximately 2 mrem/yr, because the environmental dosimeters are calibrated with a D_2O-moderated neutron source with a different energy spectrum from cosmic-ray neutrons. Therefore, a neutron reading of 2 mrem/yr is a normal background reading.

3. Quality Assurance

Division operating procedures outline the quality assurance/quality control (QA/QC) protocols. In the air sampling group, guidance is provided by the group's quality management plan (see http://www.lanl.gov/community/environment/air/). The Health Physics Measurements Group (HSR-4) calibration laboratory calibrates the dosimeters every quarter of the calendar year. The DOE Laboratory Accreditation Program has accredited the dosimeters that HSR-4 provides, and HSR-4 provides QA for the dosimeters. The uncertainty in the TLD data is estimated from the standard deviation of data from dosimeters exposed to the same dose. The overall 1s uncertainty is similar to previous data and is 8 percent.

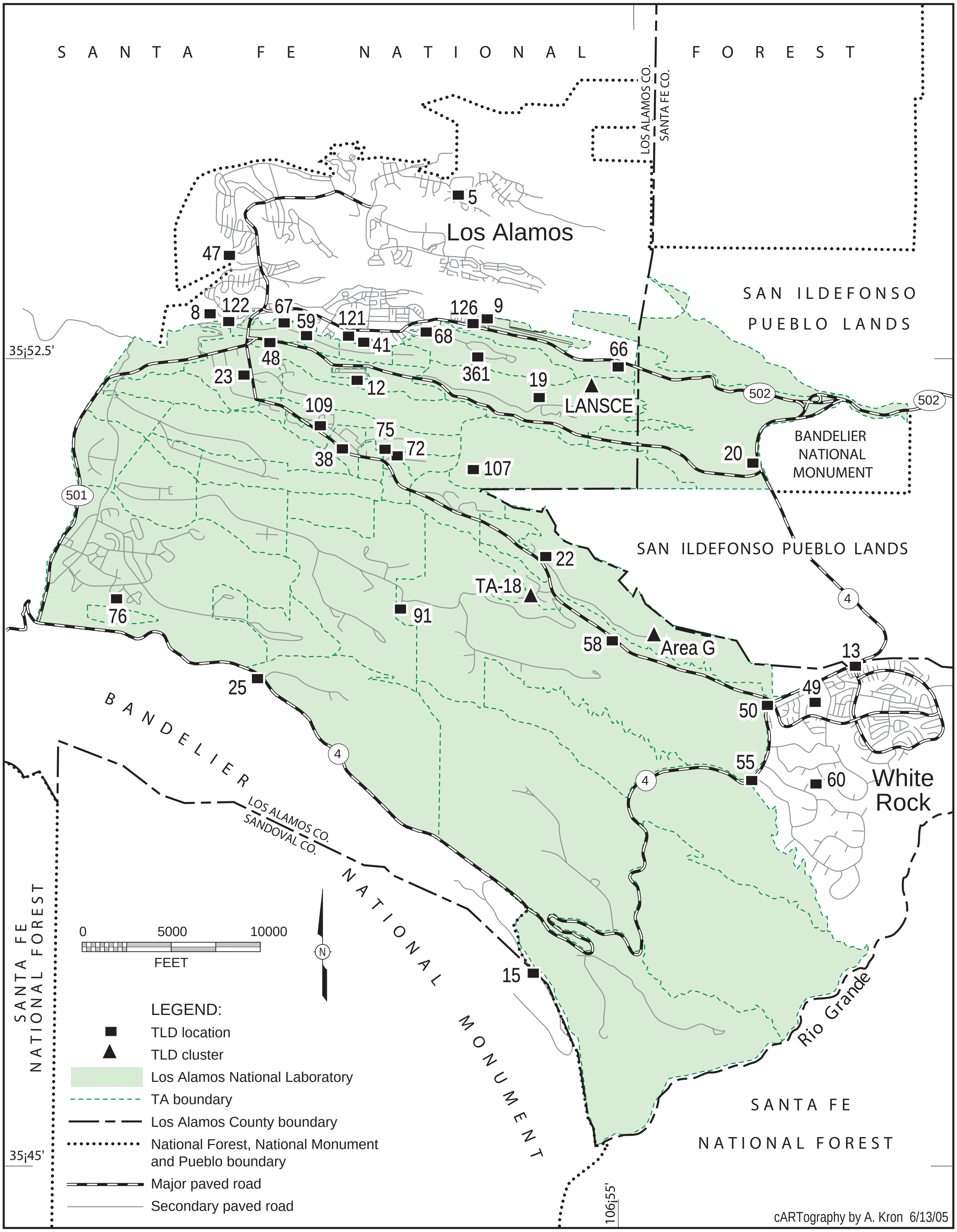

Figure 4-19. Off-site perimeter and on-site LANL TLD locations.

4. Results

The annual dose equivalents at all stations, except those at or near Area G are consistent with natural background radiation and with previous measurements. Detailed results are listed in the Data Supplement Table S4-10 and at http://www.lanl.gov/community/environment/air/.

The only location with a measurable contribution from LANL operations is near TA-54, Area G.

Figure 4-2 shows the locations of the stations at TA-54, Area G, which is a temporary storage area for transuranic waste awaiting shipment to the Waste Isolation Pilot Plant. Area G is a controlled-access area, so Area G data are not representative of a potential public dose. The public dose near this location is reported in Chapter 3.

D. NONRADIOLOGICAL AMBIENT AIR MONITORING

1. Introduction

During 2005, we continued a reduced version of the Non-Radiological Air Sampling Network (NonRadNet) implemented in 2001. Currently, the objectives of NonRadNet are to conduct monitoring to develop a database of typical background levels of selected nonradiological species in the communities nearest LANL, and to measure LANL's potential contribution to nonradiological air pollution in the surrounding communities. We retain the capability to analyze for volatile organic compounds.

2. Air-Monitoring Network

During 2005, ambient particulate matter monitoring continued at three locations—one in White Rock and two in Los Alamos. The White Rock sampling location is at the White Rock Fire Station (at AIRNET station 15). One Los Alamos station is at the Los Alamos Medical Center (at AIRNET station 61), the other near 48th Street (AIRNET station 6). Both of these latter locations lie between TA-3 and the population center of the Los Alamos town site. Two monitors are operated at each location: one for particles with diameters of 10 micrometers (µm) or less (PM-10), and another for particles with diameters of 2.5 µm or less (PM-2.5).

3. Sampling Procedures, Data Management, and Quality Assurance

A tapered-element oscillating microbalance ambient particulate monitor, fitted with either PM-10 or PM-2.5 sample inlets, collects continuous PM-10 and PM-2.5 concentrations (micrograms per cubic meter). The microbalance has an oscillating ceramic "finger" with a filter that collects particles. The added mass of the particles changes the resonant frequency of the oscillator. The change in frequency is measured and an associated mass of accumulated particulate matter is recorded and saved. The data are later downloaded to a database. Personnel use these data as an indicator of natural dust loading in the atmosphere. The sampled air volumes are calculated and the ambient air concentrations derived.

4. Ambient Air Concentrations

We achieved an overall data collection efficiency exceeding 90 percent for 2005. Annual averages and 24-hour maxima for both particle sizes at the three locations are shown in Table 4-16. The annual average for PM-10 is about 13 $\mu g/m^3$ at all locations; PM-2.5 about 7 $\mu g/m^3$. These averages are well below EPA standards (see Table 4-16). The 24-hour maxima for both PM-2.5 and PM-10 at all three locations are also much less than EPA standards.

5. Detonation and Burning of Explosives

LANL tests explosives by detonating them at firing sites operated by the Dynamic Experimentation Division and maintains records that include the type of explosives used and other material expended at each site. Table S4-11 (in the Data Supplement) summarizes the amounts of expended materials for the last five years. LANL also burns scrap and waste explosives because of treatment requirements and safety concerns. In 2005, 6.5 tons of high explosives was burned.

Table 4-16
PM-2.5 and PM-10 Concentration Data Summary for 2005 (µg/m³)

Station Location	PM-2.5		PM-10	
	Maximum 24 hour	Annual Average	Maximum 24 hour	Annual Average
48th Street, Los Alamos	20	7	34	12
Los Alamos Medical Center	27	8	55	15
White Rock Fire Station	20	7	34	13
EPA Standard	<65	<15[a]	<150	<50[a]

[a] EPA 40 CFR Part 50

An assessment of the ambient impacts of high-explosives testing (DOE 1999) indicates that high-explosives testing produces no adverse air-quality impacts. The quantities of materials detonated during 2005 were less than the amounts for which impacts are analyzed in the DOE (1999) report.

6. Beryllium Sampling

The State of New Mexico has no ambient-air-quality standard for beryllium. For comparison purposes, we use the NESHAP standard of 10 ng/m³ (40 CFR Part 61). Beryllium air concentrations for 2005 are very similar to those measured in recent years. All values are 2 percent or less of the NESHAP standard.

During 2005, we analyzed quarterly composite samples from 23 sites for beryllium, aluminum, and calcium (see Table S4-12 in the Data Supplement). These sites are located near potential beryllium sources at LANL or in nearby communities. Beryllium and aluminum concentrations in soil occur in a fairly constant ratio: note the linear dependence in Figure 4-20 (correlation coefficient = 0.94). Non-natural occurrences of beryllium would appear far from the straight line. We believe all the measured beryllium concentrations are of a natural origin and represent resuspended soil and dust.

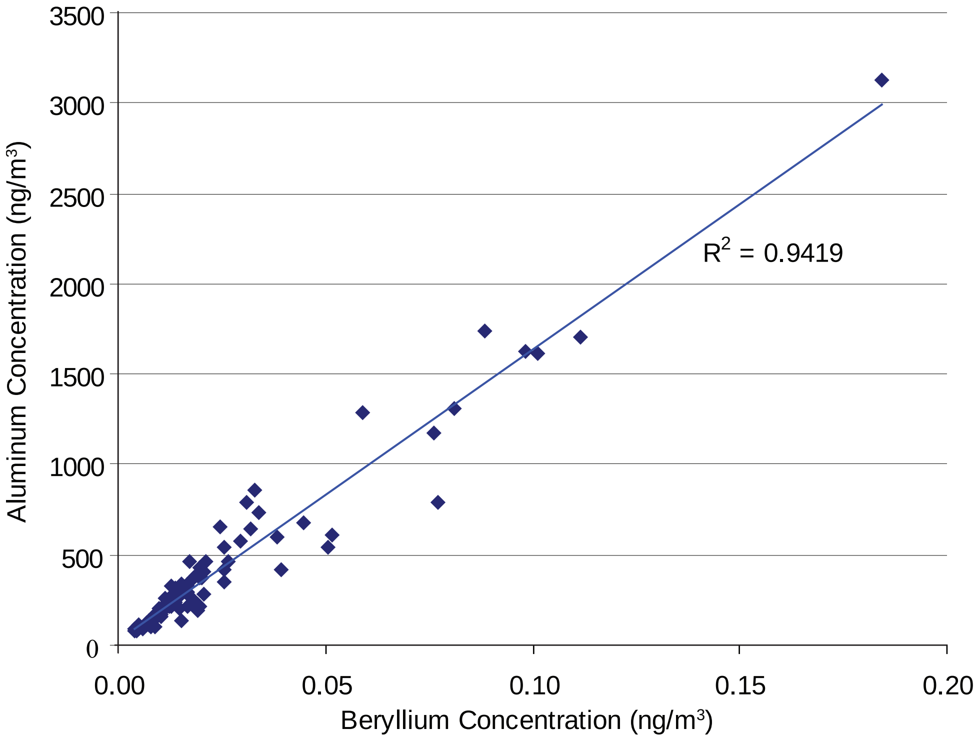

Figure 4-20. **Correlation between aluminum and beryllium concentrations in AIRNET samples.**

E. METEOROLOGICAL MONITORING

1. Introduction

Data obtained from the meteorological monitoring network support many Laboratory activities, including emergency management and response, regulatory compliance, safety analysis, engineering studies, and environmental surveillance programs. To accommodate the broad demands for weather data at the Laboratory, the meteorology team measures a wide variety of meteorological variables across the network, including wind, temperature, pressure, relative humidity and dew point, precipitation, and solar and terrestrial radiation. The Meteorological Monitoring Plan (Rishel et al. 2003) provides details of the meteorological monitoring program. An electronic copy of the "Meteorological Monitoring Plan" is available online at http://www.weather.lanl.gov/.

2. Monitoring Network

A network of six towers gathers meteorological data (winds, atmospheric state, precipitation, and fluxes) at the Laboratory. Four of the towers are located on mesa tops (TA-6, TA-49, TA-53, and TA-54), one is in a canyon (TA-41), and one is on top of Pajarito Mountain (figure 4-21). The TA-6 tower is the official meteorological measurement site for the Laboratory. A sonic detection and ranging (SODAR) instrument is located adjacent to the TA-6 meteorological tower. Precipitation is also measured at TA-16, TA-74, and in North Community of the Los Alamos town site.

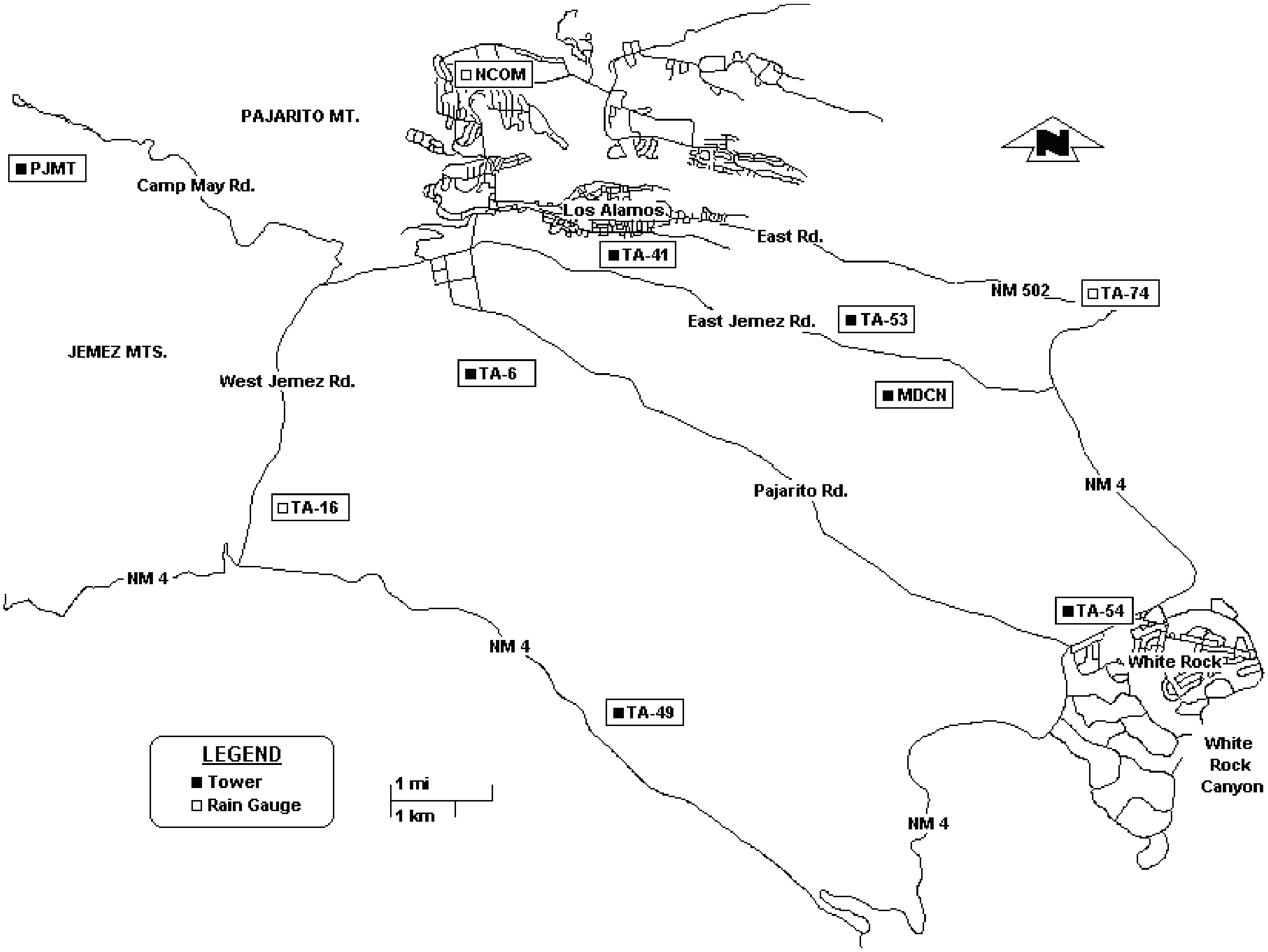

Figure 4-21. Meteorological network.

3. Sampling Procedures, Data Management, and Quality Assurance

We place instruments in the meteorological network in areas with good exposure to the elements being measured, usually in open fields, to avoid wake effects (from trees and structures) on wind and precipitation measurements. Temperature and wind are measured at multiple levels on open-lattice towers. The multiple levels provide a vertical profile of conditions important in assessing boundary layer flow and stability conditions. The multiple levels also provide redundant measurements that support data quality checks. The boom-mounted temperature sensors are shielded and aspirated to minimize solar-heating effects.

Data loggers at the tower sites sample most of the meteorological variables every 3 seconds (0.33 hertz), store the data, average the samples over a 15-min period, and transmit the data to a Hewlett-Packard workstation by telephone or cell phone. The workstation automatically edits measurements that fall outside of allowable ranges. Time-series plots of the data are also generated for a meteorologist's data-quality review. Daily statistics of certain meteorological variables (e.g., daily minimum and maximum temperatures, daily total precipitation, maximum wind gust, etc.) are also generated and checked for quality. During the past 46 years, a similar once-daily set of statistics has been telephoned to the National Weather Service. Observers log cloud type and percentage cloud cover three times daily.

All meteorological instruments are annually refurbished and calibrated during an internal audit/inspection. Field instruments are replaced with backup instruments and the replaced instruments are checked to verify that they remained in calibration while in service. All instrument calibrations are traceable to the National Institute of Standards and Technology. An external audit is typically performed once every 2–3 years, with the most recent audit performed (on only the TA-54 tower) in 2003.

4. Climatology

Los Alamos has a temperate, semiarid mountain climate. However, large differences in locally observed temperature and precipitation exist because of the 1,000-ft elevation change across the Laboratory site. Four distinct seasons occur in Los Alamos. Winters are generally mild, with occasional winter storms. Spring is the windiest season. Summer is the rainy season, with frequent afternoon thunderstorms. Fall is typically dry, cool, and calm. The climate statistics summarized here are from analyses provided in Bowen (1990 and 1992) and from historical meteorological databases maintained by the meteorology team.

Temperatures at Los Alamos have wide daily variations (a 23˚F range on average) because of the semiarid climate. Atmospheric moisture levels are low, and clear skies are present about 75 percent of the time. These conditions lead to high solar heating during the day and strong long-wave radiative cooling at night.

Winter temperatures range from 30˚F to 50˚F during the daytime and from 15˚F to 25˚F during the nighttime, with a record low temperature of -18˚F recorded in 1963. The Sangre de Cristo Mountains to the east of the Rio Grande valley act as a barrier to wintertime arctic air masses that descend into the central United States, making the occurrence of local subzero temperatures rare. Winds during the winter are relatively light, so extreme wind chills are uncommon. Summer temperatures range from 70˚F to 88˚F during the daytime and from 50˚F to 59˚F during the nighttime, with a record high temperature of 95˚F recorded in 1998.

1971 to 2000 represents the time period over which the climatological standard normal is defined, according to the World Meteorological Organization (WMO 1984). Our averages are calculated according this standard. The average annual precipitation, which includes both rain and the water equivalent for frozen precipitation, is 18.95 in. The average annual snowfall is 58.7 in.

Winter precipitation in Los Alamos is often caused by storms approaching from the Pacific Ocean, or by cyclones forming and/or intensifying leeward of the Rocky Mountains. Large snowfalls may occur locally as a result of orographic lifting of the storms by the high terrain. The record single-day snowfall is about 39 in., which occurred between 11 am on January 15th, 1987, and 11 am the next day. The record single-season snowfall is 153 in. set in 1986–87.

The two months of July and August account for 36 percent of the annual precipitation and encompass the bulk of the rainy season, which typically begins in early July and ends in early September. Afternoon thunderstorms form as moist air from the Gulf of California and the Gulf of Mexico is convected and/or orographically lifted by the Jemez Mountains. The thunderstorms yield short, heavy downpours and an abundance of lightning.

The complex topography of Los Alamos influences local wind patterns, notable in the absence of large-scale disturbances. Often a distinct diurnal cycle of winds occurs. As air close to the ground is heated during the day, it tends to be displaced by cooler air from aloft and tends to rise and flow upslope along the ground. This is called "anabatic" flow. During the night, cool air that forms close to the ground tends to flow downslope and is known as "katabatic" flow. Daytime upslope flow of heated air on the Pajarito Plateau adds a southerly component to the winds on the plateau as it flows up the Rio Grande valley. Nighttime downslope flow of cooled air from the mountains and plateau adds a light westerly-to-northerly component to local winds. Flow in the east-west-oriented canyons that interrupt the Pajarito Plateau is often aligned with the canyons, so winds are usually from the west at night as katabatic flow and from the east during the day.

5. 2005 in Perspective

Figure 4-22 presents a graphical summary of Los Alamos weather for 2005. The figure depicts the year's monthly average temperature ranges, monthly precipitation, and monthly snowfall totals compared to monthly normals (averages for each of 12 calendar months during the standard 1971–2000 time period).

The year 2005 was unusual in that it was both warmer than normal and wetter than normal. Generally, warm years are dry years and cool years are wet years. Good recent examples include 1997 (cool and wet) and 2003 (warm and dry) (see Figures 4-23 and 4-24). The average annual temperature in 2005 of 49.5˚F exceeded the normal annual average of 47.9˚F by 1.6˚F. The total precipitation in 2005 of 21.30 in. was 12 percent above normal (18.95 in.), making 2005 the wettest year since 1997. January, July, September, November, and December stand out as warm months and no months stand out as cooler than normal. The year began very wet, with January, February, and March bringing more than twice the normal precipitation. There was some worry in July, however, when the monsoon appeared to be failing. The monsoon finally arrived in August, dispelling the myth that late monsoons are weak monsoons. August and September brought the total monsoon rainfall to more than normal and secured 2005 as the wettest year in almost a decade. Ominous signs of a returning drought appeared in November, when precipitation nearly stopped entirely, a trend that continued into 2006. The annual snowfall total of 48.3 in. was 82 percent of normal (58.7 in.). The less-than-usual snowfall total in 2005 was due in part to warmer winter temperatures and in part to a return to drought conditions late in the year.

Temperature and precipitation data have been collected in the Los Alamos area since 1910. Figure 4-23 shows the historical record of temperatures in Los Alamos from 1925 through 2005. The annual average temperature is not the average temperature per se, but rather the mid-point between daily high and low temperatures, averaged over the year. One-year averages are shown in green in Figure 4-23. With the exception of 2004, years since 2000 have clearly been warmer than normal. To aid in showing longer-term trends, the five-year running mean is also shown. With five-year averaging, for example, it can be seen that the warm spell during the past few years is not as severe as the warm spell during the early-to-mid 1950s. On the other hand, it was three out of four warm years then while the recent warm spell has been five out of six years.

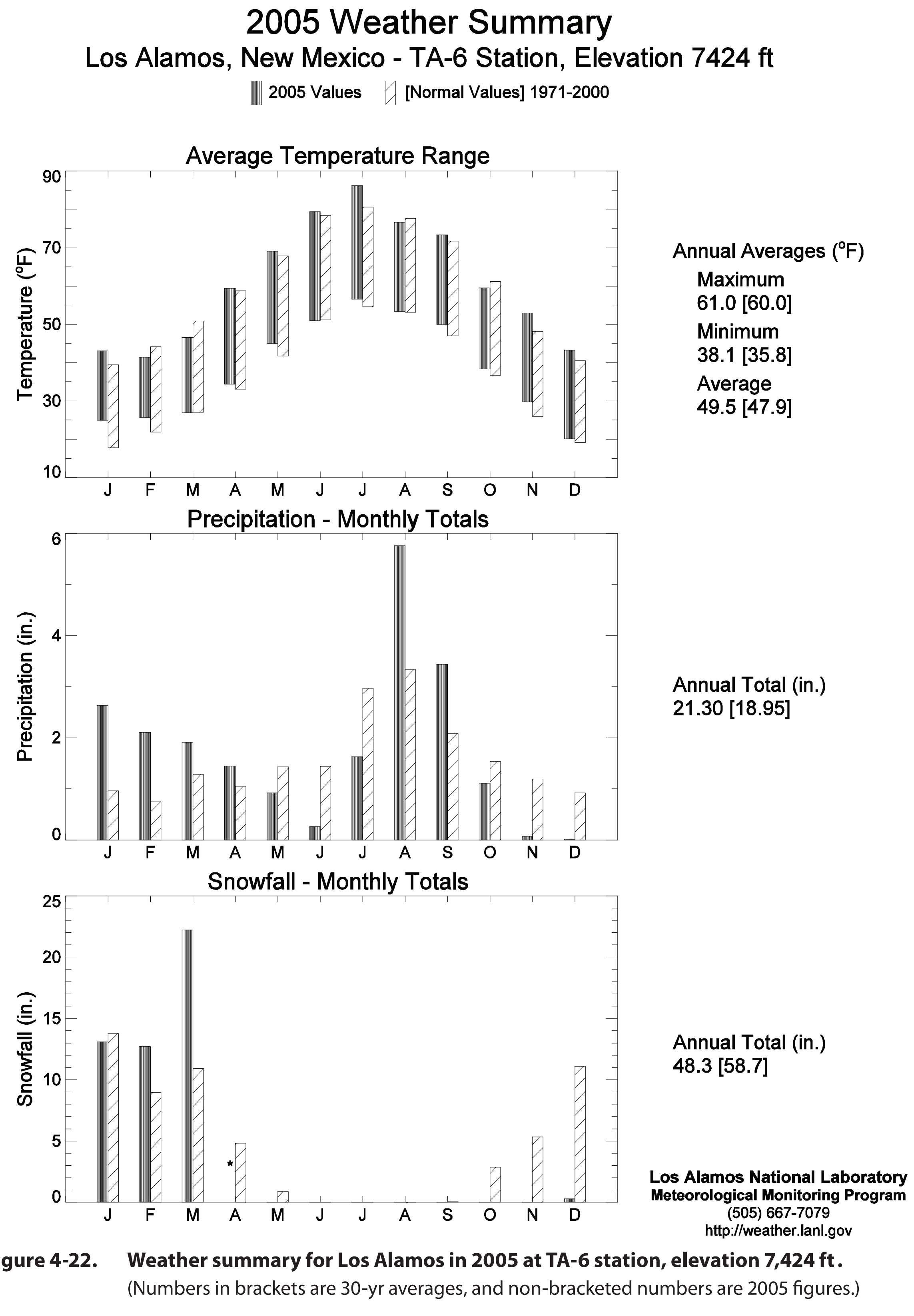

Figure 4-22. **Weather summary for Los Alamos in 2005 at TA-6 station, elevation 7,424 ft.** (Numbers in brackets are 30-yr averages, and non-bracketed numbers are 2005 figures.)

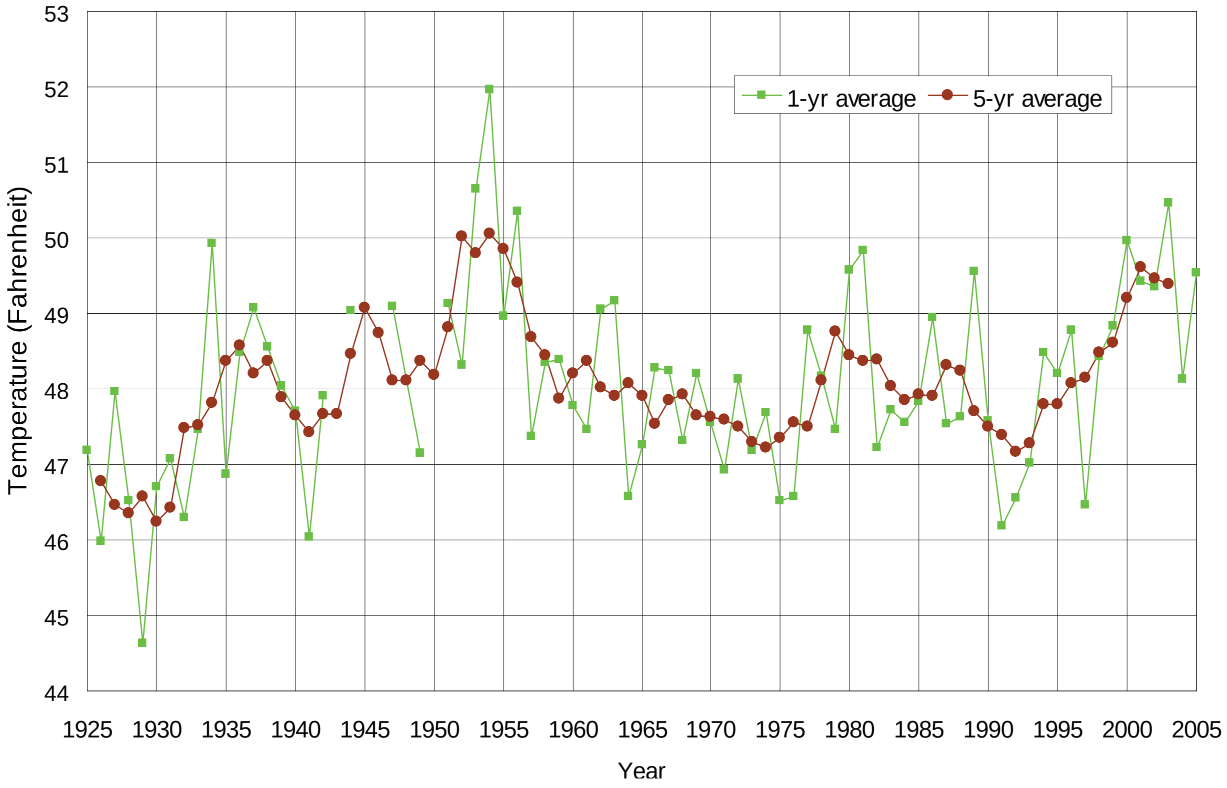

Figure 4-23. **Temperature history for Los Alamos.**

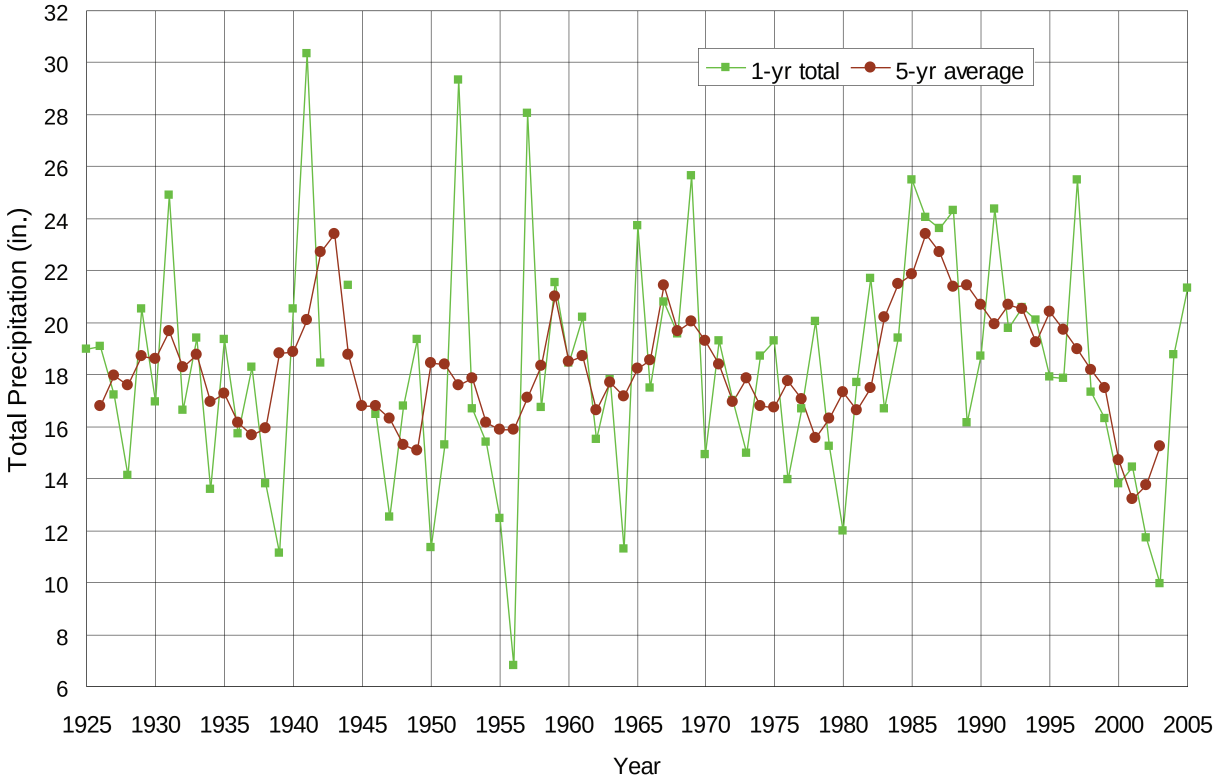

Figure 4-24. **Total precipitation history for Los Alamos.**

Figure 4-24 shows the historical record of the annually summed total precipitation. The drought appeared to end with 2003, as 2004 and 2005 have shown strong returns to nearly normal conditions. As with the historical temperature profile, the five-year running mean is also shown. The five-year average shows that the recent drought appears quite clearly to be the most severe drought on record in Los Alamos.

Daytime winds (sunrise to sunset), based on 15-minute-averaged wind observations for 2005 at the four Pajarito Plateau towers and the Pajarito Mountain tower, are shown in the form of wind roses (Figures 4-25 and 4-26). The wind roses depict the percentage of time that the wind blows from each of 16 compass rose points and the distribution of wind speed for each of the 16 directions, represented by shaded wind-rose barbs. Unlike temperature and precipitation, graphics of wind (wind roses) from different years are almost identical.

Daytime winds measured by the four Pajarito Plateau towers are predominately from the south (Figure 4-25), consistent with the typical upslope flow of heated daytime air moving up the Rio Grande valley. Nighttime winds (sunset to sunrise) on the Pajarito Plateau were lighter and more variable than daytime winds and typically from the west, resulting from a combination of prevailing winds from the west and downslope katabatic flow of cooled mountain air (Figure 4-26). Winds atop Pajarito Mountain are more representative of upper-level flows and primarily ranged from the northwest to the southwest, mainly because of the prevailing westerly winds.

F. QUALITY ASSURANCE PROGRAM IN THE AIR QUALITY GROUP

1. Quality Assurance Program Development

During 2005, the air quality group revised four quality plans that affect collection and use of air-quality-compliance data. We also issued three new implementing procedures and revised approximately 38 procedures to reflect the constant improvements in the processes. Together, these plans and procedures describe or prescribe all the planned and systematic activities believed necessary to provide adequate confidence that processes perform satisfactorily. All current quality-related documents are available on the public website: http://www.lanl.gov/community/environment/air/.

2. Field Sampling Quality Assurance

Overall quality of this portion of the program is maintained through the rigorous use of carefully documented procedures that govern all aspects of the sample-collection program.

Particulate and water-vapor samples are (1) collected from commercially available media of known performance, (2) collected under common EPA chain-of-custody procedures using field-portable electronic data systems to minimize the chances of data transcription errors, and (3) prepared in a secure and radiologically clean laboratory for shipment. They are then delivered to internal and external analytical laboratories under full chain-of-custody, including secure FedEx shipment, to all external vendors and tracked at all stages of their collection and analysis through the AIRNET and RADAIR relational databases.

Field-sampling completeness is assessed every time the analytical laboratory returns the AIRNET biweekly gross alpha/beta data. RADAIR field-sampling completeness is evaluated each week upon receipt of the gross alpha/beta and tritium bubbler data. All these calculations are performed for each ambient-air and stack-sampling site and are included in the quality-assessment memo that is prepared by stack monitoring staff to evaluate every data group received from a supplier.

3. Analytical Laboratory Quality Assessment

Specific statements of work are written to govern the acquisition and delivery of analytical-chemistry services after the Data Quality Objective process has identified and quantified our program objectives. These statements of work are sent to potentially qualified suppliers who then undergo a pre-award, on-site assessment by experienced and trained quality systems and chemistry-laboratory assessors. Statement of work specifications, professional judgment, and quality-system performance at each lab, including recent past performance on nationally conducted performance-evaluation programs, are primarily used to award contracts for specific types of radiochemical and inorganic analyses.

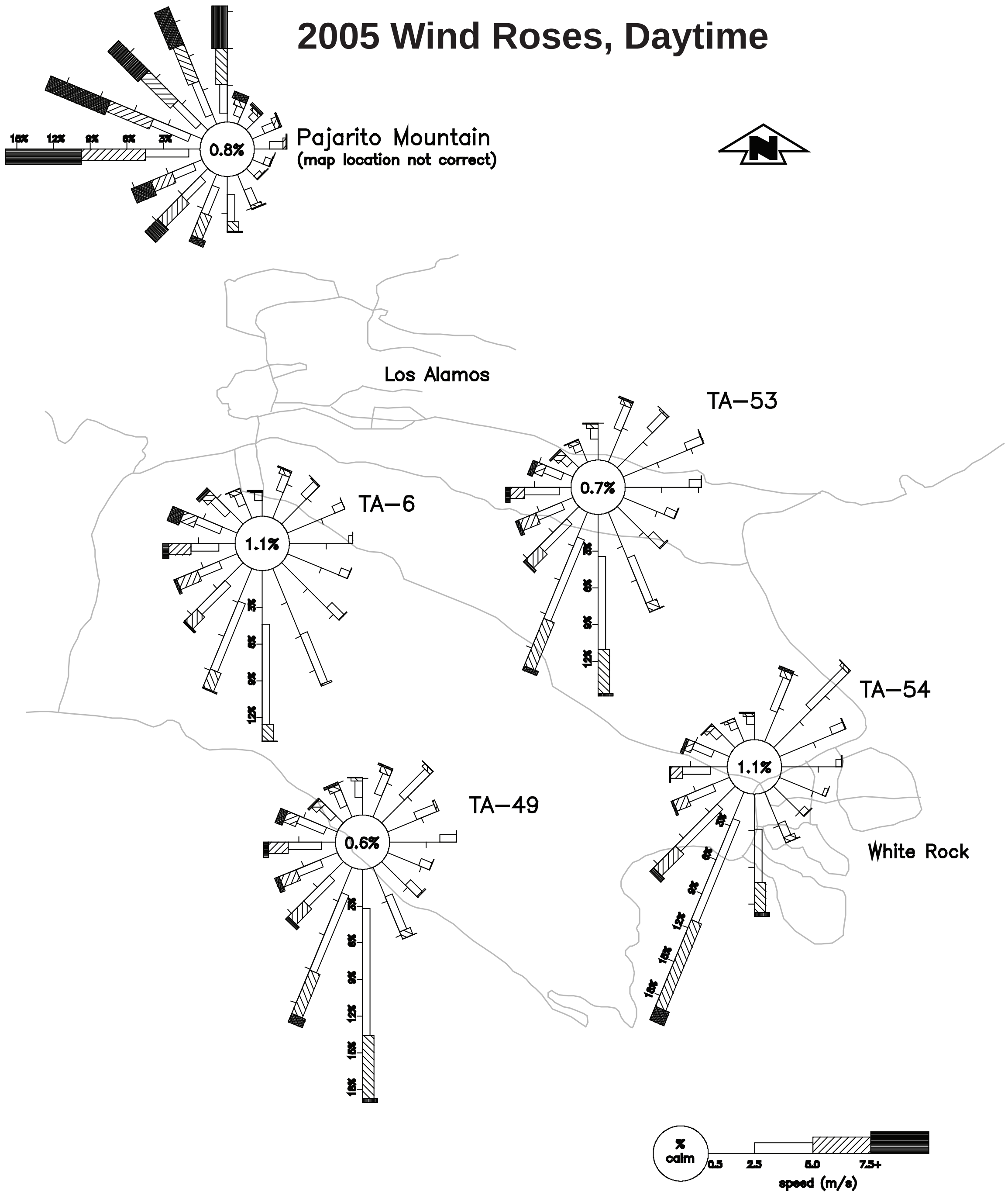

Figure 4-25. Daytime wind roses, 2005.

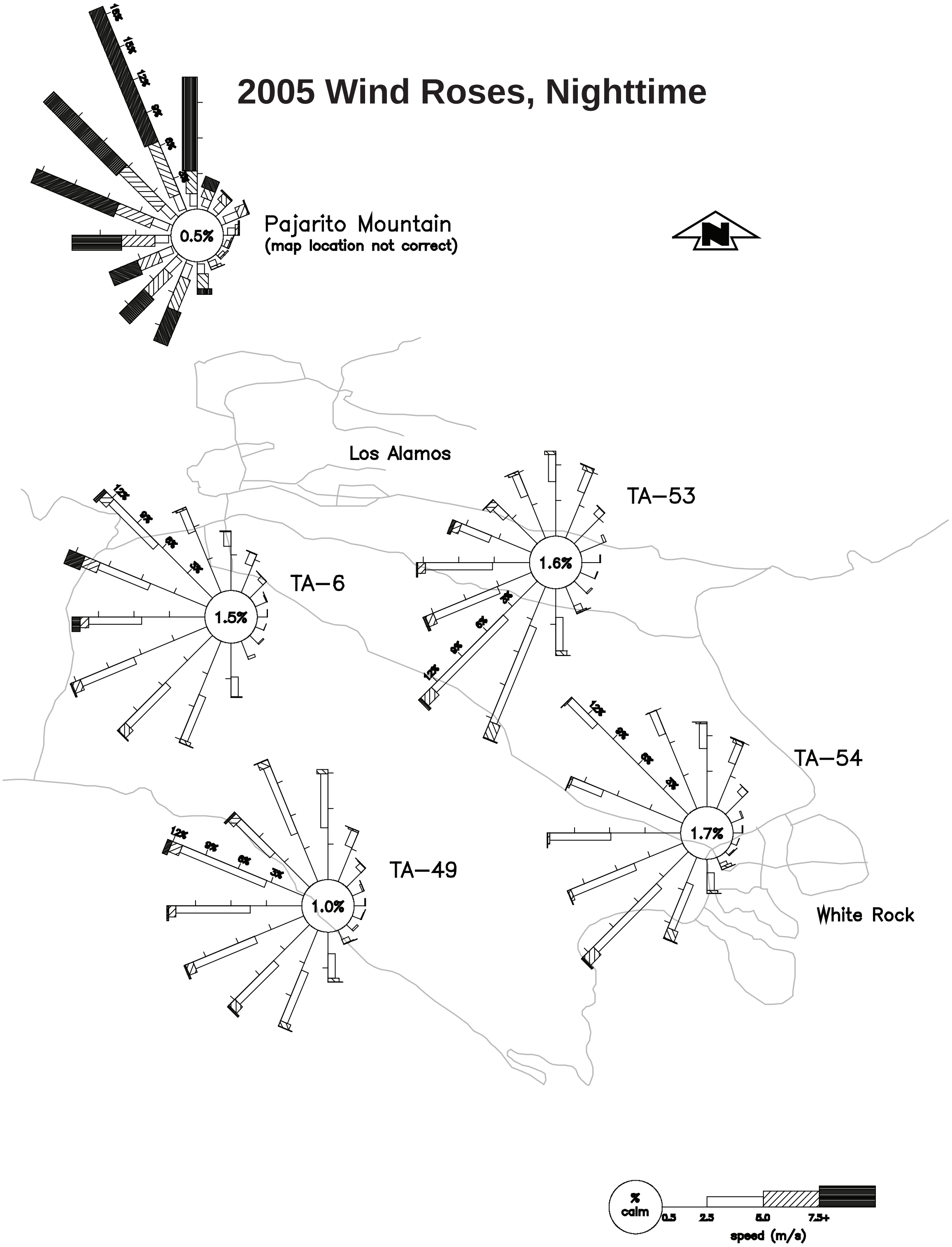

Figure 4-26. Nighttime wind roses, 2005.

Each analytical laboratory conducts its chain-of-custody and analytical processes under its own quality plans and analytical procedures. We submit independently prepared blind spiked samples with each sample set to be analyzed for tritium. Preliminary data are returned by e-mail in an electronic data deliverable of specified format and content. The analytical laboratory also submits a full paper set of records that serves as the legally binding copy of the data. Each set of samples contains all the internal QA/QC data the analytical laboratory generates during each phase of chemical analysis, including laboratory control standards, process blanks, matrix spikes, duplicates, and replicates, when applicable. The electronic data are uploaded into either the AIRNET or RADAIR databases and immediately subjected to a variety of quality and consistency checks. Analytical completeness is calculated, tracking and trending of all blank and control-sample data is performed, and all are documented in the quality-assessment memo mentioned in the field-sampling section. All parts of the data-management process are tracked electronically in each database, and periodic reports to management are prepared.

4. Field Data Quality Assessment Results

Field data completeness for AIRNET and stacks was 100 percent. Sample run time was greater than 98.6 percent for AIRNET and 99.7 percent for stacks.

5. Analytical Data Quality Assessment Results

Analytical data completeness was >98.5 percent for AIRNET stations and 99.9 percent for stacks. The Clean Air Act requires an EPA-compliant program of QC samples be included as an integral part of the sampling and analysis process. Sample- and data-management procedures document the specific evaluations of each type of QC sample for each analytical measurement. All QC data are tracked, trended, and reported in specific QC evaluation memos that are submitted to project staff along with each set of analytical data received from our chemistry laboratories. The overall results of the 2005 program of quality monitoring indicate that all analytical laboratories maintained the same high level of control that has observed in the past several years.

6. Analytical Laboratory Assessments

During 2005, one internal and one external laboratory performed all chemical analyses reported for AIRNET and RADAIR samples. Paragon Analytics, Inc., Fort Collins, Colorado, provided the following analyses:

- Biweekly gross alpha, gross beta, and gamma analyses of filters for AIRNET.
- Biweekly analyses for tritium in AIRNET silica gel.
- Weekly gross alpha, gross beta, gamma, and stable beryllium analyses on stack samples.
- Quarterly analyses for alpha-emitting isotopes (americium, plutonium, and uranium) and stable beryllium, calcium, and aluminum on AIRNET quarterly composite samples.
- Semester analyses of composites of stack filters for gross alpha, gross beta, Am-241, gamma-emitting isotopes, lead-210, polonium-210, plutonium isotopes, strontium-90, thorium isotopes, and uranium isotopes.

The Laboratory's on-site Health Physics Analytical Laboratory in HSR-4 performed instrumental analyses of tritium in stack emissions.

No assessment of Paragon Analytics was performed during 2005, but previous annual assessments have shown the laboratory performs consistently well. The laboratory participated in national performance-evaluation studies during 2005. The detailed results of these performance evaluations are included in the assessment report. Overall, the study sponsors judged the analytical lab to have acceptable performance for almost all analytes attempted in all matrices.

G. REFERENCES

Bowen 1990: B. M. Bowen, “Los Alamos climatology,” Los Alamos National Laboratory report LA 11735-MS (May 1990).

Bowen 1992: B. M. Bowen, “Los Alamos climatology summary,” Los Alamos National Laboratory report LA-12232-MS (March 1992).

DOE 1988a: US Department of Energy, “Radiation protection for occupational workers,” US Department of Energy Order 5480.11 (1988).

DOE 1988b: US Department of Energy, “Internal dose conversion factors for calculation of dose to the public,” US Department of Energy DE88-014297 (July 1988).

DOE 1999: US Department of Energy, “Site-Wide Environmental Impact Statement For Continued Operation of the Los Alamos National Laboratory,” DOE/EIS-0238 (January 1999).

Duncan 1986: A. J. Duncan, Quality Control and Industrial Statistics, 5th ed. (Irwin, Homewood, Homewood, IL, 1986) 1123 pp.

Eisenbud and Gesell 1997: M. Eisenbud and T. Gesell, Environmental Radioactivity from Natural, Industrial, and Military Sources, 4th ed. (Academic Press, San Diego, California, 1997).

EPA 1989: US Environmental Protection Agency, “National Emission Standards For Emissions Of Radionuclides Other Than Radon From Department Of Energy Facilities,” Code of Federal Regulations, Title 40, Part 61, Subpart H (December 15, 1989).

ESP 2001: Environmental Surveillance Program, “Environmental surveillance at Los Alamos during 2000,” Los Alamos National Laboratory report LA-13861-ENV (September 2001).

ESP 2002: Environmental Surveillance Program, “Environmental surveillance at Los Alamos during 2001,” Los Alamos National Laboratory report LA-13979-ENV (October 2002).

Gilbert 1987: R. O. Gilbert, Statistical Methods for Environmental Pollution Monitoring, (Van Nostrand Reinhold, New York, 1987), 320 pp.

McNaughton et al. 2000: M. W. McNaughton, D. H. Kraig, and J. C. Lochamy, “Siting of Environmental Direct-Penetrating-Radiation Dosimeters,” Los Alamos National Laboratory document LA-UR-00-1168 (2000).

NCRP 1975: National Council on Radiation Protection and Measurements, “Natural background Radiation in the United States,” National Council on Radiation Protection and Measurements report 45 (November 1975).

NCRP 1987: National Council on Radiation Protection and Measurements, “Ionizing radiation exposure of the population of the United States,” National Council on Radiation Protection and Measurements report 93 (September 1987).

Rishel et al. 2003: J. Rishel, S. Johnson, D. Holt, B. Olsen, and M. Coronado, “Meteorological Monitoring at Los Alamos,” Los Alamos National Laboratory document LA-UR-03-8097 (2003).

RN 2001: Rad-NESHAP Project, “2001 LANL Radionuclide Air Emissions Report,” Los Alamos National Laboratory Report LA-13957-PS (June 2002).

RN 2005: Rad-NESHAP Project, “2005 LANL Radionuclide Air Emissions Report,” Los Alamos National Laboratory Report LA-14298 (June 2005).

Walker et al. 1989: F. W. Walker, J. R. Parrington, and F. Feiner, Nuclides and Isotopes, 14th ed. (General Electric Company, 1989).

World Meteorological Organization 1984. Technical Regulations, Vol. I. WMO-No. 49. Geneva, Switzerland.

5. GROUNDWATER MONITORING

contributing authors:
David B. Rogers, Bart J. Vanden Plas, and Mark P. Haagenstad

To Read About **Turn to Page**

A. INTRODUCTION

Los Alamos National Laboratory (LANL or the Laboratory) routinely analyzes groundwater samples to monitor water quality on the Pajarito Plateau and in the surrounding area. The Laboratory conducts groundwater monitoring and characterization programs to comply with the requirements of the Department of Energy (DOE) Orders and New Mexico and federal regulations. The objectives of the Laboratory's groundwater programs are to determine compliance with waste discharge requirements and to evaluate any impact of Laboratory activities on groundwater resources. This program addresses regulatory compliance, environmental monitoring, resource management, aquifer protection, and hydrogeologic investigations (LANL 1996, 1998).

Because of the Laboratory's semiarid, mountainside setting, significant groundwater is found only at depths of more than several hundred feet. The Los Alamos County public water supply comes from supply wells that draw water from the regional aquifer (found at depths of 600 to 1,200 feet). Groundwater protection efforts at the Laboratory focus on (1) the regional aquifer underlying the region and include (2) the shallow perched groundwater found within canyon alluvium and (3) the perched groundwater at intermediate depths above the regional aquifer.

Since the 1940s, liquid effluent disposal by the Laboratory has affected water quality in the shallow perched groundwater that lies beneath the floor of a few canyons. These water quality impacts extend in some cases to perched groundwater at depths of a few hundred feet beneath these canyons and to the underlying regional aquifer. The contaminated alluvial and intermediate perched groundwater bodies are separated from the regional aquifer by hundreds of feet of dry rock, so recharge from the shallow groundwater occurs slowly. As a result, less contamination reaches the regional aquifer than the shallow perched groundwater bodies, and impacts on the regional aquifer are reduced.

In 2005, sampling at one regional aquifer monitoring well beneath Mortandad Canyon found contamination by hexavalent chromium at a concentration that is over four times the Environmental Protection Agency (EPA) maximum contaminant level (MCL) of 100 μg/L and eight times the NM groundwater standard. Past cooling tower discharges in Sandia Canyon are identified as the likely hexavalent chromium source (ERSP 2006). The Laboratory also discovered a volatile organic compound, dioxane[1,4-], at values just below Consent Order-specified risk levels in two intermediate wells in Mortandad Canyon. This compound is commonly used as a stabilizer for organic solvents. The Laboratory has begun investigation of these issues in cooperation with New Mexico Environment Department (NMED).

With one exception, drinking water wells in the Los Alamos area have not been adversely impacted by Laboratory discharges. The exception is well O-1 in Pueblo Canyon, where perchlorate is found at concentrations that average 1/10th of the EPA's Drinking Water Equivalent Level of 24.5 µg/L. This well is not used by Los Alamos County for water supply. All drinking water produced by the Los Alamos County water supply system meets federal and state drinking water requirements.

To comply with the requirements of the NMED Consent Order, LANL significantly expanded the number of monitored groundwater locations during 2005. The Laboratory collected groundwater samples from wells and springs within or adjacent to the Laboratory and from the nearby Pueblo de San Ildefonso.

B. HYDROGEOLOGIC SETTING

1. Geologic Setting

Los Alamos National Laboratory is located in northern New Mexico on the Pajarito Plateau, which extends eastward from the Sierra de los Valles (the eastern range of the Jemez Mountains) (Figure 5-1).

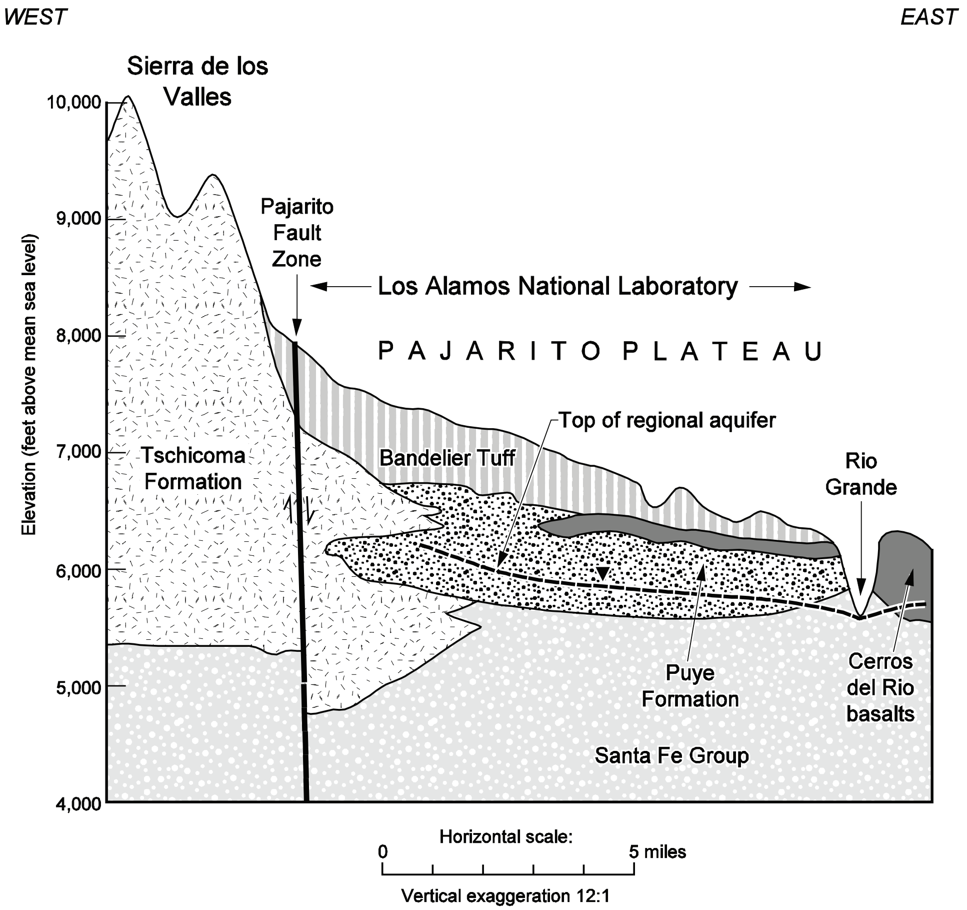

Figure 5-1. Generalized geologic cross section of the Pajarito Plateau.

The Rio Grande borders the Laboratory on the east. Rocks of the Bandelier Tuff cap the Pajarito Plateau. The tuff formed from volcanic ashfall deposits and pyroclastic flows erupted from the Jemez Mountains volcanic center approximately 1.2 to 1.6 million years ago. The tuff is more than 1,000 ft thick in the western part of the plateau and thins eastward to about 260 ft adjacent to the Rio Grande.

On the western part of the Pajarito Plateau, the Bandelier Tuff overlaps the Tschicoma Formation, which consists of older volcanics that form the Jemez Mountains (Figure 5-1). The Puye Formation conglomerate underlies the tuff beneath the central and eastern portion of the plateau. The Cerros del Rio basalt flows interfinger with the Puye Formation conglomerate beneath the Laboratory. These formations overlie the sediments of the Santa Fe Group, which extend across the Rio Grande Valley and are more than 3,300 ft thick.

2. Groundwater Occurrence

Due to its location on a semiarid mountainside, the Laboratory lies atop a thick zone of mainly unsaturated rock, with the principal aquifer found 600 to 1200 ft below the ground. Groundwater beneath the Pajarito Plateau occurs in three modes, two of which are perched (Figure 5-2). Perched groundwater is retained above less permeable layers and is separated from underlying groundwater by unsaturated rock. The three modes of groundwater occurrence are (1) perched alluvial groundwater in canyon bottoms, (2) zones of intermediate-depth perched groundwater whose location is controlled by availability of recharge and by subsurface changes in rock type and permeability, and (3) the regional aquifer beneath the Pajarito Plateau. The regional aquifer extends throughout the neighboring Española Basin.

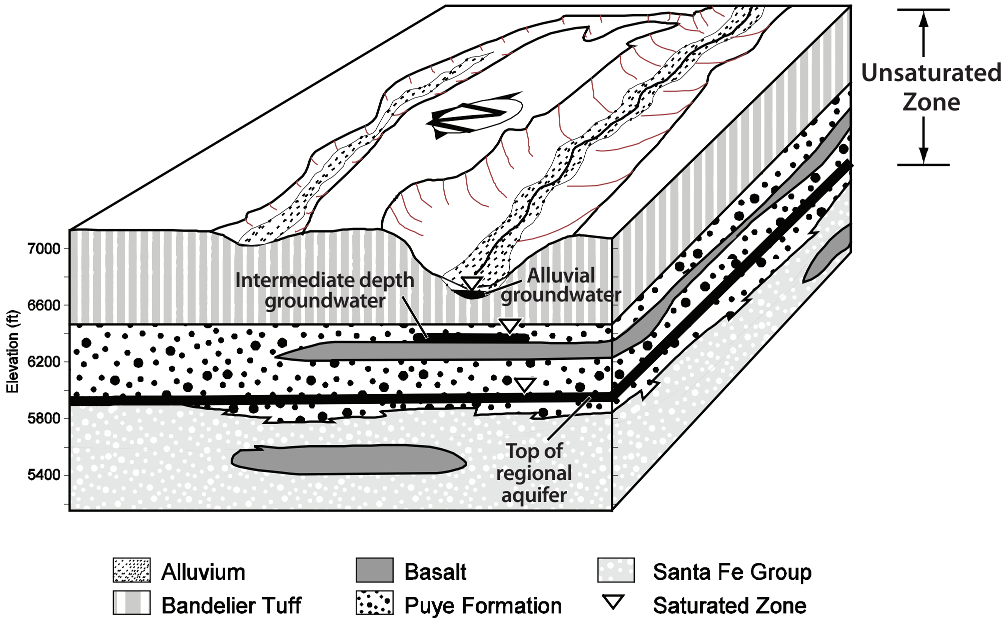

Figure 5-2. Illustration of geologic and hydrologic relationships in the Los Alamos area, showing the three modes of groundwater occurrence.

Stream runoff may be supplemented or maintained by Laboratory discharges. Many relatively dry canyons have little surface water flow and little or no alluvial groundwater. Streams have filled some parts of canyon bottoms with alluvium up to 100 ft thick. In wet canyons, runoff percolates through the alluvium until downward flow is impeded by less permeable layers of tuff or other rocks, maintaining shallow bodies of perched groundwater within the alluvium. Evapotranspiration and infiltration into underlying rocks deplete the alluvial groundwater as it moves down the canyon. The chemical quality of some of the alluvial groundwater shows the effects of Laboratory discharges.

Underneath portions of Pueblo, Los Alamos, Mortandad, Sandia, and other canyons, intermediate perched groundwater occurs within the lower part of the Bandelier Tuff and within the underlying Puye Formation and Cerros del Rio basalt (Figure 5-2). These intermediate-depth groundwater bodies are formed in part by recharge from the overlying perched alluvial groundwater. Intermediate groundwater occurrence is controlled by availability of recharge and variations in permeability of the rocks underlying the plateau. Depths of the intermediate perched groundwater vary: approximately 120 ft in Pueblo Canyon, 450 ft in Sandia Canyon, and 500–750 ft in Mortandad Canyon.

Some intermediate perched water occurs in volcanics on the flanks of the Sierra de los Valles to the west of the Laboratory. This water discharges at several springs (Armstead and American) and yields a significant flow from a gallery in Water Canyon. Intermediate perched water also occurs in the southwest portion of the Laboratory just east of the Sierra de los Valles, in the Bandelier Tuff at a depth of approximately 700 ft. The source of this perched water may be infiltration from streams that discharge from canyons along the mountain front and also underflow of recharge from the Sierra de los Valles.

The regional aquifer of the Los Alamos area occurs at a depth of 1,200 ft along the western edge of the plateau and 600 ft along the eastern edge (Figures 5-1 and 5-3). The regional aquifer lies about 1,000 ft beneath the mesa tops in the central part of the plateau. This aquifer is the only aquifer in the area capable of serving as a municipal water supply. Water in the aquifer flows generally east or southeast toward the Rio Grande, and groundwater model studies indicate that underflow of groundwater from the Sierra de los Valles is the main source of recharge for the regional aquifer (Nylander et al., 2003). Groundwater velocities vary spatially but are typically 30 ft/yr.

The surface of the aquifer rises westward from the Rio Grande within the Tesuque Formation, part of the Santa Fe Group (Figure 5-1). Underneath the central and western part of the plateau the aquifer rises farther into the Cerros del Rio basalt and the lower part of the Puye Formation.

The regional aquifer is separated from alluvial and intermediate perched groundwater by approximately 350 to 620 ft of unsaturated tuff, basalt, and sediments with generally low (<10 percent) moisture content. Water lost by downward seepage from alluvial and intermediate groundwater zones travels through the underlying rock by unsaturated flow. This percolation is a source of contaminants that may reach the regional aquifer within a few decades. The limited extent of the alluvial and intermediate groundwater bodies, along with the dry rock that underlies them, limits their volumetric contribution to recharge reaching the regional aquifer.

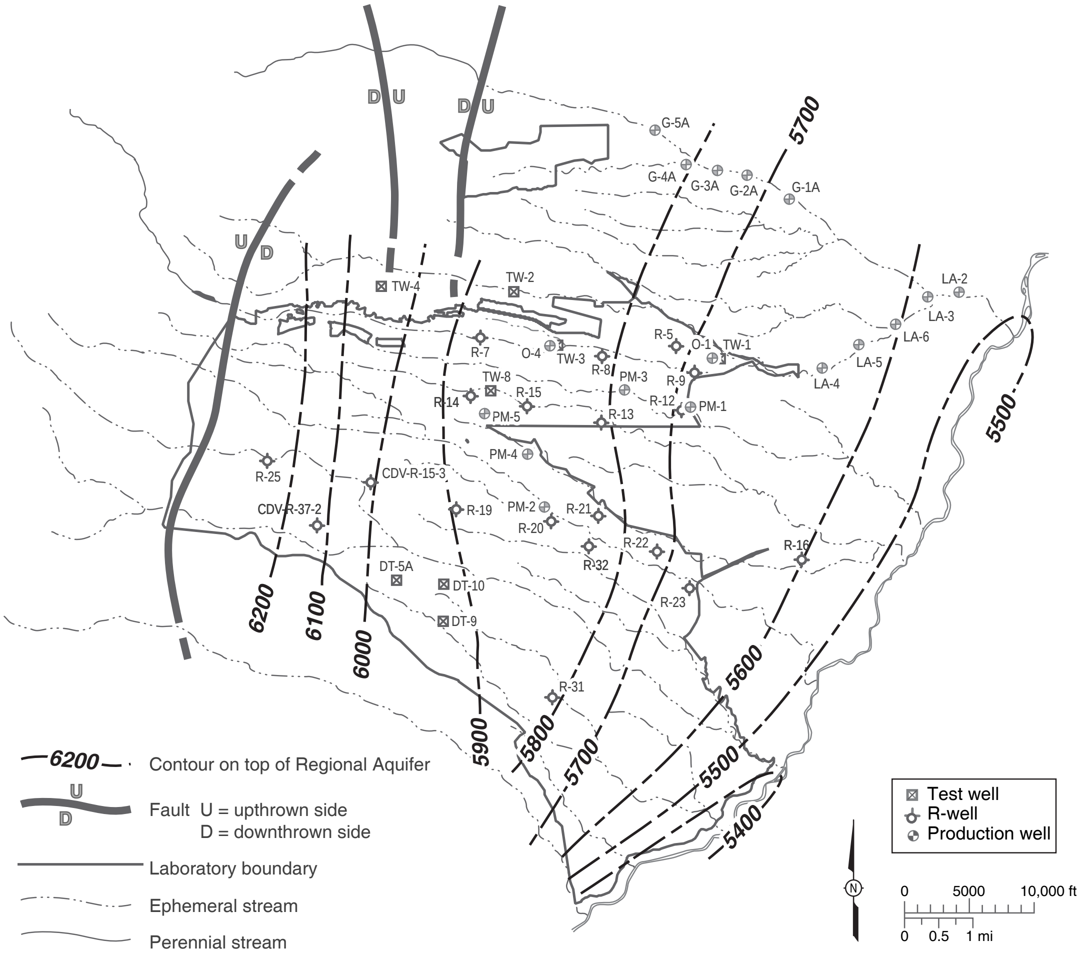

Figure 5-3. Generalized water level contours for the regional aquifer (Nylander et al., 2003).

3. Overview of Groundwater Quality

Liquid effluent disposal is the primary means by which Laboratory contaminants have impacted deep groundwater, including intermediate perched zones and the regional aquifer. Where Laboratory contaminants are found at depth, the setting is either a canyon where alluvial groundwater is usually present (perhaps because of natural runoff or Laboratory effluents) or a location beneath a mesa-top site where large amounts of liquid effluent have been discharged. The discharge of effluents to canyons or mesa-top locations in the Laboratory's semiarid setting initiates or increases downward percolation of water. Even under unsaturated flow conditions, this percolation may move significant amounts of water and contaminants to the regional aquifer within a few decades.

Liquid effluent disposal at the Laboratory has impacted the quality of alluvial groundwater in several canyons (Figure 5-4). Groundwater contamination is primarily the result of past effluent discharges. Since the early 1990s, the Laboratory has significantly reduced both the number of industrial outfalls (from 141 to 17) and the volume of water released (by more than 80 percent). For 1993 to 1997, total estimated average flow was 1,300 M gal/yr; flow decreased to 230 M gal/yr for 1998 to 2005 (Rogers 2006). The quality of the remaining discharges has been improved through treatment process improvements so that it meets applicable standards.

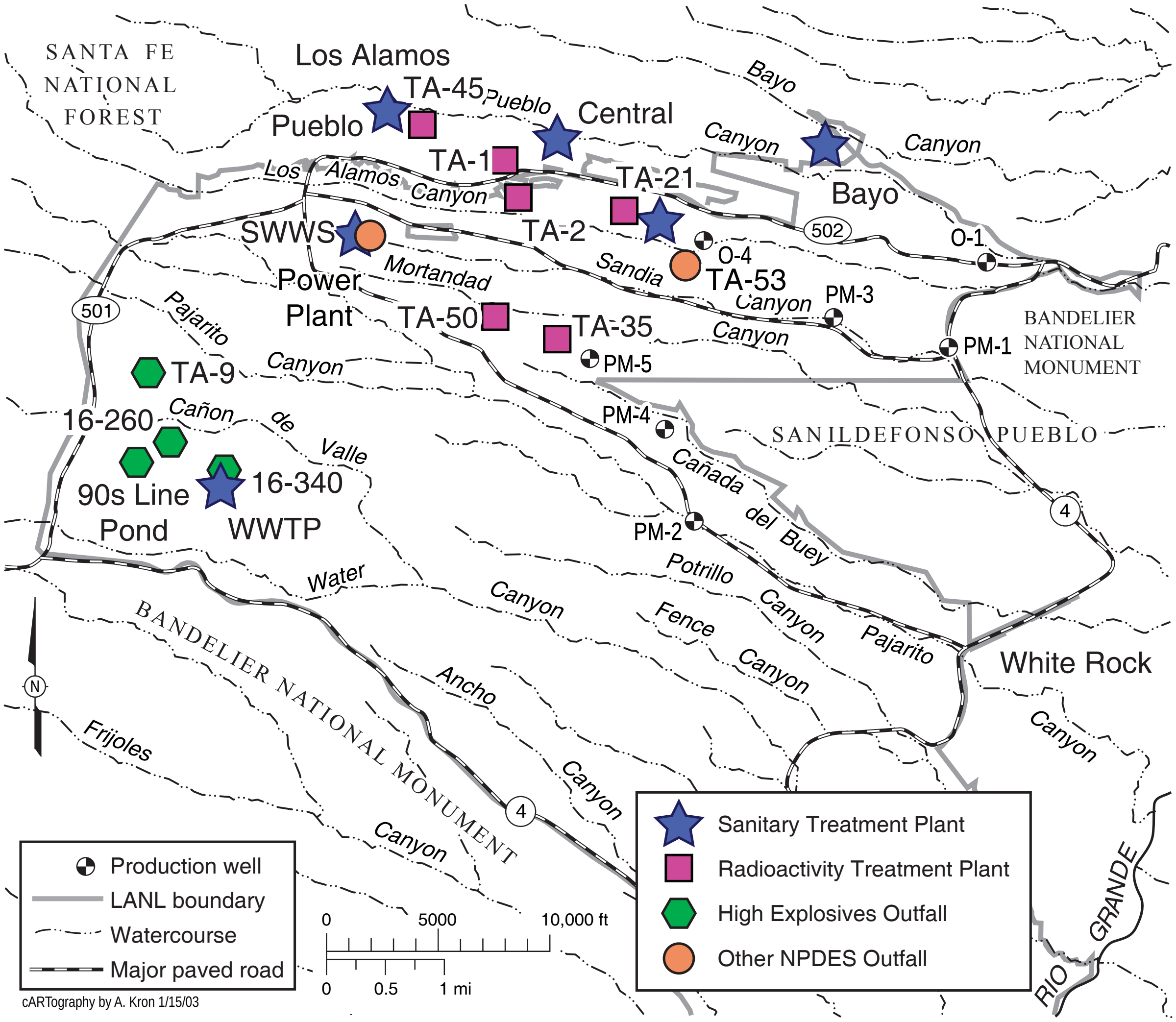

Figure 5-4. **Major liquid release sources (effluent discharge) potentially affecting groundwater. Most outfalls shown are inactive.**

Liquid effluent discharges have affected intermediate perched groundwater and the regional aquifer to a lesser degree. The intermediate groundwater in various locations shows localized radioactive (tritium), organic (high explosives [HE], chlorinated solvents, dioxane[1,4-]), and inorganic (hexavalent chromium, barium, boron, perchlorate, and nitrate) contamination from Laboratory operations. Traces of HE, tritium, perchlorate, and nitrate are also found in the regional aquifer. Hexavalent chromium has been found in several wells, including one well at concentrations above state and federal drinking water standards.

Drainages that received liquid radioactive effluents include Mortandad Canyon, Pueblo Canyon from its tributary Acid Canyon, and Los Alamos Canyon from its tributary DP Canyon. Rogers (2001) and Emelity (1996) summarize radioactive effluent discharge history at the Laboratory.

Because of release of power plant cooling water and water from the Laboratory's Sanitary Wastewater Systems (SWWS) Plant, Sandia Canyon has received the largest liquid discharge volumes of any canyon in recent decades.

Water Canyon and its tributary Cañon de Valle have received effluents produced by HE processing and experimentation (Glatzmaier 1993; Martin 1993). Over the years, Los Alamos County has operated three sanitary treatment plants in Pueblo Canyon (ESP 1981). Only the Bayo sanitary treatment plant is currently operating. The Laboratory has also operated numerous sanitary treatment plants, three of which are shown in Figure 5-4.

C. GROUNDWATER STANDARDS

We apply regulatory standards and risk levels to evaluation of groundwater samples according to Table 5-1. For water supply wells, which draw water from the regional aquifer, we compare concentrations of radionuclides in samples to (1) the derived concentration guides (DCGs) for ingested water calculated from DOE's 4-mrem drinking water dose limit and (2) the EPA MCLs. For risk-based radioactivity screening, groundwater samples from sources other than water supply wells may be compared with DOE's 4-mrem drinking water DCGs and with EPA MCLs.

The New Mexico drinking water regulations and EPA MCLs apply as regulatory standards to nonradioactive constituents in water supply samples and may be used as risk-based screening levels for other groundwater samples. The New Mexico Water Quality Control Commission (NMWQCC) groundwater standards (NMWQCC 2002) apply to concentrations of nonradioactive chemical quality parameters in all groundwater samples. Following requirements of the Consent Order, we screened the toxic pollutants listed in the NMWQCC groundwater standards at a risk level of 10^{-5} for cancer-causing substances or a hazard index of one (HI = 1) for non-cancer-causing substances. A hazard index value of 1 or less indicates that no (noncancer) adverse human health effects are expected to occur. We used the EPA Region VI tap water screening levels to screen the NMWQCC toxic pollutant compounds (http://www.epa.gov/earth1r6/6pd/rcra_c/pd-n/screen.htm). For cancer-causing substances, the Region VI tap water screening levels are at a risk level of 10^{-6}, so we use 10 times these values to screen for a risk level of 10^{-5}.

Groundwater is a source of flow to springs and other surface water that neighboring tribal members and wildlife use. The standards for groundwater or NMWQCC's (NMWQCC 2000) surface water standards, including the wildlife habitat standards (see Chapter 6), also apply to this water.

D. MONITORING NETWORK

In 2005 the Laboratory signed a Consent Order with the NMED, which specifies the process for conducting groundwater monitoring at the Laboratory. The Consent Order requires that the Laboratory submit an Interim Facility Groundwater Monitoring Plan (Interim Plan) to the department for its approval. The first Interim Plan was approved in June 2006. Prior to approval of the Interim Plan, the Laboratory expanded the number of groundwater locations monitored during 2005 to comply with the draft Consent Order.

Table 5-1
Application of Standards to LANL Groundwater Monitoring Data

Constituent	Sample Location	Standard or DCG	Risk-Based Screening Level	Reference	Location	Notes
Radionuclides	Water Supply Wells	DOE 4-mrem Derived Concentration Guides, EPA MCLs		DOE Order 5400.5, 40 CFR 141-143	On-site and off-site	A 4-mrem/year dose rate limit and EPA MCLs apply to drinking water systems
Radionuclides	Effluent samples	DOE 100-mrem Derived Concentration Guides		DOE Order 5400.5	On site	DOE Public Dose Limit is 100 mrem/yr, applies to effluent discharges.
Radionuclides	Other groundwater samples		4-mrem Derived Concentration Guides, EPA MCLs	DOE Order 5400.5, 40 CFR 141-143	On-site and off-site	A 4-mrem/year dose rate limit and EPA MCLs are for comparison because they apply only to drinking water systems
Non-radionuclides	Water Supply Wells	EPA MCLs, NM groundwater standards, EPA 10^{-5}, and HI = 1 risk levels for NM toxic pollutants with no NM standard		40 CFR 141-143, 20.6.2 New Mexico Administrative Code, NMED Consent Order	On-site and off-site	EPA MCLs apply to drinking water systems. Use EPA Region VI table for 10^{-5} and HI = 1 risk values
Non-radionuclides	Other groundwater samples	NM groundwater standards, EPA 10^{-5} and HI = 1 risk levels for NM toxic pollutants with no NM standard	EPA MCLs	40 CFR 141-143, 20.6.2 New Mexico Administrative Code, NMED Consent Order	On-site and off-site	NMED regulations protect all groundwater. EPA MCLs are for comparison because they apply only to drinking water systems. Use EPA Region VI table for 10^{-5} and HI = 1 risk values

Groundwater sampling locations are divided into three principal groups related to the three modes of groundwater occurrence: the regional aquifer, perched alluvial groundwater in the bottom of some canyons, and localized intermediate-depth perched groundwater systems (Figures 5-5, 5-6, and 5-7). The springs and wells are described by Purtymun (1995), Nylander et al. (2003), and individual well completion reports. To document the potential impact of Laboratory operations on Pueblo de San Ildefonso land, the DOE signed a memorandum of understanding in 1987 with the Pueblo and the Bureau of Indian Affairs to conduct environmental sampling on pueblo land. Groundwater monitoring stations at Pueblo de San Ildefonso are shown in Figure 5-8 and mainly sample the regional aquifer. Basalt Spring is an intermediate groundwater sampling point, and wells LLAO-1B and LLAO-4 sample alluvial groundwater.

Water quality monitoring results are given in accompanying supplemental data tables, which include results for several boreholes. The water quality results for these borehole samples are for screening purposes indicating a need for further investigation; they cannot be used to evaluate aquifer conditions because they reflect a mixture of high-turbidity water affected by drilling fluids water and rock material from a large portion of the borehole. Following well installation, well development is used to remove aquifer and drilling materials from the well before sampling.

LANL conducts a regular program of water level measurement for monitoring wells. A summary of groundwater level measurements for 2005 is given in Allen et al. (2006).

1. Regional Aquifer and Intermediate Groundwater Monitoring

Sampling locations for the regional aquifer and intermediate perched groundwater include monitoring wells, supply wells, and springs. Wells recently constructed under the Hydrogeologic Workplan (LANL 1998) are intended for additional groundwater characterization efforts and to extend the Laboratory's groundwater monitoring system. Several of these wells were added to the monitoring well network beginning in 2002. New wells completed in 2005 are described in Chapter 2, Section B.9.b (page 56).

In the 1950s and 1960s, the Laboratory located the first regional aquifer monitoring wells where they might detect contaminants infiltrating from areas of effluent disposal or underground weapons-testing operations. These wells penetrate only a few tens or hundreds of feet into the upper part of the regional aquifer. Although the wells have surface casing to seal off entrance of surface water or shallow groundwater, the casings were not cemented, which would prevent deeper infiltration along the boreholes. The newer characterization wells were installed beginning in 1998 (Nylander et al., 2003). Some of these newer wells penetrate down to 600 ft into the regional aquifer, and several have multiple sampling ports within intermediate perched zones and the regional aquifer. A column on the supplemental data tables identifies the groundwater zones sampled by different ports of these wells and gives the depth of the port or top of the well screen.

The Laboratory collects samples from 12 deep water supply wells in three well fields that produce water for the Laboratory and the community. The water supply wells are screened up to lengths of 1,600 ft within the regional aquifer, and the wells draw samples that integrate water over a large depth range. Los Alamos County owns and operates these wells. The county is responsible for demonstrating that the supply system meets Safe Drinking Water Act requirements. This chapter reports on supplemental sampling of those wells by the Laboratory. Koch and Rogers (2003) summarized operation of the water supply system for the years 1998–2001.

Additional regional aquifer samples come from wells located on Pueblo de San Ildefonso and from the Buckman well field operated by the City of Santa Fe.

We sample numerous springs near the Rio Grande because they mainly represent natural discharge from the regional aquifer (Purtymun et al. 1980). The springs serve to detect possible discharge of contaminated groundwater from underneath the Laboratory into the Rio Grande.

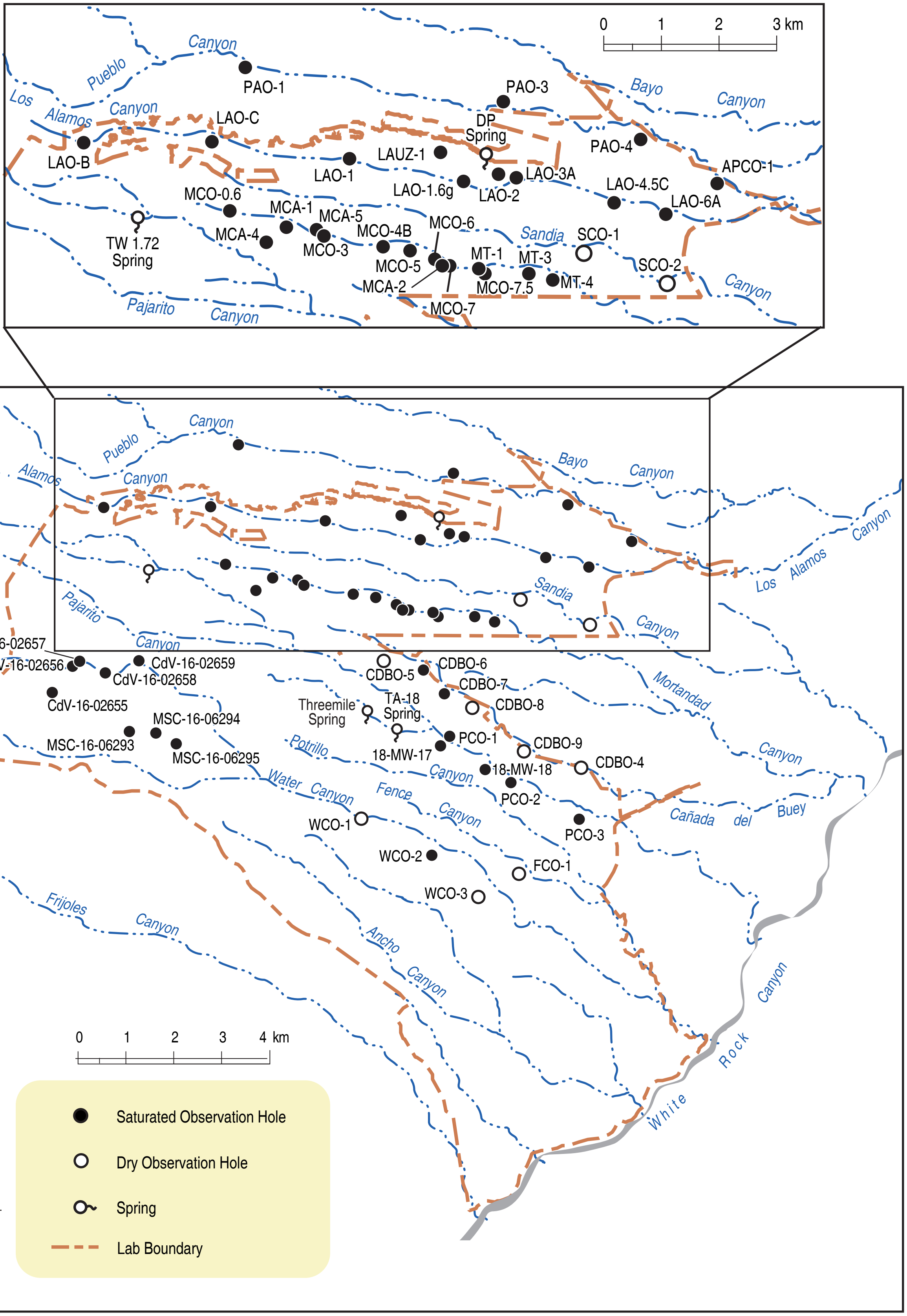

Figure 5-5. **Springs and wells used for alluvial groundwater monitoring.**

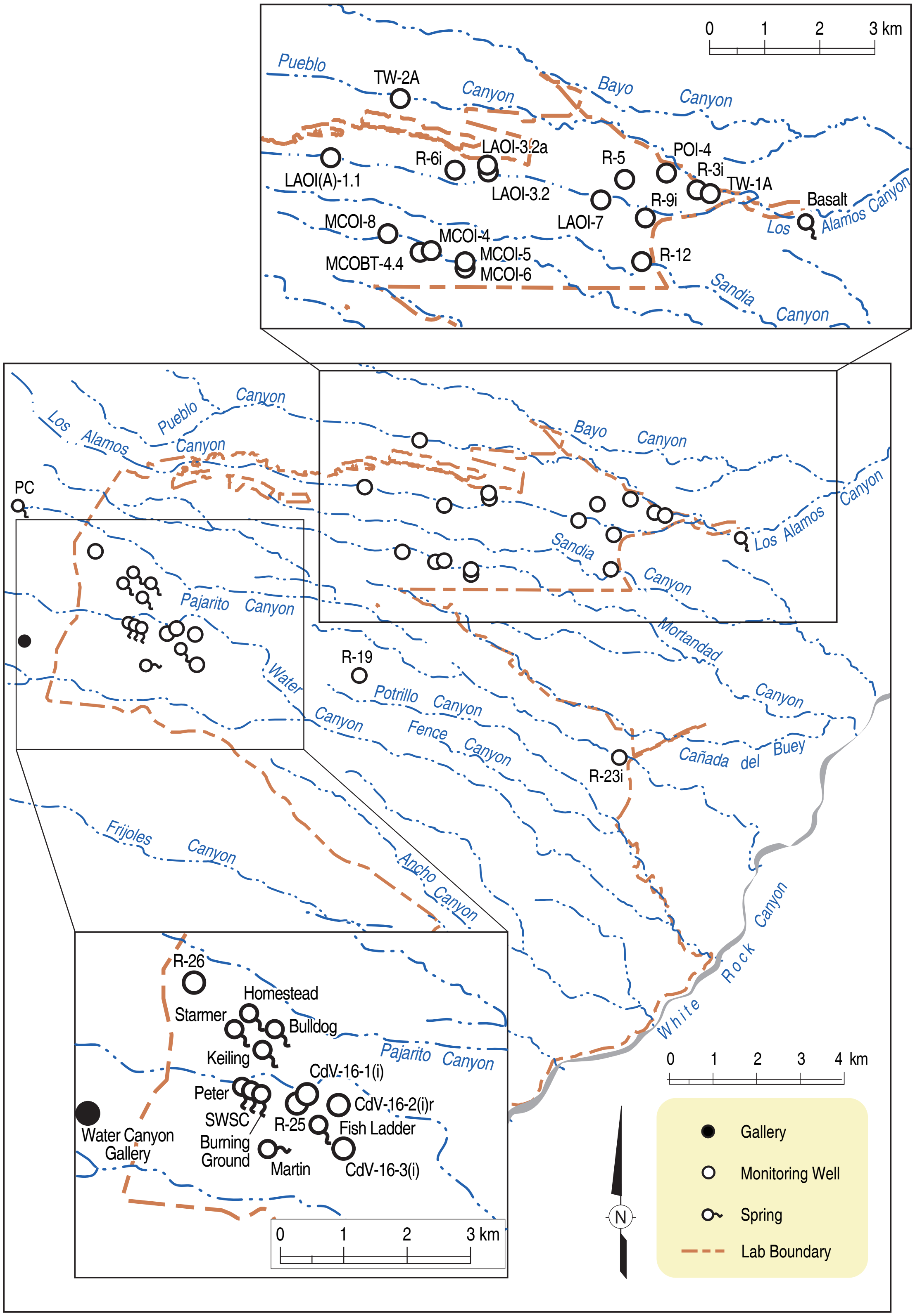

Figure 5-6. Springs and wells used for intermediate perched zone monitoring.

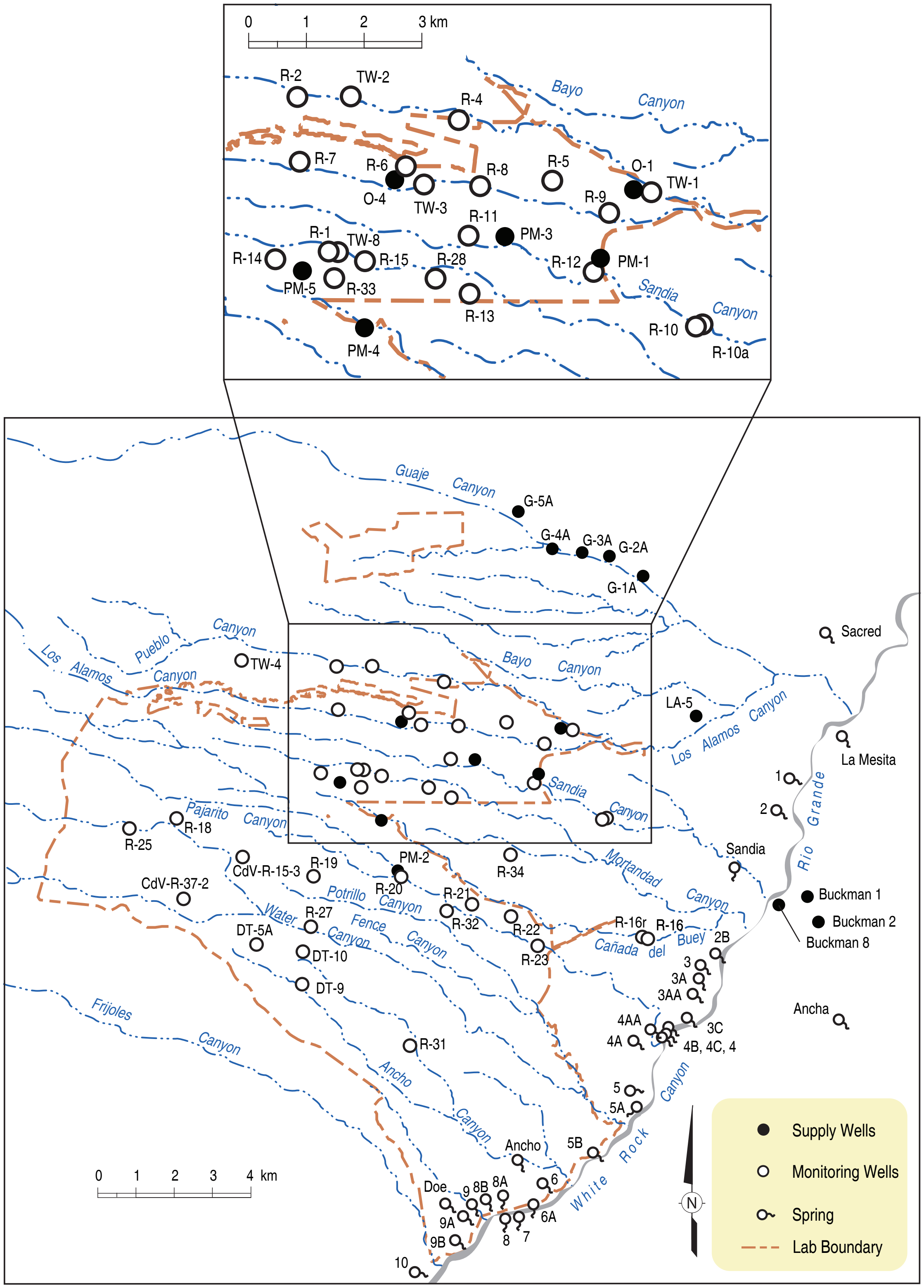

Figure 5-7. Springs and wells used for regional aquifer monitoring.

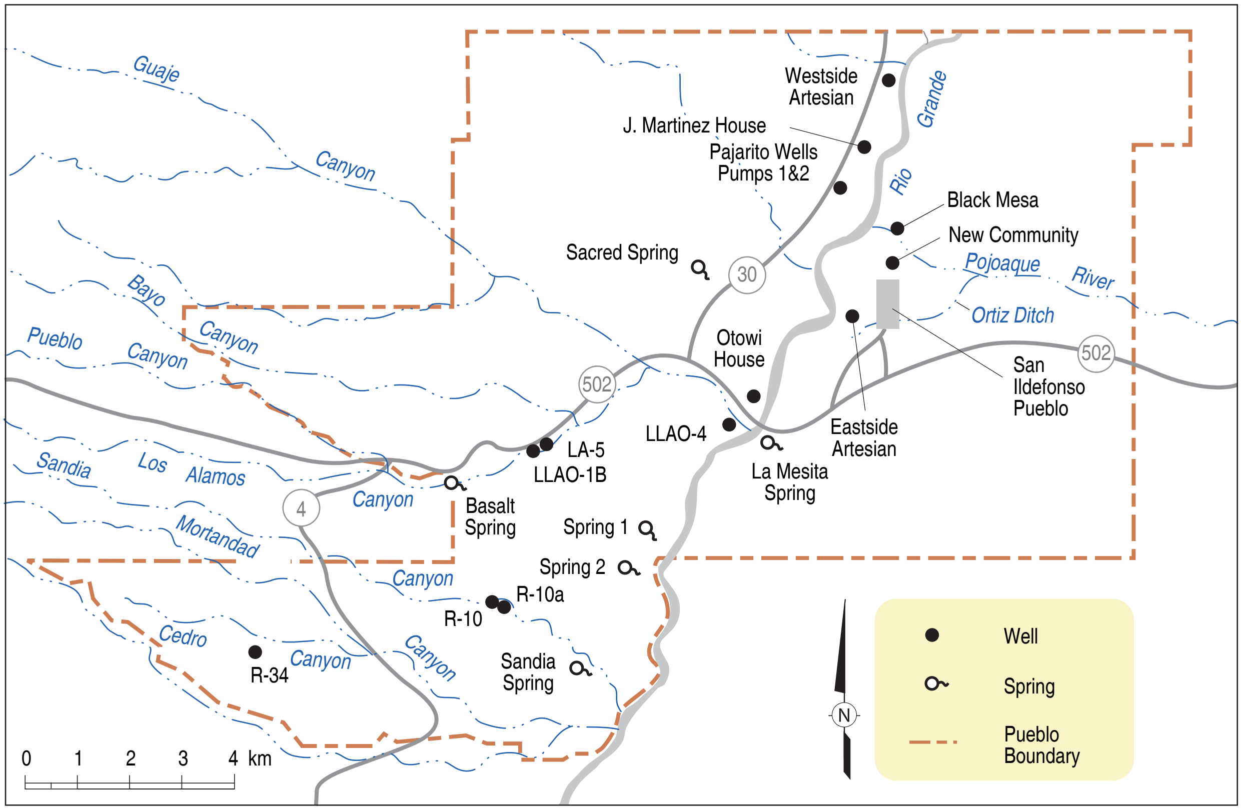

Figure 5-8. Springs and wells used for groundwater monitoring on Pueblo de San Ildefonso.

2. Alluvial Groundwater Monitoring

To determine the effect of present and past industrial discharges on water quality, we use shallow wells and some springs to sample perched alluvial groundwater in several canyons (Pueblo, Los Alamos, Mortandad, and Pajarito Canyons, Cañon de Valle, and Cañada del Buey). In any given year, some of these alluvial observation wells may be dry, and water samples cannot be obtained. Some observation wells in Water, Fence, and Sandia Canyons have most often been dry since their installation in 1989. All but one of the wells in Cañada del Buey are generally dry.

E. GROUNDWATER SAMPLING RESULTS BY CONSTITUENTS

Supplemental data tables present groundwater monitoring data for 2005. Columns on the data tables identify the groundwater zones sampled—whether alluvial, intermediate, or regional—and indicate if the location is a spring. For wells with several sampling ports, the the depth and groundwater zone sampled for each port appear in the table. For single screen wells, the depth of screen top is given. Springs have a depth of 0, and wells with unknown depth list a value of –1. Supplemental data Table S5-1 provides definitions for sample description codes used in the data tables.

Supplemental data Table S5-2 lists the results of radiochemical analyses of groundwater samples for 2005. The table also gives the total propagated one-sigma (one standard deviation) analytical uncertainty and the analysis-specific minimum detectable activity (MDA), where available. Uranium was analyzed by chemical methods and by isotopic methods. Table S5-3 shows low-detection-limit tritium results from analyses done by the University of Miami. Table S5-4 lists radionuclides detected in groundwater samples.

Two analytical methods are reported for University of Miami tritium laboratory results (Table S5-3): a higher detection limit analysis, method "LL," and the low detection method results by method "LLEE." If we are not certain that a sample has an activity less than 100 pCi/L, the tritium laboratory first counts the sample using LL until they are satisfied that it is below 100 pCi/L. In this case, they stop the counts and analyze the sample with

LLEE. The tritium laboratory no longer reports the LL values in cases where the sample is analyzed by LLEE, as the LL samples are only screening results in those cases.

A data interpretation issue relates to comparing values determined by the two methods, as the incomplete count for the less-sensitive method indicates an apparent detection at a higher value. One example is a result for the regional aquifer at R-22, at 907 ft, of 86 pCi/L by LL, with a corresponding LLEE result of 3 pCi/L. Both results are presented as detections. This LL value is well below the 10 sigma quantitation limit (meaning that it is not quantified), but above the 3 sigma detection limit based on the reported uncertainties. Thus, the LL and LLEE results are in agreement given the uncertainties, but the LL results have far less precision. The LLEE results are similar to earlier values from R-22.

For most radionuclide measurements, we report a detection as an analytical result that does not include an analytical laboratory (or in some cases, secondary validation) qualifier code of X or U (indicating nondetect). University of Miami tritium data do not have laboratory qualifiers; in that case, a result is reported as detected when analytical results are greater than three times the reported (one sigma) uncertainty.

Qualifier codes are shown in Supplemental Table S5-4 to provide additional information on analytical results that are not detections; in some cases, for example, the analyte was found in the laboratory blank, or there were other analytical issues. The table shows two categories of qualifier codes: those from the analytical laboratory and those from secondary validation (Tables S5-5, S5-6, and S5-7 in the Data Supplement). After we receive the analytical laboratory data packages, the packages receive secondary validation by an independent contractor, Analytical Quality Associates (AQA). The reviews by AQA include verifying that holding times were met, that all documentation is present, and that analytical laboratory quality control measures were applied, are documented, and are within contract requirements.

Because gross alpha and gross beta are usually detected in water samples, Table S5-4 indicates occurrences of these measurements above threshold values. We selected threshold levels of 5 μg/L for uranium, 5 pCi/L for gross alpha, and 20 pCi/L for gross beta, which are lower than the respective EPA MCLs or screening levels. The right-hand columns of Table S5-4 compare results to the standards shown on the table. For gross alpha, the DCG assumes that the radioactivity comes solely from americium-241 plus plutonium-239,240 and for gross beta, from strontium-90; thus, the gross alpha and gross beta DCG values are for screening purposes and are conservative.

Supplemental Table S5-8 lists the results of general chemical analyses of groundwater samples for 2005. Table S5-9 lists groundwater perchlorate results. We analyzed samples for perchlorate by two methods. This table includes all perchlorate results determined by the liquid chromatography/mass spectrometry/mass spectrometry (LC/MS/MS) method (now EPA 6850 Modified, formerly SW-846:8321A[M]) and all detections by the ion chromatography (IC) method (EPA:314.0). The method detection limit (MDL) for the IC method is 4 μg/L; the LC/MS/MS method MDL is 0.05 μg/L or larger if the sample had higher concentrations and was analyzed using sample dilution. We use both methods because LC/MS/MS by SW-846 6850 (or EPA 6850 Modified) for perchlorate has not yet been officially promulgated by the EPA (expected in December of 2006). The results of trace metal analyses appear in Table S5-10.

In the following sections, we discuss groundwater quality results for each of the three groundwater modes in the major watersheds that encompass the Laboratory. The accompanying maps depict the extent of groundwater contaminants that exceed regulatory or risk levels. The maps provide a spatial context for distribution of groundwater contamination. Rather than showing data for 2005 alone, the maps represent a synthesis of the last several years of groundwater data collected for Laboratory groundwater monitoring and characterization programs.

The contaminant distribution maps show contaminant locations extrapolated beyond the area covered by monitoring wells. This extrapolation takes into account the location of contaminant sources and direction of groundwater flow. Question marks on the maps indicate where contaminant extent is inferred, but not confirmed by monitoring coverage. For alluvial groundwater in canyons, the extent of contamination lateral to the canyon is not to scale: contaminated groundwater is confined to the canyon bottom alluvium and is quite narrow at the map scale.

1. Organic Chemicals in Groundwater

In 2005, we analyzed samples from selected springs and monitoring wells for organic constituents. Table S5-11 summarizes stations sampled and organic chemical suites for which samples were analyzed. These samples were analyzed for some or all of the following organic chemical suites: volatile organic compounds, semivolatile organic compounds, polychlorinated biphenyls (PCBs), pesticides, diesel-range organics (DROs), and HEs. The quality assurance section of this chapter, Section G, covers analytes and analytical methods.

a. Organic Sample Quality Control Program

Because of the sensitive nature of organic chemical sampling and analysis, a carefully designed field and analytical laboratory quality control program is essential for evaluating the presence of organic constituents in environmental samples. Organic analytes may be detected in field quality control samples such as field blanks or equipment blanks, indicating that they are not truly present in associated groundwater samples. These analytes may be present in the quality control samples because of inadvertent contamination of sampling or analytical laboratory equipment by organic constituents that come from other sources.

We rejected many of the possible organic detections that the analytical laboratory reported because the compounds were either detected in method blanks (that is, they were introduced during laboratory analysis) or were detected in field quality control (QC) samples, including equipment and trip blanks. Equipment blanks use distilled water with which sampling equipment is rinsed before sampling to check for organic contamination acquired during sampling. Trip blanks accompany samples during sample preparation, transportation, and shipment to determine if organic contamination occurs. Table S5-12 shows organic compounds detected in 2005 and results from field QC samples.

Most analytical methods require the analysis of laboratory-prepared method blanks or instrument blanks with each batch of samples. Target organic chemicals that are detected in these blanks indicate contamination from the sampling or analytical environments. Certain organic compounds used in analytical laboratories are frequently detected in laboratory blanks, that is, contamination introduced by the analytical process is common for these compounds. These compounds include acetone, methylene chloride, toluene, 2- butanone, di-n-butyl phthalate, di-n-octyl phthalate, and bis(2-ethylhexyl)phthalate (Fetter 1993). Numerous field, trip, and equipment blanks collected during this reporting period contained toluene, acetone, butanone[2-], and hexanone[2-], which indicates inadvertent sample contamination in either the field or analytical laboratory.

2. Radioactivity in Groundwater

In 2005, no regional aquifer radioactivity analyte activity or concentration values exceeded the 4-mrem DOE DCGs applicable to drinking water in groundwater samples, other than naturally occurring radionuclides (for example, radium-226 and uranium-234). The main radioactive element detected in the regional aquifer is naturally occurring uranium, found in springs and wells throughout the Rio Grande Valley. The large gross alpha values found in samples from springs and wells in the Rio Grande Valley result from the decay of naturally occurring uranium in the water. Other naturally occurring radioactivity in groundwater samples comes from members of the uranium-235, uranium-238, and thorium-232 decay chains. Potassium-40 is also a source of natural radioactivity.

For well samples from intermediate perched groundwater, several wells in Mortandad Canyon had tritium activities that were close to or above screening levels. Tritium in MCOBT-4.4 was above the EPA MCL of 20,000 pCi/L and three other wells had tritium values ranging from 20 percent to 65 percent of the MCL.

For radioactivity from a DOE (LANL) source, perched alluvial groundwater results for the following constituents were near or exceeded the 4-mrem DOE DCGs applicable to drinking water (which we use as a screening level because the DCGs are not applicable to the alluvial groundwater itself, which is not a source of drinking water): strontium-90 from alluvial groundwater in Mortandad and DP/Los Alamos Canyons; total uranium in Mortandad Canyon (likely an outlier) and Cañon de Valle; and americium-241, plutonium-238, and plutonium-239,240 in Mortandad Canyon. The maximum strontium-90 values in alluvial groundwater from Mortandad and DP/Los Alamos Canyon were also above the EPA MCL which we use as a screening level (Figure 5-9). Total LANL-derived radioactivity exceeded the 4 mrem screening level in alluvial groundwater samples from Los Alamos Canyon (due to strontium-90 in DP Spring and well LAUZ-1) and Mortandad Canyon (wells MCA-5, MCO-4B, MCO-5, MCO-6 and MCO-7) (Figure 5-10). Gross beta values in some samples from alluvial wells in Mortandad and DP/Los Alamos Canyon exceeded the EPA 50 pCi/L drinking water screening level.

Our analytical laboratory (GEL) indicates that the MDA for tritium analysis by liquid scintillation counting lies between about 140 pCi/L and 230 pCi/L, averaging about 200 pCi/L. For 2005, using this analytical method, several groundwater results between 145 and 238 pCi/L are indicated as detections but reanalyses at a detection limit of 1 pCi/L resulted in no detection of tritium for many of these samples.

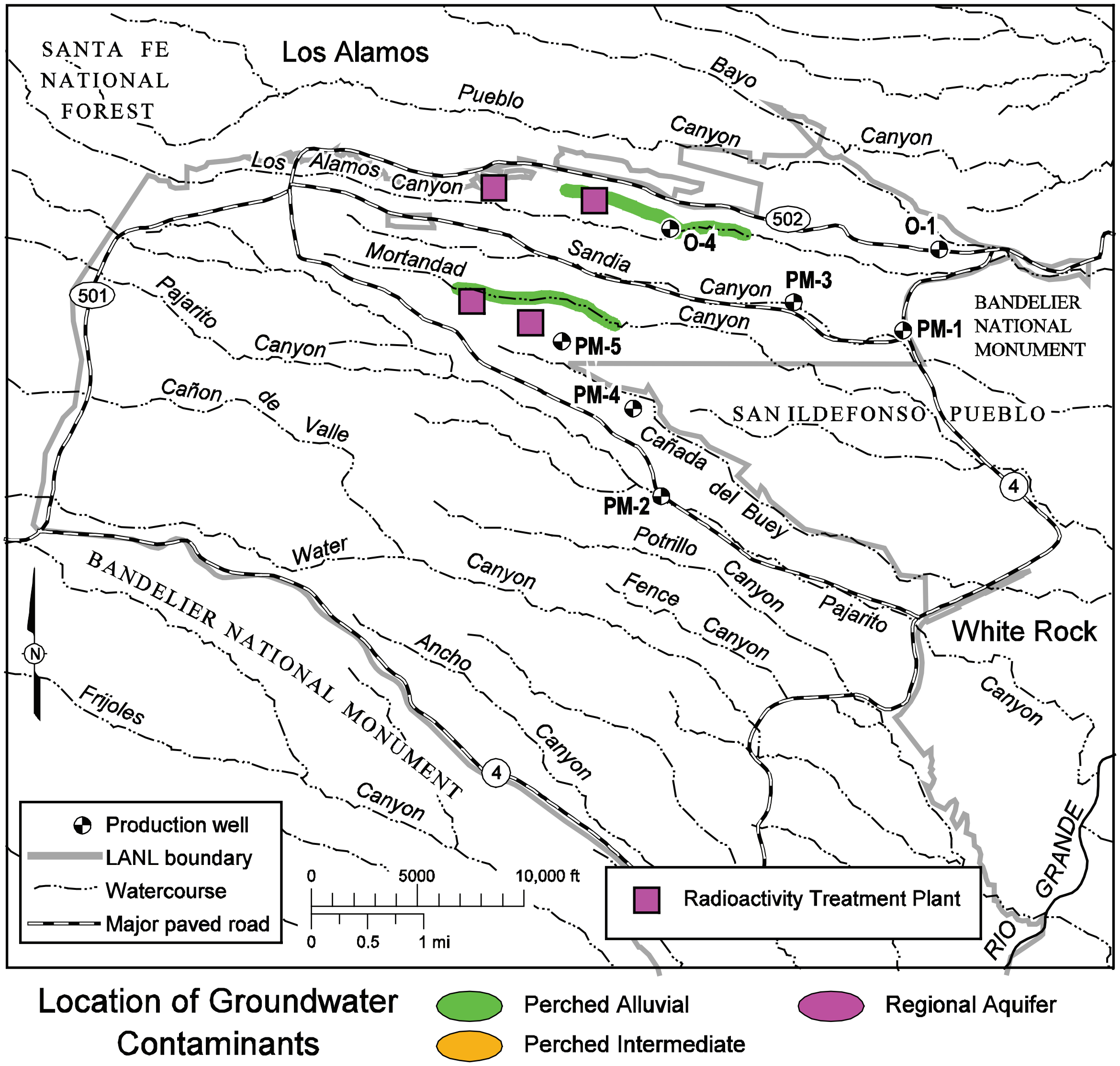

Figure 5-9. **Location of by strontium-90 above the 8 pCi/L EPA MCL. Different colors indicate the affected groundwater zones. Along canyons, the extent of alluvial groundwater contamination lateral to the canyon is not to scale: contamination is confined to the alluvium within the canyon bottom and is narrow at the map scale.**

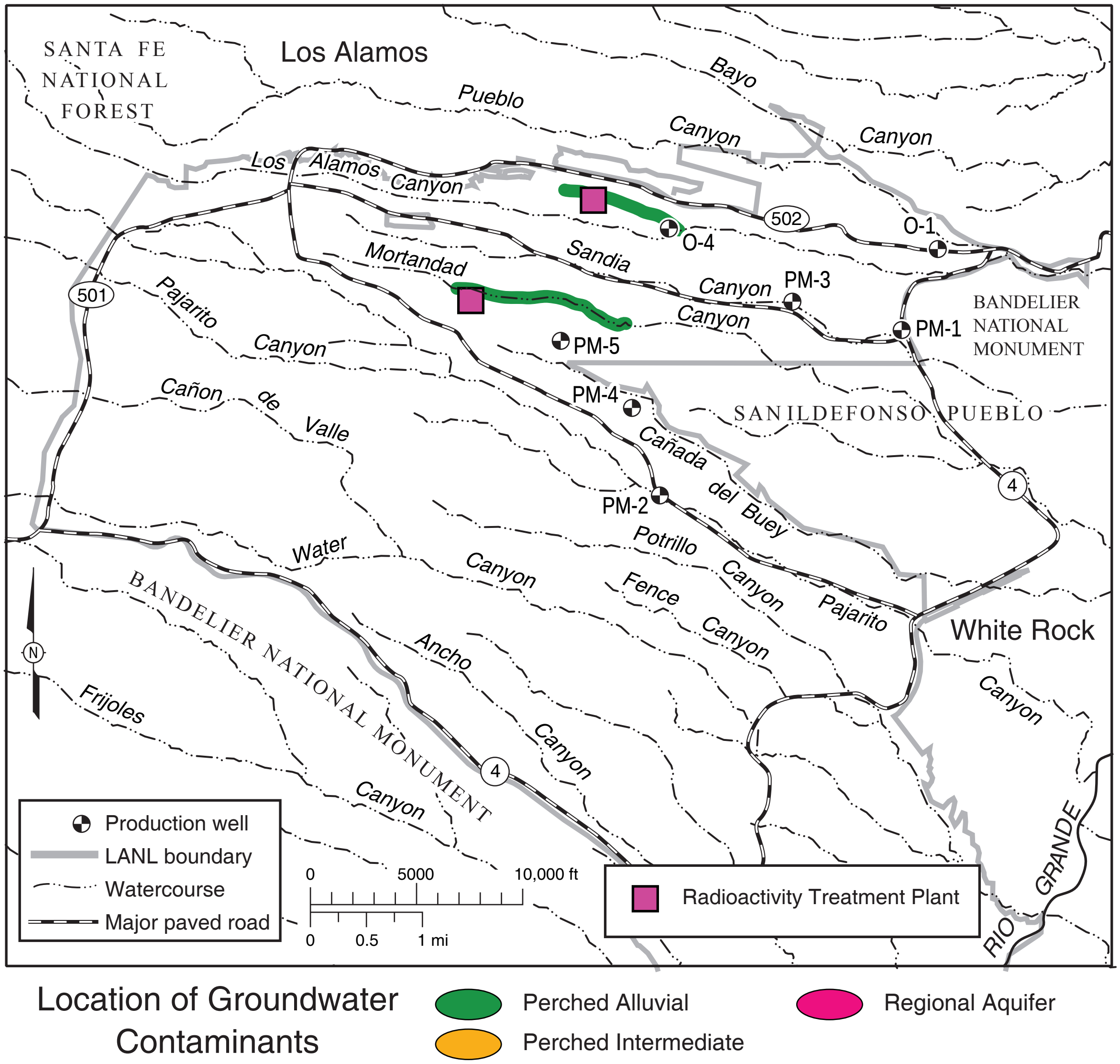

Figure 5-10. **Location of strontium-90, plutonium-238, plutonium-239,240, and americium-241 above the screening level of 4-mrem DOE DCG for drinking water. The 2005 maximum value was in Mortandad Canyon alluvial groundwater at well MCA-5. Different colors indicate the affected groundwater zones.**

3. Perchlorate in Groundwater

During the last decade, the EPA has recognized the potential for perchlorate toxicity at concentrations in the µg/L range. Based on a new toxicity assessment by the National Academy of Sciences, the EPA set a Drinking Water Equivalent Level of 24.5 µg/L for perchlorate in 2006.

LANL and the NMED DOE Oversight Bureau have found perchlorate in most groundwater samples analyzed from across northern New Mexico. This result suggests that perchlorate has widespread occurrence in groundwater at concentrations below 1 µg/L. Numerous studies (Bao et al. 2004; Michelski et al. 2004, Plummer et al., 2006) show that perchlorate is formed naturally in the upper atmosphere, is deposited on the earth's surface by precipitation, and accumulates in soils and groundwater of arid regions. Perchlorate in arid region groundwater may also arise from other sources such as fertilizers, or from natural sources like mineral weathering or electrochemical reactions (Jackson et. al 2005). Jackson reported that perchlorate was present in 73 percent of 217 public water supply wells across a large portion of northwest Texas, with 35 percent at levels near or above 4 µg/L.

The NMED DOE Oversight Bureau's recent unpublished study concluded that a value of 0.6 µg/L constitutes an upper limit for background for naturally occurring perchlorate in local groundwater samples. The perchlorate concentrations in samples not affected by known contaminant sources range from nondetect (<0.05 µg/L) to 0.85 µg/L. Several wells and a spring upstream of LANL and east of the Rio Grande (hence unaffected by LANL discharges) have perchlorate values of 0.52 µg/L, 0.60 µg/L, and 0.85 µg/L. Plummer et al. (2006) found perchlorate concentrations ranging from 0.12 µg/L to 1.8 µg/L in samples of north-central New Mexico groundwater that have ages predating anthropogenic influence and are not affected by industrial perchlorate sources. Whether or not it is an accurate delimiter of background, the value of 0.6 µg/L appears to be a useful dividing line. Many, but not all, water samples from LANL locations show perchlorate concentrations below 0.6 µg/L, but samples taken downstream from inactive perchlorate release sites show concentrations above that value.

4. Metals in Groundwater

In 2005 LANL found hexavalent chromium in Mortandad Canyon monitoring well samples from the regional aquifer at levels above the NM groundwater standard and in intermediate depth groundwater at levels just below the NM groundwater standard. Barium occurs at concentrations above the NM groundwater standard in alluvial groundwater beneath Cañon de Valle, and molybdenum concentrations have been near the NM groundwater standard in Los Alamos Canyon alluvial groundwater for over a decade. Other metals occur in groundwater at concentrations near or above regulatory standards because of well-sampling and well-construction-related issues rather than LANL releases. In some LANL characterization wells, the use of fluids to assist well drilling impacted chemistry of groundwater samples (Bitner 2004, ERSP 2005). New wells undergo extensive well development to reduce the turbidity of water samples and to remove drilling fluids from the rock formations. Effects of drilling fluid on water quality appear to linger longer in multiple completion wells than in single completion wells because the latter can be developed more vigorously. Well screens installed in lower permeability zones are also difficult to develop.

Most Pajarito Plateau groundwater is under chemically oxidizing conditions, meaning that free oxygen is dissolved in the water. Addition of organic matter in drilling fluids into the aquifer near a well stimulates bacterial activity, which reduces available oxygen and changes the chemical behavior of several constituents found in groundwater and adjacent aquifer material. With reducing conditions (absence of oxygen), the solubility of metals such as manganese and iron increases, and they are dissolved from the surface of minerals that make up the aquifer's rock framework or possibly from well fittings. Several other chemical constituents may also increase or decrease in concentration as a result of the mainly temporary effect of the drilling fluids on the region near the well (Bitner 2004, ERSP 2005).

In addition to the effect of drilling fluids, well samples may have relatively high turbidity. The presence in water samples of residual aquifer material leads to detection of metals, such as aluminum, iron, and manganese, which are primary constituents of the silicate and other minerals that make up the aquifer framework. These effects of turbidity on water quality (with high values of iron, manganese, and aluminum) are also seen in many samples from alluvial wells and springs (in the case of springs, because they incorporate surrounding soil material).

The older LANL test wells have steel casings and galvanized metal well fittings that are subject to rust and metal flaking. Over time and with wear, corrosion, and work on the wells, water samples have shown increasing content of metals like iron, lead, manganese, and zinc.

A number of groundwater samples have selenium results that exceed the NM Livestock Watering Standard of 5 µg/L. All but one of these results were analyzed using SW-846:6010B, which has a nominal detection limit of 6 µg/L. Nearly all of the detections using this method were estimated. We plan to revise methods used for analysis of selenium in surface and groundwater to obtain more sensitive results.

F. GROUNDWATER SAMPLING RESULTS BY WATERSHED

1. Guaje Canyon (includes Rendija and Barrancas Canyons)

Guaje Canyon is a major tributary in the Los Alamos Canyon watershed that heads in the Sierra de los Valles and lies north of Laboratory land. The canyon has not received any effluents from LANL activities. The Guaje well field, located northeast of the Laboratory, contains five water supply wells. No tritium was detected in low-detection-limit (1 pCi/L) analysis of samples from these wells (Table S5-3). Groundwater with such a tritium activity below approximately 1.6 pCi/L is probably old and isolated from surface recharge. The age of such groundwater is more than 3,000 years, but large dating uncertainties may be associated with small tritium activities (Blake et al., 1995).

G-1A and G-2A both had arsenic at about 12 percent of the EPA MCL of 50 µg/L. For the new MCL of 10 µg/L, which will be effective in 2006, this value would be 60 percent of the MCL. This naturally occurring arsenic has been found in this well field at such levels during its entire history. Perchlorate was found in each of the five wells at concentrations ranging from 0.25 to 0.44 µg/L, which is consistent with background levels and prior findings for these wells. We attribute the presence of two volatile organic compounds (acetone and methylene chloride) at low levels in one sample from G-1A to inadvertent contamination during sampling or analysis rather than to their presence in groundwater.

2. Los Alamos Canyon (includes Bayo, Acid, Pueblo, and DP Canyons)

a. Pueblo Canyon

Pueblo Canyon receives effluent from Los Alamos County's Bayo Sewage Treatment Plant. Acid Canyon, a tributary, received radioactive industrial effluent from 1943 to 1964. Little radioactivity shows up in groundwater at this time. Tritium and perchlorate results from regional aquifer groundwater in this canyon, though below standards, may indicate the lingering influence of past discharges from radioactive wastewater outfalls in Acid Canyon. High nitrate concentrations found in alluvial and intermediate groundwater may be due to sanitary effluent from the Los Alamos County Bayo Sewage Treatment Plant.

A low-detection-limit tritium result for supply well O-1 was 33 pCi/L, indicating a subdued effect of past tritium-bearing surface water recharge on tritium activity at the regional aquifer (this well was out of service much of the year). Three O-1 samples showed perchlorate at an average of 2.3 µg/L, and O-1 also has above-background nitrate (1.2 mg/L nitrate as nitrogen, compared to an MCL of 10 mg/L).

Low-detection-limit tritium values in Pueblo Canyon regional aquifer monitoring wells increased downstream, from nondetection at Test Well 4 above the former outfall, to 117 pCi/L at Test Well 1 (near O-1).

Regional aquifer nitrate and perchlorate values also increased downstream, with nitrate nondetect at Test Well 4 and near background (0.3 mg/L) at R-2. Test Well 1 (near O-1) showed nitrate (as nitrogen) at up to 53 percent of the 10-mg/L EPA MCL in the regional aquifer. Perchlorate was nondetect at Test Well 4, at background in R-2, and at the highest concentration for these wells in R-4 at 4 µg/L. Downstream, R-5 had 1.5 µg/L and Test Well 1 had 1.9 µg/L to 2.2 µg/L of perchlorate.

For years, samples from the older wells have shown levels of iron, lead, and manganese in the range of the EPA MCLs. These levels were related to aging steel and galvanized well components. Test Wells 4, 2, and 1 showed high levels of iron, manganese, and lead in 2005. New characterization well R-2 showed high levels of aluminum, iron, and manganese; these may be due to effects from drilling. Samples from R-2 and R-4 showed a large number of volatile and semivolatile organic compounds in field and equipment blanks, which may be the result of field or analytical laboratory contamination.

Pueblo Canyon intermediate well Test Well 2A showed 944 pCi/L of tritium, consistent with long-term trends in that well. Low-detection-limit tritium values in intermediate wells ranged from nondetection in R-5 to 24 pCi/L in POI-4 and 34 pCi/L in Test Well 1A. R-5 showed 1.1 mg/L of fluoride in the intermediate zone, 66 percent of the NM groundwater standard, which is similar to prior data. Perchlorate values from the intermediate zone were nondetection or background, except for a result of 1.5 µg/L from R-5. Older well Test Well 1A showed high iron, manganese, lead, and zinc related to aging well components. Two pesticides (DDE[4,4'-] and DDT[4,4'-]) were found in Test Well 1A; this is the first time samples from this well have been analyzed for these substances. Several other volatile and semivolatile organic compounds were found in this well, which may be the result of field or analytical laboratory contamination.

All four alluvial wells in Pueblo Canyon had strontium-90 at values ranging from 6 percent to 14 percent of the 8-pCi/L EPA MCL. Three wells had detectable plutonium-239,240 as in prior years. Perchlorate concentrations ranged from nondetect to 1.9 μg/L in well PAO-1, the farthest upstream well, located just upstream from the mouth of Acid Canyon. The wells show the effects of high turbidity by high aluminum, manganese, and iron, much of these apparently colloidal. Well APCO-1 also has high nitrate, phosphate, fluoride, turbidity, and total suspended solids; the solutes indicate the influence of sanitary effluent from the Bayo Sewage Treatment Plant, which discharges just upstream. Higher organic content of the effluent or the well's location in marshland may result in anoxic groundwater conditions, leading to higher concentrations of dissolved or colloidal manganese.

b. Los Alamos Canyon

Los Alamos Canyon received releases of radioactive effluents during the earliest Manhattan Project operations at TA-1 (1942–1945) and until 1993 from nuclear reactors at TA-2. From 1952 to 1986, a liquid-waste treatment plant discharged effluent containing radionuclides from the former plutonium-processing facility at TA-21 into DP Canyon, a tributary to Los Alamos Canyon. Los Alamos Canyon also received radionuclides and metals in discharges from the sanitary sewage lagoons and cooling towers at the Los Alamos Neutron Science Center (LANSCE) at TA-53. Except for strontium-90, contaminant concentrations in shallow groundwater have decreased dramatically over the years.

Low values of tritium were found in a few regional aquifer wells in Los Alamos Canyon, indicating a small contribution from recent recharge. Values in Test Well 3 and R-9 were 5.7 pCi/L and 14.9 pCi/L, respectively, while results from other wells were nondetections. Values in R-8 and supply well O-4 were nondetect, based on reanalyses of samples. Perchlorate in R-9 was 0.98 μg/L, while other regional aquifer and supply wells in Los Alamos Canyon were at background, that is, below 0.6 μg/L.

Several of the newer regional aquifer wells had high levels in samples of aluminum, iron, and manganese due to drilling fluid or turbidity effects. Older Test Well 3 also had significant lead (near the EPA screening level) and other metals, related to aging casing. Because of a leaking fuel tank found at TA-21 during 2002, supply well O-4 was sampled four times during 2005 for Diesel Range Organics. The compound was found in one sample near the detection limit but not in other samples, suggesting a false positive. The PCB compound Aroclor-1254 was found in one sample from R-8. The compound was not found in any of the four samples collected the previous year, so is likely an analytical artifact.

A filtered sample from Basalt Spring in lower Los Alamos Canyon, which is fed by intermediate groundwater, contained plutonium-238 just above the detection limit, as in some prior years. No plutonium-238 was detected in the unfiltered sample so the result may be a false positive. Otherwise, the plutonium may have come from surface sediments near the spring which discharges close to the streambed. Samples from intermediate wells R-6i and LAOI-3.2 contained 4300 pCi/L and 890 pCi/L of tritium, respectively. These wells both lie downstream from the former radioactive liquid waste discharge in DP Canyon. R-6i and LAOI-3.2 samples also had 8.1 μg/L and 2.5 μg/L of perchlorate.

Alluvial groundwater in DP and Los Alamos Canyons continues to show strontium-90 above the 8-pCi/L EPA MCL (Figure 5-9). The strontium-90 values in DP Spring and well LAUZ-1 were also above the 4-mrem DOE DCG screening level for drinking water dose. Several other LANL-derived radionuclides were found in alluvial groundwater, but at values well below the 4-mrem DCG screening level. Tritium levels in alluvial groundwater in these two canyons have fallen sharply since the cessation of discharges. Tritium is now present at values between 80 pCi/L to 200 pCi/L. In lower Los Alamos Canyon, a filtered sample in LLAO-4 showed plutonium-238 just above the detection limit.

Metals concentrations in alluvial wells in Los Alamos Canyon showed the effect of turbidity, with relatively high values of aluminum and iron. In Los Alamos Canyon, molybdenum in LAO-2 was 72 percent of the NM groundwater limit (Figures 5-11 and 5-12). The molybdenum came from cooling towers at TA-53 (LANSCE). Use of sodium molybdate was discontinued in June 2002. Molybdenum concentrations in Los Alamos Canyon alluvial groundwater have been quite variable in recent years, perhaps because of large variation in stream flow caused by drought conditions.

Aroclor-1260 was detected in LAO-B, a background well upstream from Laboratory contaminant sources. This is one of only two Aroclor detections in Los Alamos Canyon alluvial groundwater over more than six years, suggesting the result is a false positive.

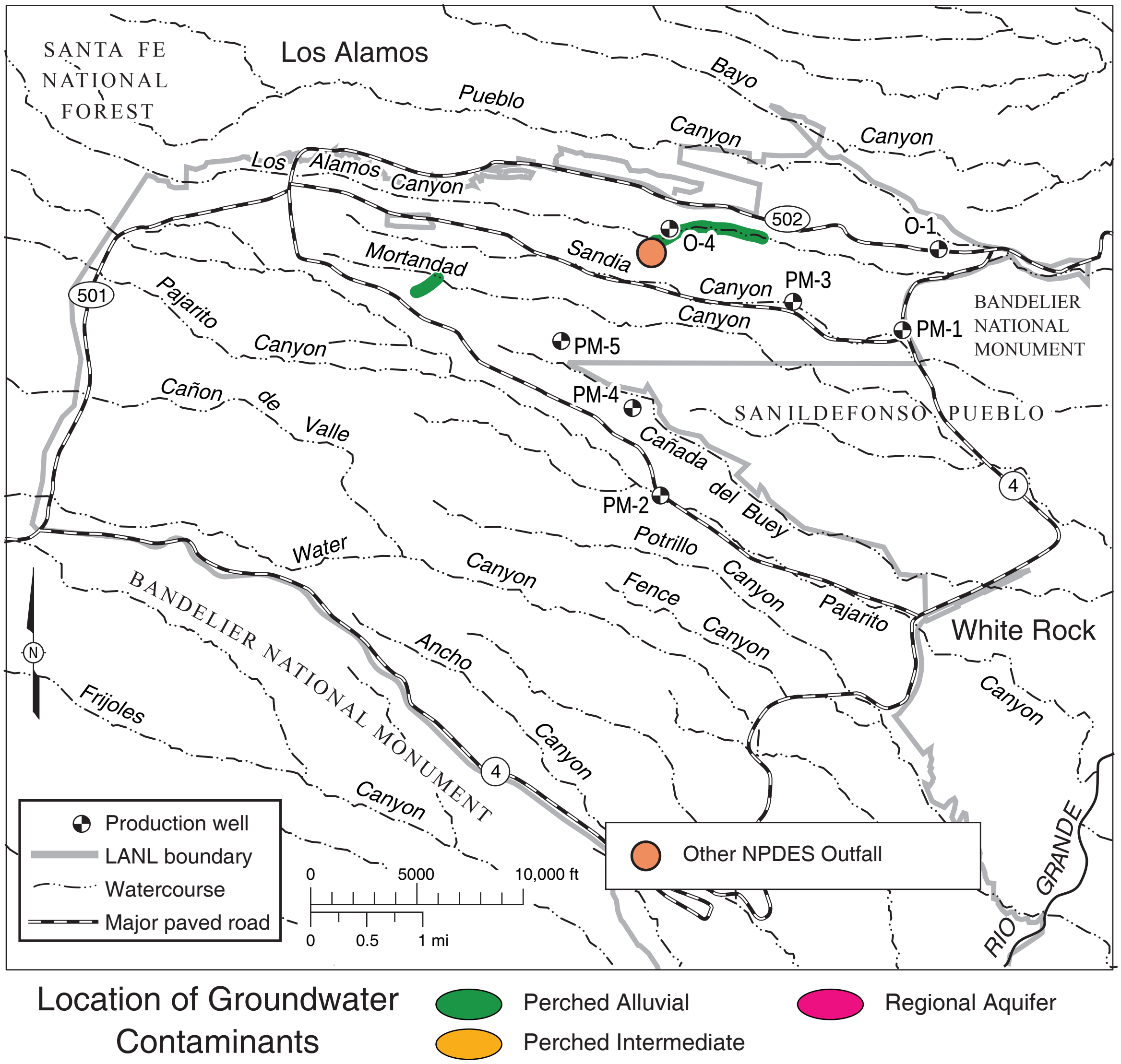

Figure 5-11. **Location of molybdenum above the 1 mg/L New Mexico groundwater standard for irrigation use. The maximum 2005 value in Los Alamos Canyon alluvial groundwater was 72 percent of the groundwater standard. Different colors indicate the affected groundwater zones.**

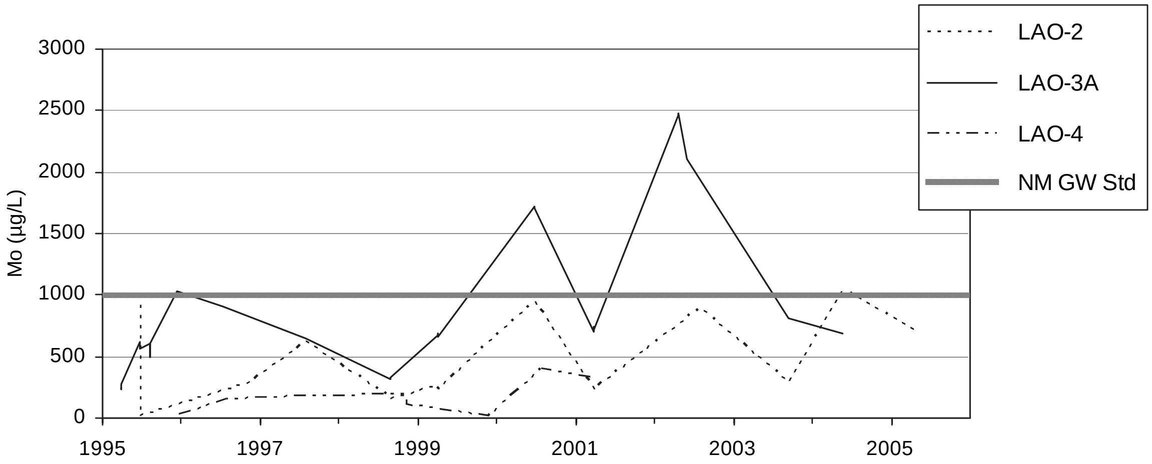

Figure 5-12. **Molybdenum concentration histories in Los Alamos Canyon alluvial groundwater compared with the New Mexico groundwater standard.**

3. Sandia Canyon

Sandia Canyon has a small drainage area that heads at TA-3. The canyon receives the largest liquid discharges of any canyon at the Laboratory from the cooling tower at the TA-3 power plant and from treated effluents from the TA-46 SWWS Plant that have been routed to Sandia Canyon since 1992. The use of chromate for treatment of cooling water at the power plant was discontinued in 1972 (ESP 1973). These discharges are tentatively identified as the source for hexavalent chromium concentrations discovered in the regional aquifer beneath Mortandad Canyon that exceed New Mexico groundwater and EPA drinking water standards by factors of 8 and 4, respectively. Sandia and Mortandad Canyons lie close together, and water infiltrating beneath Sandia Canyon may have been diverted to the south by southwesterly-dipping basalts prior to reaching the regional aquifer (ERSP 2006). Chromium concentrations in samples from regional aquifer well R-11 in Sandia Canyon averaged 20 µg/L in both filtered and unfiltered samples; later analyses show the chromium is in the hexavalent form. These concentrations are above the range for hexavalent chromium found in off-site water supply wells (up to 6 µg/L), which are remote from any LANL contaminant sources.

Samples from supply well PM-3 showed no tritium using the 1 pCi/L detection limit analytical method. Analyses of one sample from PM-1 detected tritium, whereas reanalysis of that sample and results from other samples were nondetections; these latter results indicate the detection is an analytical error.

In Sandia Canyon, perchlorate values at R-12 in intermediate groundwater and the regional aquifer were nondetects. Regional wells R-11 and R-10a had values in the range of 0.77 µg/L and 0.62 µg/L, respectively, or slightly above background. Values in supply wells PM-1 and PM-3 were about 0.42 µg/L, similar to prior results and within background.

Several intermediate and regional R-12 samples had high iron or manganese (in the range of EPA MCLs), a result of well construction and use of drilling fluids (Longmire 2002, ERSP 2005). Samples from R-10a and R-11 contained aluminum and iron above or near standards, resulting from turbidity or drilling fluids. Organic compounds detected in well samples appear to result from inadvertent low-level contamination during analysis or sampling.

4. Mortandad Canyon (includes Ten Site Canyon and Cañada del Buey)

Mortandad Canyon has a small drainage area that heads at TA-3. This drainage area receives inflow from natural precipitation and a number of National Pollutant Discharge Elimination System (NPDES) outfalls, including one from the Radioactive Liquid Waste Treatment Facility (RLWTF) at TA-50. Past discharges into tributary Ten Site Canyon included a previous radioactive effluent treatment plant at TA-35.

Cañada del Buey, a tributary to Mortandad Canyon, contains a shallow perched alluvial groundwater system of limited extent, and only two observation wells have ever contained water. Because treated effluent from the Laboratory's SWWS Facility may at some time be discharged into the Cañada del Buey drainage system, a network of five shallow groundwater monitoring wells and two moisture-monitoring holes was installed during the early summer of 1992 within the upper and middle reaches of the drainage. Past discharges included accidental releases from experimental reactors and laboratories at TA-46.

a. 2005 Radioactive Liquid Waste Treatment Facility Discharges

Data on the RLWTF's yearly radionuclide discharge into Mortandad Canyon from 2002 through 2005 appear in Table S5-13 in the Data Supplement. Table S5-13 also shows mean annual levels in effluent for each radionuclide and the ratio of this to the 100-mrem DOE DCG for public dose. Figures 5-13 and 5-14 show the relationship of RLWTF average annual radionuclide activities and mineral concentrations in discharges to DOE DCGs or New Mexico groundwater standards since 1996. The 2005 discharges from the RLWTF met all DOE and New Mexico requirements. Beginning in 1999, LANL made significant upgrades to the RLWTF treatment system. As a result, for the last six years the RLWTF has met all DOE radiological discharge standards, all NPDES requirements, and for all but two weeks has voluntarily met NM groundwater standards for fluoride, nitrate, and total dissolved solids (TDS). Two weekly composite samples exceeded the fluoride standard in 2003.

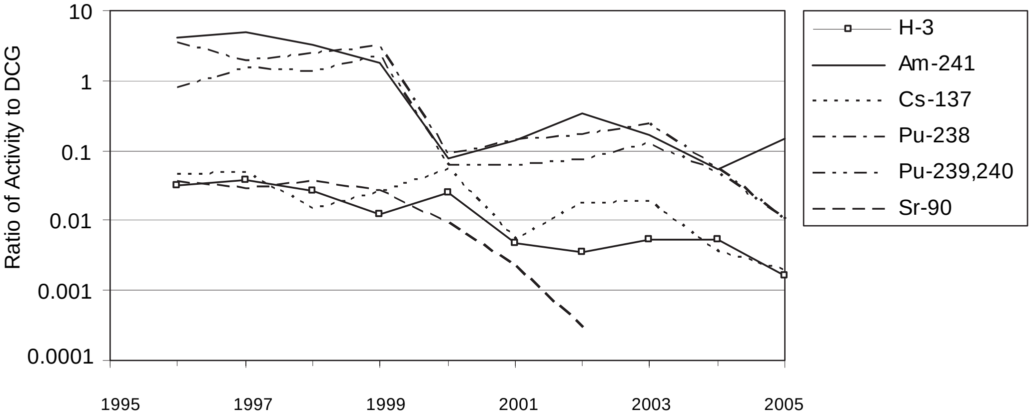

Figure 5-13. **Ratio of 1996–2005 average annual radionuclide activity in RLWTF discharges to the 100-mrem public dose DOE DCGs**

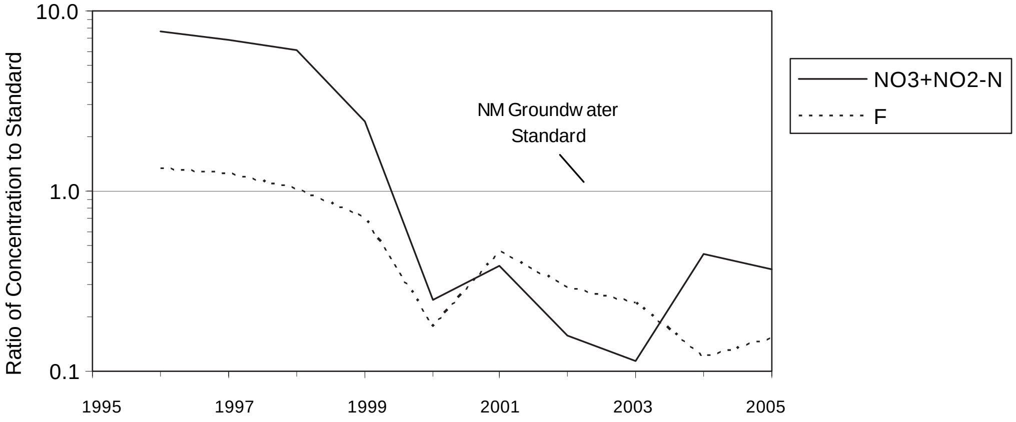

Figure 5-14. **Ratio of 1996–2005 average annual mineral concentration in RLWTF discharges to the New Mexico groundwater standards.**

During 2005, the nitrate + nitrite (as nitrogen) concentrations of all effluent discharges from the RLWTF were less than the New Mexico groundwater standard for nitrate (as nitrogen) of 10 mg/L (Figure 5-15). The average 2005 effluent total nitrate + nitrite (as nitrogen) concentration was 3.7 mg/L. In 2005, the highest nitrate concentration in a Mortandad Canyon base flow grab sample taken below the Effluent Canyon outfall was 1.6 mg/L.

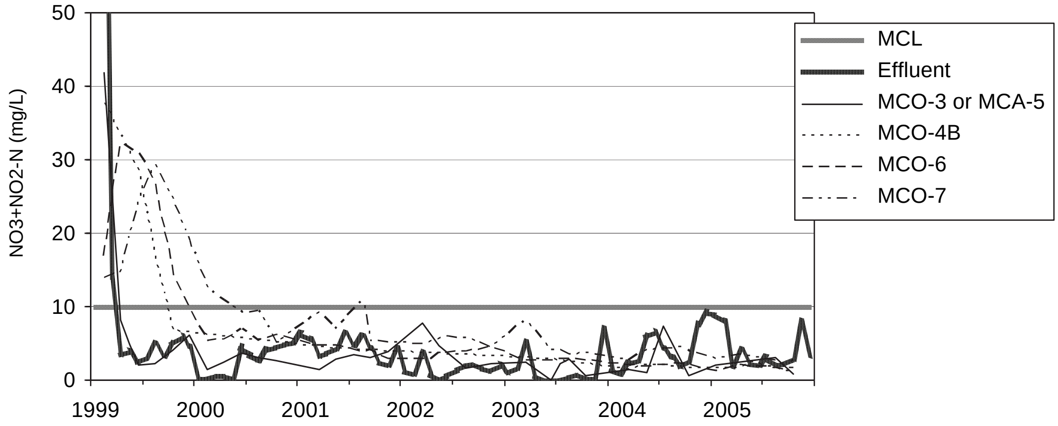

Figure 5-15. **Nitrate in RLWTF effluent and Mortandad Canyon alluvial groundwater from 1999 through 2005.**

The fluoride concentration in the discharge has also declined over the last few years (Figure 5-16). The 2005 effluent fluoride concentration (average value of 0.24 mg/L) was below the New Mexico groundwater standard of 1.6 mg/L. In 2005, the fluoride concentration in Mortandad Canyon at the surface water station Mortandad below Effluent Canyon was 0.44 mg/L.

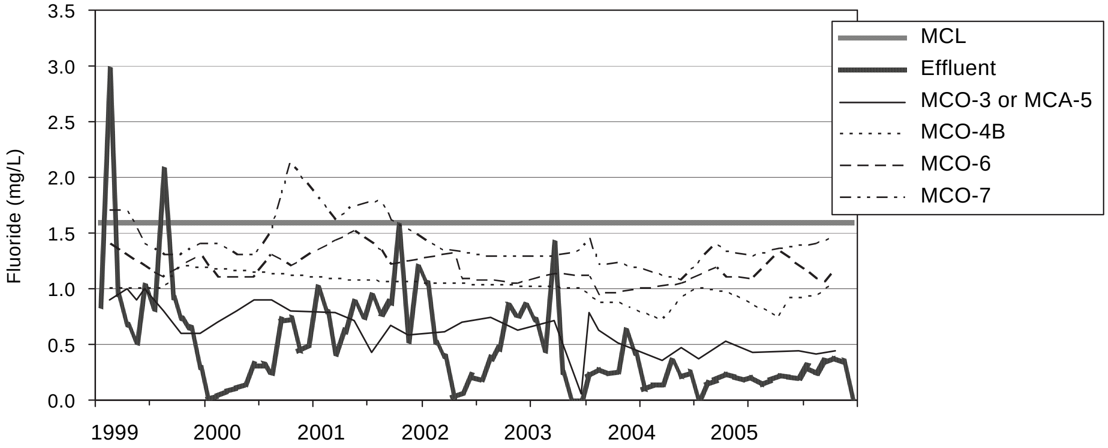

Figure 5-16. **Fluoride in RLWTF effluent and Mortandad Canyon alluvial groundwater from 1999 through 2005.**

A system for removing perchlorate from the RLWTF effluent became operational on March 26, 2002; no perchlorate has been detected in the effluent after this date (Figure 5-17). For 2005, the annual perchlorate discharge was effectively zero.

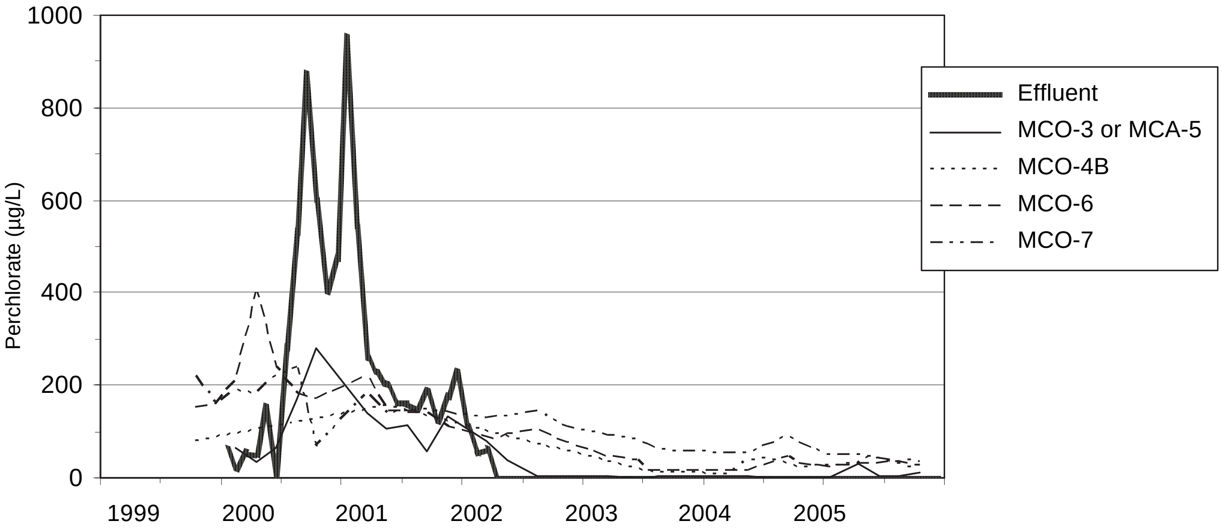

Figure 5-17. **Perchlorate in RLWTF effluent and Mortandad Canyon alluvial groundwater from 1999 to 2005.**

b. Mortandad Canyon Intermediate Groundwater and Regional Aquifer

The regional aquifer beneath Mortandad Canyon shows some impact from past LANL discharges; intermediate groundwater shows a larger effect. In 2005, sampling at regional aquifer monitoring well R-28 in Mortandad Canyon found contamination by hexavalent chromium at four times the EPA MCL of 100 µg/L (Figure 5-18) and eight times the NM groundwater standard. The Laboratory has begun investigation of this issue in cooperation with NMED, with past cooling tower discharges in Sandia Canyon identified as the likely source (ERSP 2006). MCOI-6, an intermediate groundwater well in Mortandad Canyon, consistently showed filtered chromium above the NM groundwater standard of 50 µg/L. Other intermediate wells had much higher unfiltered chromium values, which we attribute to aquifer or drilling-related materials present in the sample.

A sample from regional well R-34 had technetium-99 at 5.24 pCi/L, well below the 4-mrem DCG of 4,000 pCi/L; this result was just above the MDA; three other samples from the well and reanalysis of this sample were nondetect. Since 2000, R-15 tritium has shown an increase from 2 pCi/L to recent values of 31 pCi/L (Figure 5-19). The latest values indicate some contribution of recent recharge to the regional aquifer at R-15. A corresponding increase has occurred for perchlorate (from less than 5 µg/L to 7 µg/L), but not nitrate (Figure 5-20). The earlier perchlorate data have a MDL of 4 µg/L giving lower precision for that period. Possible explanations for the increase in tritium and perchlorate levels include lingering effects of well installation with a delay in return to predrilling values (perhaps caused by addition of water during drilling or well development), or some change of concentration within the surrounding groundwater during this time. R-28 has tritium values up to 181 pCi/L and perchlorate concentrations in the range of 1 µg/L; these results along with the chromium levels indicate impact of LANL effluents. No other regional aquifer well in Mortandad Canyon had repeatable low-detection limit tritium detections, and other perchlorate values were below 0.5 µg/L.

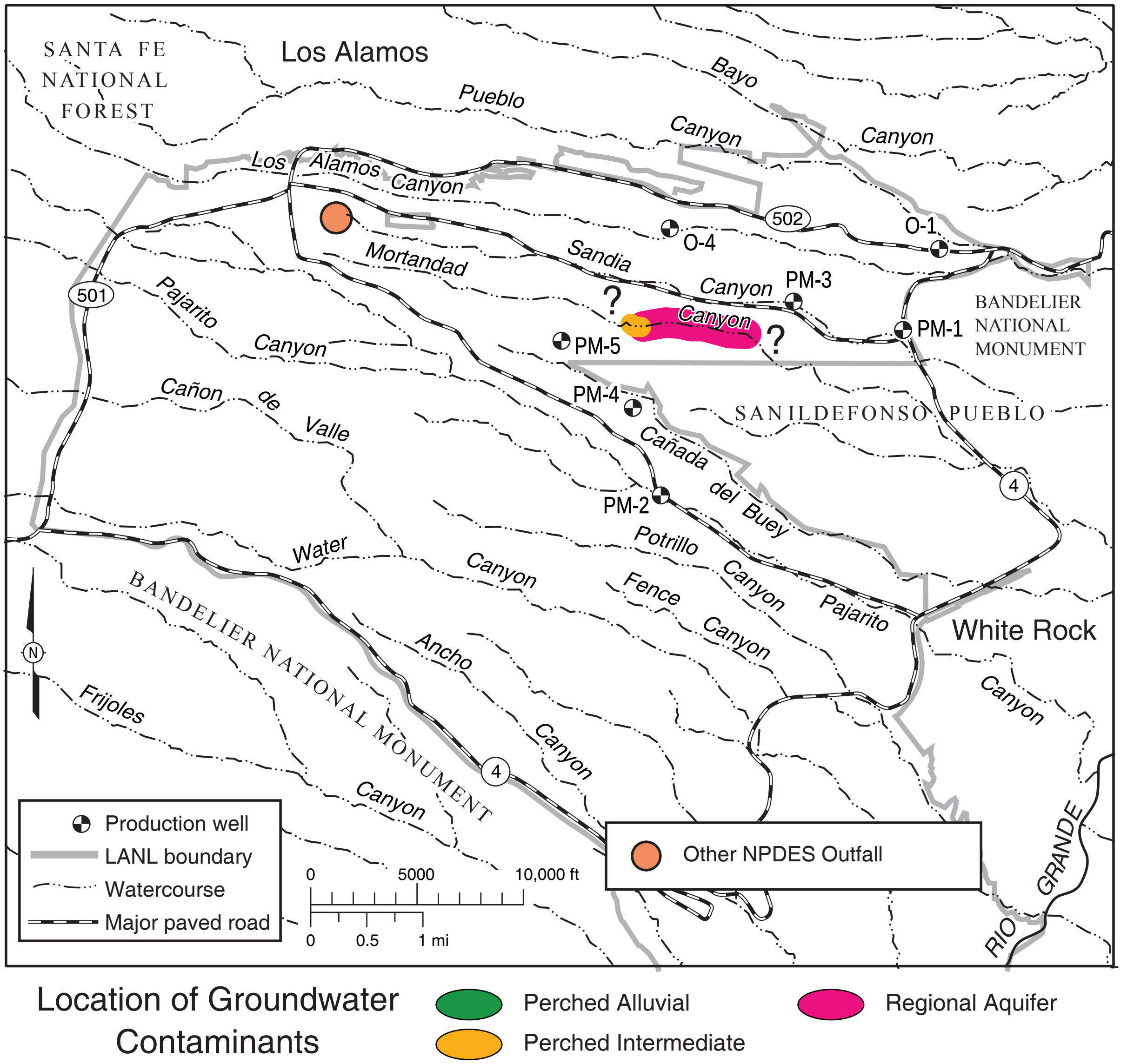

Figure 5-18. **Location of hexavalent chromium above the 50 µg/L New Mexico Groundwater Standard. The maximum 2005 value in the regional aquifer was over eight times the groundwater standard. Different colors indicate the affected groundwater zones. The extent of intermediate groundwater and regional aquifer contamination is based on a limited number of wells: question marks on the maps indicate where contaminant extent is inferred, not necessarily substantiated.**

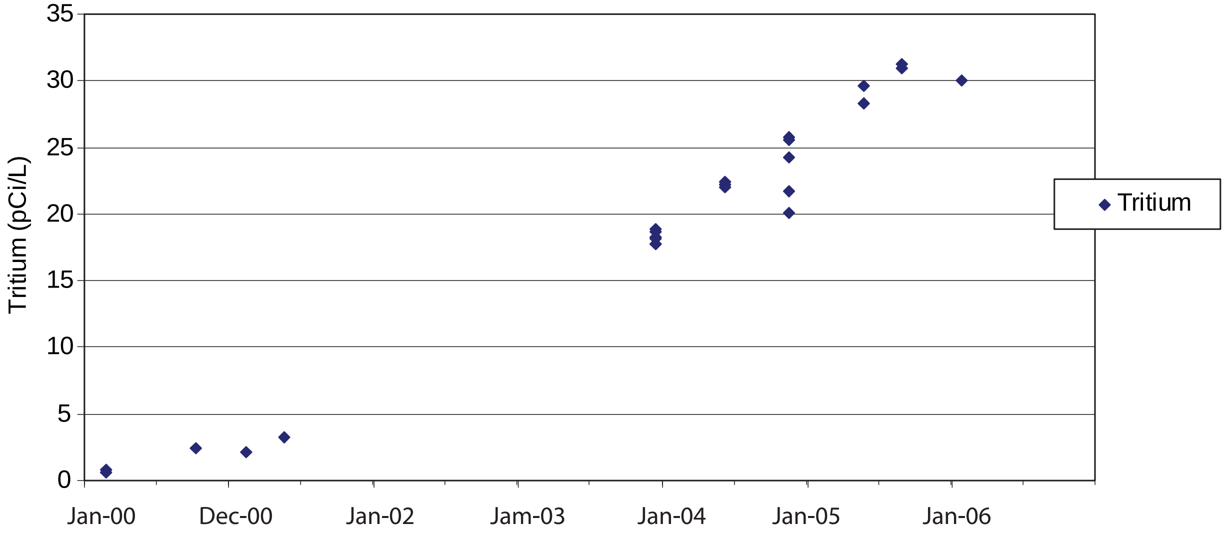

Figure 5-19. **Tritium history in Mortandad Canyon regional aquifer well R-15.**

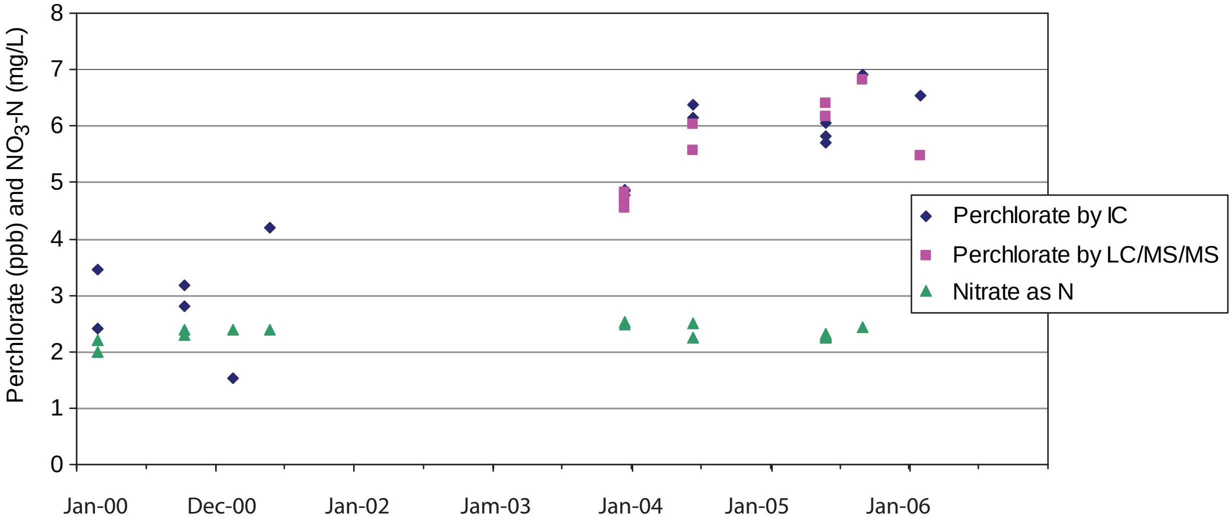

Figure 5-20. **Perchlorate and nitrate histories in Mortandad Canyon regional aquifer well R-15.**

Several regional wells in Mortandad Canyon had other metals present at concentrations near or above groundwater standards. Aluminum, iron, and manganese are related to turbidity or drilling fluid effects. Arsenic was found in a few samples, but not consistently. Filtered and total chromium results in R-28 have been above 400 µg/L and have been confirmed as hexavalent chromium by separate analysis. R-33 had one filtered nickel result in June 2005 at 1124 ft of 168 µg/L; the unfiltered value was 25 µg/L. Two turbidity measurements were 0.97 NTU and 24 NTU; this wide range suggests a large change in water quality during sampling which may be the source of the high nickel result. Subsequent nickel values from two sampling events for R-33 at this depth average 30 µg/L for filtered and 15 µg/L for unfiltered samples. Iron concentrations were near the EPA secondary drinking water standard of 300 µg/L, but no other metal concentrations were elevated.

Several PAH compounds were found in reanalysis of a sample from R-14 at 1,204 ft, but not in the original analysis or in three prior or one subsequent samples. This suggests that, rather than the compounds being present in the groundwater sample, the results are analytical artifacts.

Contaminants found in Mortandad Canyon intermediate groundwater indicate an impact by LANL effluents, with several compounds above regulatory standards. In intermediate perched groundwater from four wells, tritium was found at activities ranging from 4,300 pCi/L to 23,500 pCi/L; the latter value is just above the MCL of 20,000 pCi/L (Figure 5-21). At MCOI-8, the well farthest upstream toward the effluent discharge location, the tritium value was 136 pCi/L. Technetium-99 was detected in three wells at values from 2.6 pCi/L to 7.9 pCi/L; the values are near the detection limit and well below the 4-mrem DCG of 4,000 pCi/L. Nitrate (as nitrogen) in three of the wells ranged from 13 mg/L to 16.8 mg/L, all above the NM groundwater standard of 10 mg/L (Figure 5-21). Perchlorate was not detected in the well farthest upstream (MCOI-8) but in four other wells ranged from 81 μg/L to 256 μg/L; the EPA's Drinking Water Equivalent Level is 24.5 μg/L (Figure 5-22).

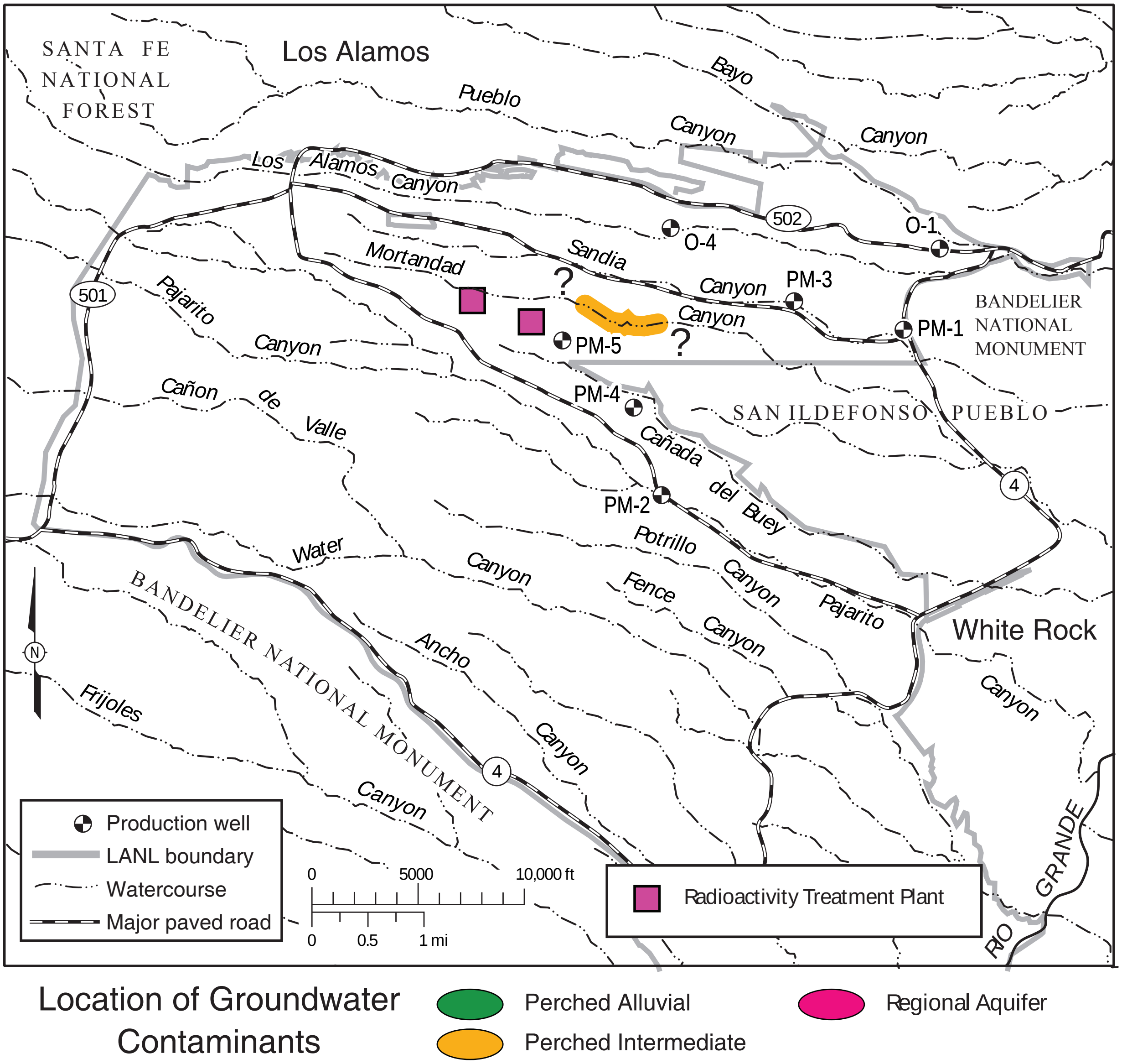

Figure 5-21. **Location of nitrate (as nitrogen) above the 10 mg/L EPA MCL and tritium above the 20,000 pCi/L EPA MCL. Different colors indicate the affected groundwater zones.**

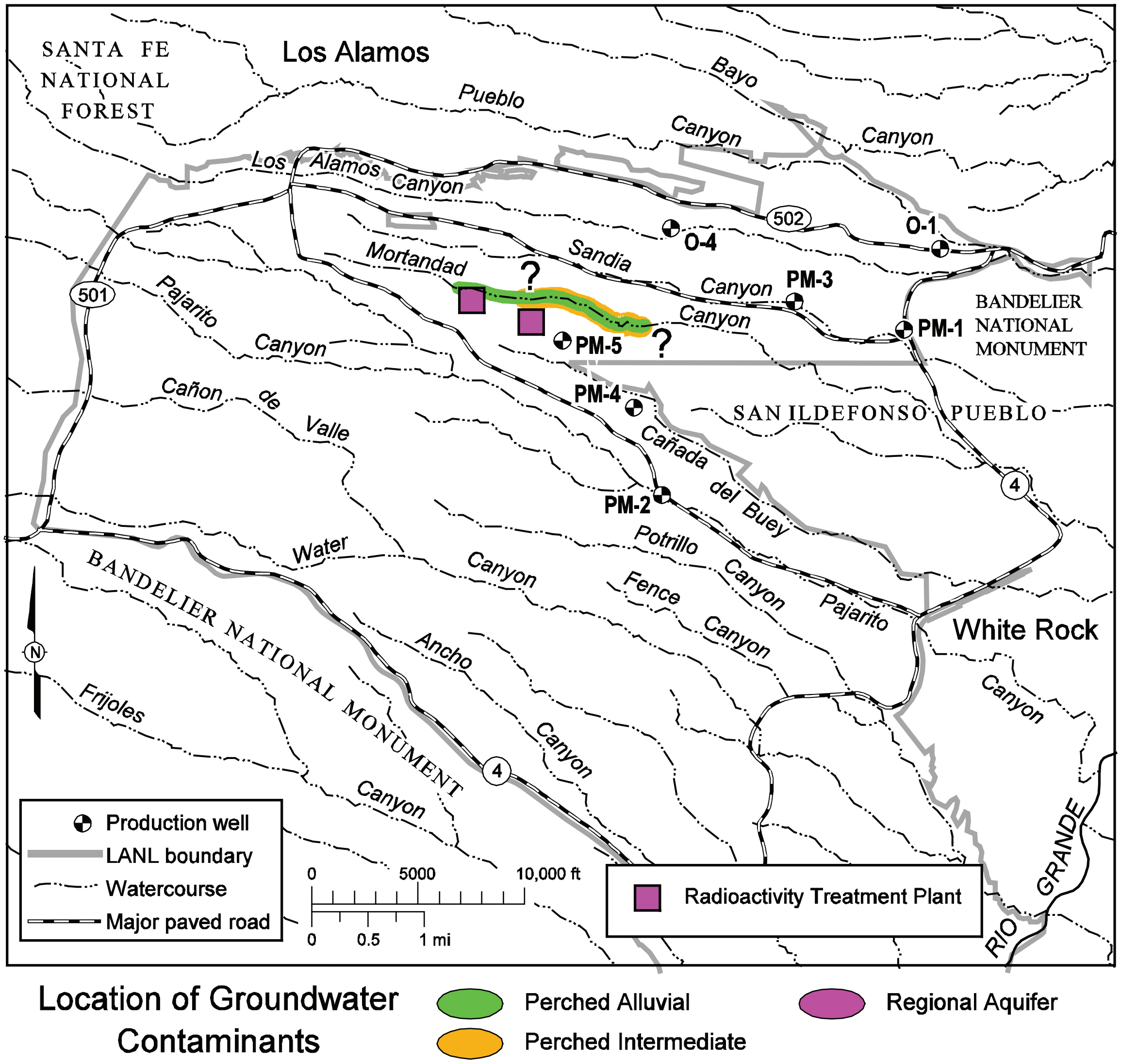

Figure 5-22. **Location of perchlorate above the 24.5 µg/L EPA Drinking Water Equivalent Level. Maximum values in Mortandad Canyon were 50 µg/L in alluvial groundwater and 256 µg/L in intermediate groundwater during 2005. Different colors indicate the affected groundwater zones.**

Chromium was detected in three of the newest intermediate-depth wells: MCOI-4, -5, and -6. In MCOI-4 and MCOI-5 the filtered values are much lower than the unfiltered values, leading to the conclusion that the chromium comes from aquifer or well materials, rather than the groundwater. Elevated nickel concentrations in MCOI-5 support a conclusion of metal corrosion as a chromium source in this well. Because these wells have little water, they must be sampled with a bailer, which produces very turbid samples (turbidities of 16 NTU to 83 NTU). MCOI-6 has sufficient water to allow use of a pump, producing lower turbidity samples (4.9 NTU to 6.4 NTU). Both filtered and unfiltered chromium values in this well are slightly above 50 µg/L (the NM GW Standard) and analysis in 2006 confirms that this chromium is predominantly in the form of hexavalent chromium. MCOI-5 also had values near or above standards of nickel, lead, and antimony. Most of these results were in unfiltered samples suggesting a relationship to drilling or casing materials; the unfiltered nickel values were much lower but still about 60 percent of EPA MCL.

In June of 2005 the volatile organic compound dioxane[1,4-] was detected in two intermediate wells in Mortandad Canyon. The compound was found in several sampling events and in field duplicates and results were confirmed by reanalyzing samples. All detected analytical results were below or slightly above the practical quantitation limit (PQL) of 50 µg/L (the MDL is 20 µg/L) and qualified as estimated values. There is no federal or New Mexico standard for dioxane[1,4-]. The Consent Order requires LANL to evaluate risk for contaminants with no regulatory standard at a 10^{-5} excess cancer risk level, using the EPA Region VI risk calculations. The EPA Region VI dioxane[1,4-] 10^{-5} risk value is 61 µg/L; the recent dioxane (estimated) results range up to 56 µg/L. A principal use of dioxane is as a solvent stabilizer in commercial formulations of chlorinated solvents such as trichloroethane, and it has many other uses in manufactured products and analytical processes. The Laboratory is working with NMED on a strategy to determine the extent and impact of dioxane[1,4-] as a groundwater contaminant in Mortandad Canyon. Dioxane[1,4-] has not been detected in any other water samples at the Laboratory; one 2005 detection in a City of Santa Fe supply well was not confirmed by reanalysis of the sample.

c. Alluvial Groundwater

Radionuclide levels in Mortandad Canyon alluvial groundwater are, in general, highest nearest to the TA-50 RLWTF outfall at well MCA-5 (which replaces MCO-3) and decrease down the canyon. Most radionuclides are adsorbed to sediment closer to the outfall. The levels of strontium-90 and gross beta are usually above EPA drinking water criteria, which we use as screening levels, in many of the wells. In past years, the levels of strontium-90, plutonium-238, plutonium-239,240, and americium-241 exceeded the 4-mrem DOE drinking water DCGs (which are not applicable to the alluvial groundwater, as it is not a source of drinking water). Since the early 1990s, those radionuclide levels have not exceeded the 100-mrem DOE DCGs for public dose for ingestion of environmental water. In 2005, total LANL-derived radioactivity was above 4 mrem in Mortandad Canyon alluvial groundwater samples from wells MCA-5, MCO-4B, MCO-5, MCO-6 and MCO-7 (Figure 5-10). For radioactivity from a DOE source, results for the following constituents were near or above the 4-mrem DOE DCG screening level: strontium-90 in MCA-5, MCO-4B, MCO-5, and MCO-6; total uranium in MCO-7 (not supported by lab replicate, likely an outlier); and unfiltered americium-241, plutonium-238, and plutonium-239 -240 in MCA-5. The levels of strontium-90 are also above the EPA MCL by a factor of up to 5.4 times. Gross beta values in samples from most alluvial wells were near or exceeded the EPA 50 pCi/L drinking water screening level. While cesium-137 is not usually detected in groundwater due to its strong adsorption to aquifer material, it was detected at MCA-5 in 2005 at 6 percent of the 4-mrem DCG screening level. Cesium-137 was found in both filtered and unfiltered samples.

Under the Laboratory's groundwater discharge plan application for the RLWTF, we collected additional quarterly samples for nitrate, fluoride, perchlorate, and total dissolved solids during 2005 from four alluvial monitoring wells in Mortandad Canyon: MCA-5 (or MCO-3), MCO-4B, MCO-6, and MCO-7. Nitrate (as nitrogen) concentrations in Mortandad Canyon alluvial groundwater were below the NMWQCC groundwater nitrate standard of 10 mg/L (Figure 5-15), and fluoride (Figure 5-16) concentrations were below the NMWQCC groundwater standard of 1.6 mg/L. MCO-7 had nitrate (as nitrogen) at about 34 percent of the NMWQCC groundwater standard. Five results from three wells (MCA-5, MCO-3, and MCO-4B) were unusually high due to field preservation errors. All of the Mortandad Canyon alluvial groundwater samples had fluoride concentrations ranging from 60 percent to 90 percent of the New Mexico groundwater standard. Two downstream wells (MT-1 and MCO-7.5) had fluoride values above the standard, a result of past effluent discharge. As shown in Figures 5-15 and 5-16, the nitrate (as nitrogen) and fluoride concentrations of effluent discharge from the RLWTF after March 1999 have been below the New Mexico groundwater standards.

Mortandad Canyon alluvial groundwater samples had some of the highest perchlorate concentrations found at LANL (Figures 5-17 and 5-22). Alluvial groundwater concentrations of perchlorate have dropped following the reduction of perchlorate in RLWTF effluent in March 2002, especially near the outfall. The 2005 concentrations at upstream wells MCA-5 and MCO-3 were up to 28 µg/L, above the EPA's Drinking Water Equivalent Level of 24.5 µg/L. Perchlorate concentration generally increased downstream, with 21 µg/L to 44 µg/L at MCO-4B, and 35 µg/L to 50 µg/L at MCO-7. As with nitrate and fluoride, the decrease over time of perchlorate near the outfall and downstream indicates that the concentrations in alluvial groundwater are decreasing in response to improved effluent quality.

Several PAH compounds were found in the April 20 sample from MT-3, all near the detection limit and at estimated concentrations. One of the compounds, chrysene, was above the EPA MCL screening level. This is the only time chrysene has been detected in this well. The compound has only been detected seven times in groundwater samples at the Laboratory, but not more than once at a particular location. PAH compounds are subject to carryover between analytical laboratory samples and are readily transferred as field contamination from sources such as used motor oil, diesel fuel, and combustion products.

d. Long-Term Radioactivity Trends

Figures 5-23 through 5-27 depict long-term trends of radionuclide concentrations in surface water and shallow perched alluvial groundwater in Mortandad Canyon downstream from the RLWTF outfall at TA-50. The figures show only radionuclide detections. If more than one sample was collected in a year, the average value for the year is plotted. The surface water samples are from the station Mortandad below Effluent Canyon (formerly GS-1), a short distance downstream from the outfall. Radioactivity levels at this station vary daily depending on the concentration of a release from the RLWTF. These samples also vary in response to changing amounts of runoff from other sources in the drainage.

The alluvial groundwater samples are from observation well MCO-5 in the middle reach of the canyon. Groundwater radioactivity at MCO-5 is more stable than surface water sampled at station Mortandad below Effluent Canyon because groundwater responds more slowly to variations in runoff water quality. Because of its strong adsorption to sediments, cesium-137 is not usually detected in groundwater samples, though it was detected in 2005 at alluvial well MCA-5, which is nearest the outfall.

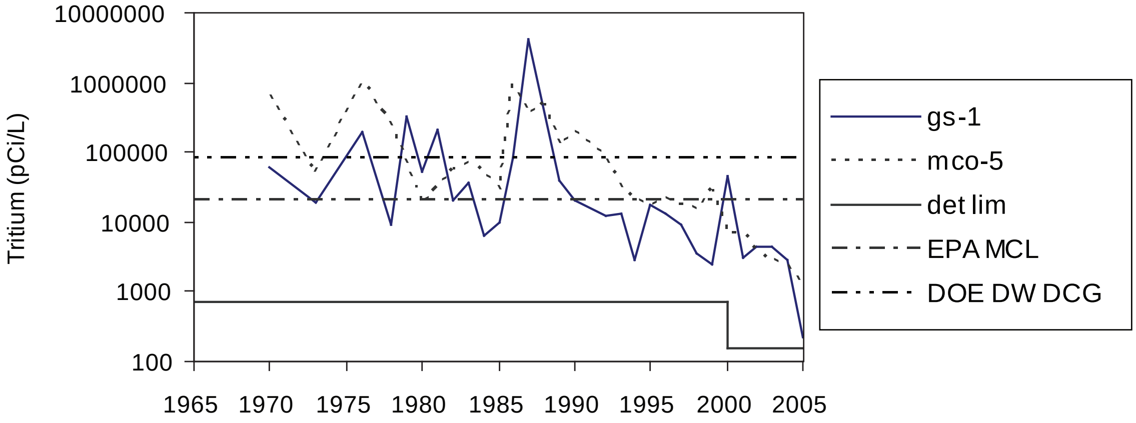

Figure 5-23. **Average annual tritium activity in Mortandad Canyon surface water and alluvial groundwater.**

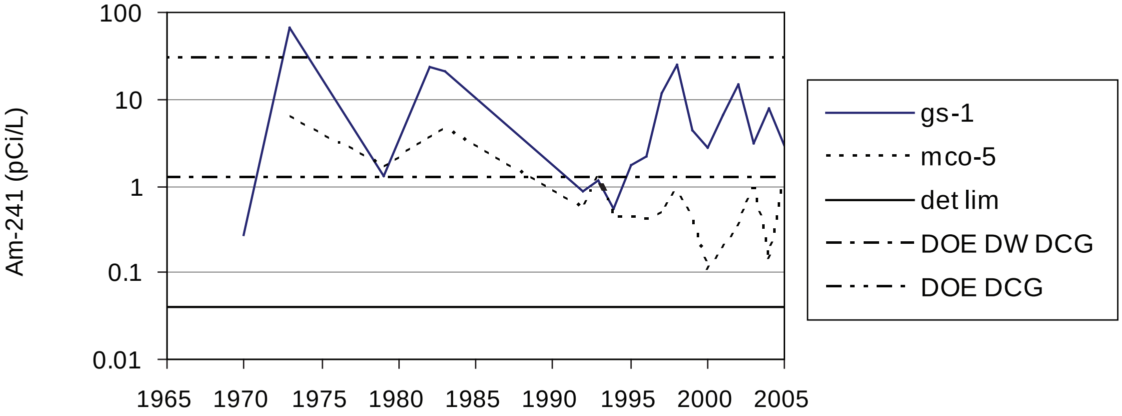

Figure 5-24. **Average annual americium-241 activity in Mortandad Canyon surface water and alluvial groundwater.**

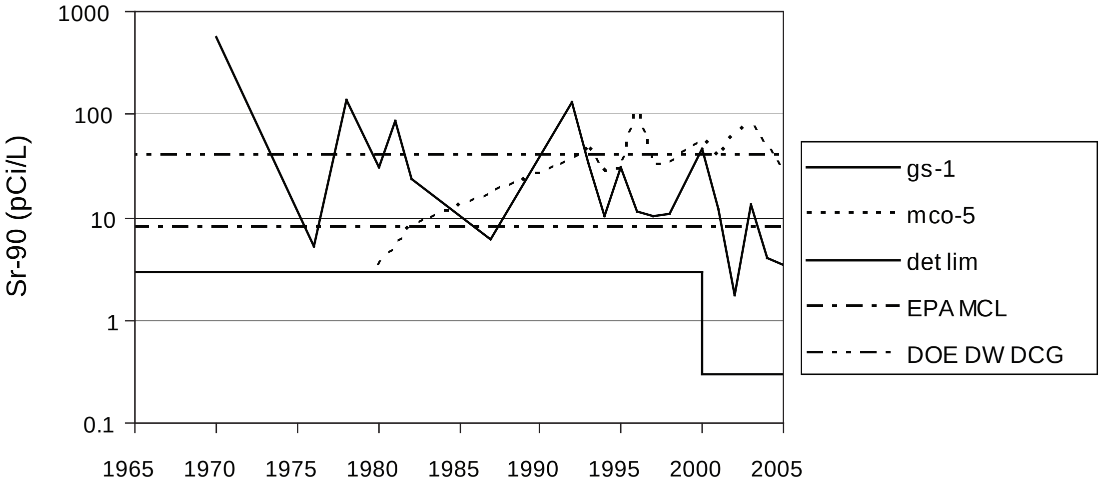

Figure 5-25. Average annual strontium-90 activity in Mortandad Canyon surface water and alluvial groundwater.

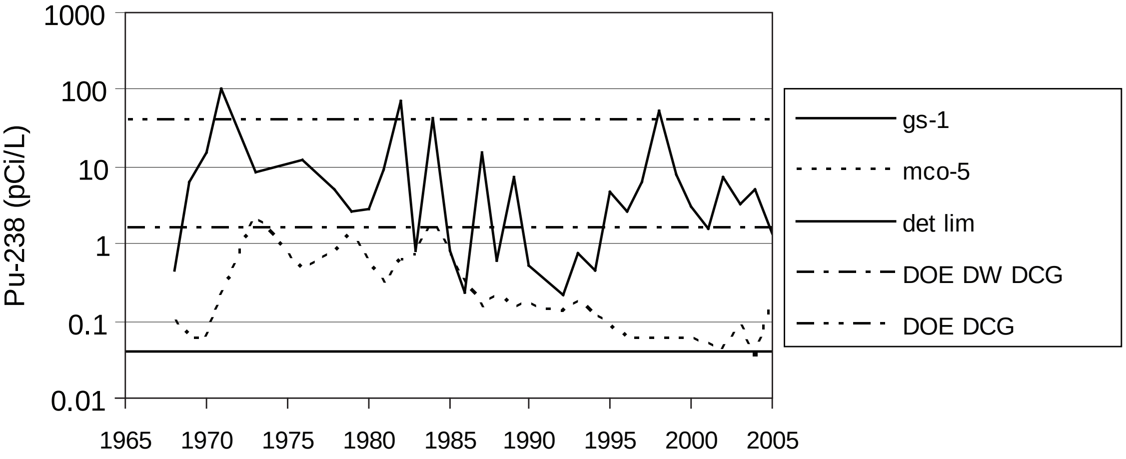

Figure 5-26. Average annual plutonium-238 activity in Mortandad Canyon surface water and alluvial groundwater.

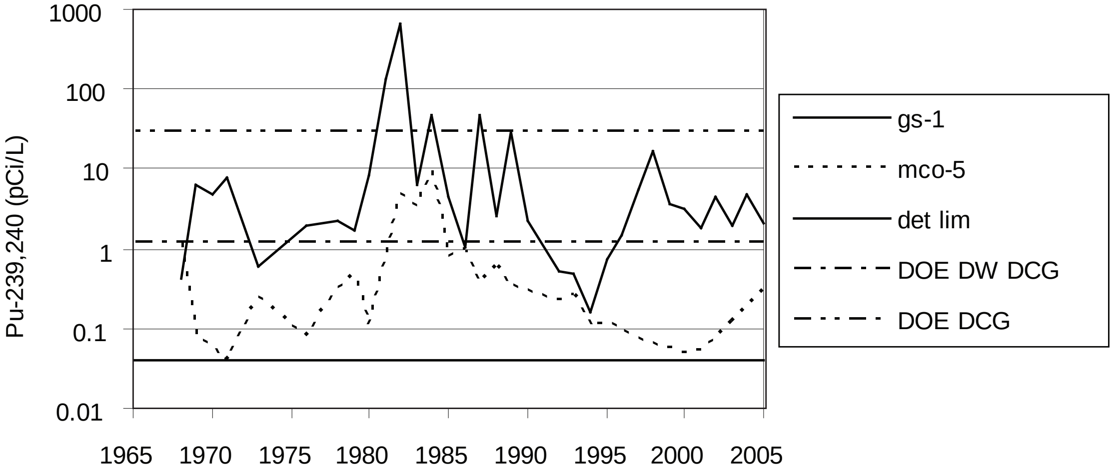

Figure 5-27. Average annual plutonium-239, 240 activity in Mortandad Canyon surface water and alluvial groundwater.

Chemical reactions such as adsorption do not delay tritium transport, so tritium activity is relatively uniform throughout the alluvial groundwater. Tritium activities within the Mortandad Canyon alluvial groundwater have been below the EPA MCL since 2001 (Figure 5-23). Average annual tritium activity in the RLWTF effluent dropped below 20,000 pCi/L in 2001, and tritium activity has dropped in surface water and alluvial groundwater since then.

Before 1990, americium-241 activity was not measured regularly at monitoring stations in Mortandad Canyon. For most years up to 1999, the americium-241 activity of RLWTF discharges was above the 100-mrem DOE DCG for public dose of 30 pCi/L. In the last few years, americium-241 in surface water nearest the outfall has been just below the 100-mrem DOE DCG, whereas in the groundwater nearest the outfall it is closer to the 4-mrem DCG screening level (Figure 5-24). Americium-241 in alluvial groundwater downstream at MCO-5 has been below the 4-mrem DOE DCG since the early 1990s.

In 2005, strontium-90 was detected in surface water at Mortandad below Effluent Canyon and in all alluvial groundwater observation wells down to MCO-7.5 (Figure 5-25). The strontium-90 activities in the upstream wells remain at values in the range of the 4-mrem DOE DCG screening level for drinking water (40 pCi/L) and the EPA MCL (8 pCi/L). It appears that strontium-90 has been retained by cation exchange within the upstream portion of the alluvium. The level of strontium-90 has risen gradually at downstream wells MCO-5 and MCO-6 during the last 20 years, suggesting that the mass of the radionuclide is moving slowly downstream.

Both plutonium isotopes were detected in surface water at Mortandad below Effluent Canyon and at nearly all alluvial wells in 2005 (Figures 5-26 and 5-27). Both isotopes have been historically detected at Mortandad below Effluent Canyon and at MCO-3 (now MCA-5) at levels near the 100-mrem DOE public dose DCGs (30 pCi/L for plutonium-239,240 and 40 pCi/L for plutonium-238), but the levels have decreased during the past few years. Values at other alluvial observation wells, except for MCO-4 and MCO-7.5, were near the detection limit in the 1990s. Plutonium has, in general, been detected in all alluvial observation wells in Mortandad Canyon but appears to be decreasing in activity at downstream locations.

e. Cañada del Buey

Water supply wells PM-4 and PM-5 are on the mesa top just south of Cañada del Buey. PM-4 operates as a backup well and during 2005 had one sample event. Analysis of one sample from PM-5 detected tritium, although reanalysis of that sample and results from other samples were nondetections. Analyses for perchlorate in samples from PM-4 and PM-5 had an average concentration of 0.34 µg/L, similar to earlier results and to other supply wells in northern New Mexico. No HE compounds were detected in samples from these wells.

No alluvial wells were sampled in Cañada del Buey in 2005 because of lack of water in the alluvium.

5. Pajarito Canyon (Includes Twomile and Threemile Canyons)

Pajarito Canyon has a drainage that extends into the Sierra de los Valles, west of the Laboratory. In lower Pajarito Canyon near the eastern Laboratory boundary, saturated alluvium occurs but does not extend beyond that boundary. In the past, the Laboratory released wastewater into tributaries of Pajarito Canyon from several HE-processing sites at TA-9. Some firing sites border portions of tributaries Twomile and Threemile canyons. A nuclear materials experimental facility occupies the floor of Pajarito Canyon at TA-18. Waste management areas, used for disposal of organic solvents and low-level radioactive waste, occupy the mesa north of the lower part of the canyon.

In 2005, samples from supply well PM-2 did not have tritium detectable by the low-detection-limit method (MDA about 1 pCi/L). Six perchlorate analyses had an average concentration of 0.31 µg/L, similar to prior data. The HE compound 2,4-diamino-6-nitrotoluene was detected at a value just above the detection limit in PM-2 on May 18, but not in a sample taken November 16 or in earlier samples, suggesting the result is an analytical artifact. Two apparent detections of DOE-derived radionuclides were found in Pajarito Canyon regional aquifer well samples, but both are inconsistent with other data. A detection of cobalt-60 in R-18 is at odds with nondetections in a field duplicate sample taken at the same time and from another sampling event in 2005. In R-19 at 1190 ft plutonium-239,240 was found in a filtered sample but not the corresponding unfiltered sample, and two reanalyses of the filtered sample produced nondetections.

Regional aquifer well R-22 lies just east of MDA G, the low-level radioactive waste management facility. In 2005, R-22 showed tritium at 2–3 pCi/L in the uppermost of five regional aquifer ports. This result is consistent with previous sampling observations. Tritium was also found at 11 pCi/L in the deepest port, consistent with earlier results. Otherwise, tritium was not detected and perchlorate was at background values in regional aquifer samples from Pajarito Canyon.

High concentrations of iron and manganese (in the range of EPA MCLs) in R-20, R-22, and R-32 are a result of materials used in well drilling and construction (ERSP 2005). Other metals (arsenic, beryllium, chromium, mercury, antimony, and selenium) appeared sporadically in samples. Chromium was found at 31.4 µg/L in an unfiltered sample from 907 ft in R-22, but was 1.8 µg/L in the filtered sample. Prior unfiltered chromium analyses were nondetect or up to 3.2 µg/L; thus this latest unfiltered chromium result does not yet lend itself to a pattern that can be evaluated. Selenium results are just above the MDL of 2.5 µg/L (SW 846:6020). The values in samples from three wells ranged from 2.6 µg/L to 5.3 µg/L (this largest value in R-20 at 907 ft), and a result of 3 µg/L was found in a field blank (also in R-20 at 907 ft). One of the well results occurred in a field duplicate but not the companion sample.

Organic results from these wells do not indicate any consistent presence of organics with one exception: In R-22, sampling for volatile organic compounds and semivolatile organic compounds again found isopropylbenzene at 907 ft. This compound has been detected at this port in five prior sampling events (concentrations are between 0.54 µg/L and 1.0 µg/L and all but one are estimated values), and also in a deeper port at 1448 ft in a 2002 sample. Isopropylbenzene may be a temporary result of drilling fluids used (Longmire and Goff 2002). Xylene was found in a sample from R-23 but not in a field duplicate. Fluorophenol[2-] and phenol-d6 were found in one sample at R-18 but not in the field duplicate sample.

Tritium was found in intermediate borehole R-23i, near the eastern LANL boundary, at 60 pCi/L. Water in borehole screening samples is of indeterminate origin, making interpretation difficult. Personnel sampled five springs in the Upper Pajarito Canyon drainage. PC, Homestead, Starmer, Keiling, and Bulldog Springs are fed by intermediate-depth groundwater from within adjacent mesas. PC Spring lies west of LANL in the Sierra de los Valles, so likely reflects background conditions. These intermediate springs mainly issue along canyon sides above adjacent streams. No LANL-derived radioactivity was found in these spring samples. High nitrate values reported for three springs in June were due to a field preservation error. Except for a perchlorate result from Bulldog Spring of 0.6 µg/L, results from intermediate springs and wells were within a background range. These perchlorate results are about half the values found in 2004. Aluminum and iron reflecting turbidity and selenium near the detection limit of 2.5 µg/L were the metals detected in these spring and well samples. The Bulldog Spring sample also contained HE compounds HMX and RDX, the latter at 17 percent of the of the EPA tap water screening level of 6.1 µg/L (corresponding to 10^{-5} excess cancer risk). In 2004, RDX was present in this spring at 83 percent of the EPA tap water screening level.

Cesium-137 was detected in a filtered sample from alluvial well PCO-2 at 8 percent of the 120 pCi/L 4-mrem DCG screening level, but was not detected in the filtered sample. Comparison data are sparse for this well during the last decade due to lack of water in the alluvium. Strontium-90 was found in PCO-3 at 6 percent of the 8 pCi/L MCL. This result is near the detection limit; a similar value was found in a filtered sample in 2001 but at that time no strontium-90 was detected in the unfiltered sample. Perchlorate was either not detected or within background ranges for alluvial springs and wells. A small amount of the HE compound HMX was found in the sample from Threemile Spring.

6. Water Canyon (Includes Cañon de Valle, Potrillo Fence, and Indio Canyons)

Water Canyon and Cañon de Valle (a tributary) pass through the southern portion of LANL where the Laboratory conducts explosives development and testing. In the past, the Laboratory released wastewater into both canyons from several HE-processing sites in TA-16 and TA-9. In 1997, the Laboratory consolidated these individual NPDES outfalls into one outfall, the High Explosives Wastewater Treatment Facility. Alluvial groundwater in Cañon de Valle shows barium above 1 mg/L, the New Mexico groundwater standard (Figure 5-28), and RDX above 6.1 µg/L, an EPA risk-based tap water screening level that corresponds to a 10^{-5} excess cancer risk.

Intermediate perched groundwater in this area also shows RDX above 6.1 µg/L (Figure 5-29). The Potrillo, Fence, and Indio canyon watersheds contain several open-burning/open-detonation and firing sites used for open-air testing of weapons systems. These three small canyons have surface water only in response to precipitation events, and no known shallow groundwater.

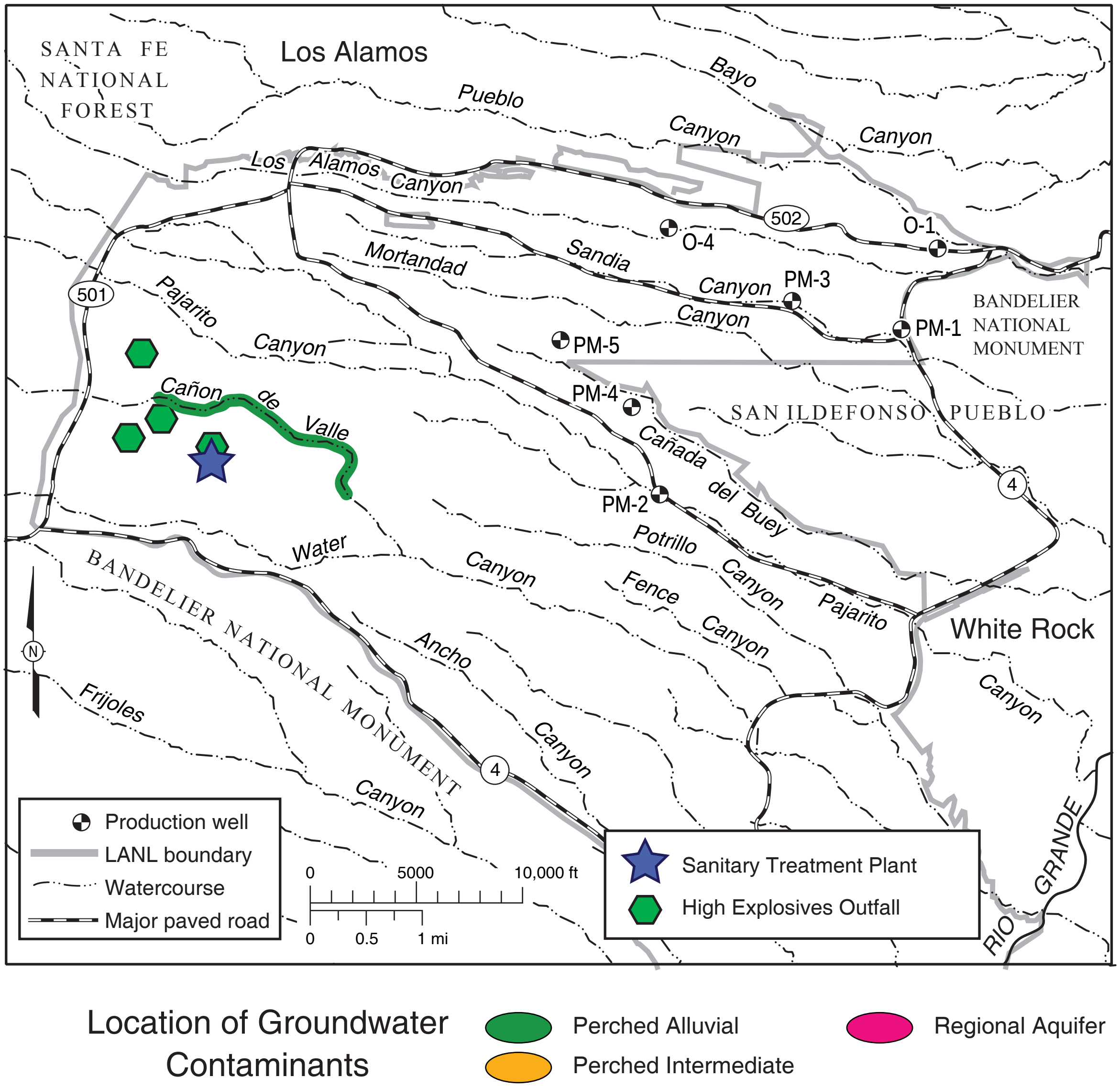

Figure 5-28. **Location of RDX above the EPA Region VI tap water screening level of 6.1 µg/L, and barium above the New Mexico groundwater standard of 1 mg/L in perched alluvial groundwater. Different colors indicate the affected groundwater zones.**

No tritium was detected in any regional aquifer samples within this watershed. Perchlorate was either not detected or values were below 0.31 µg/L and thus within the background range. The main metals found in well samples were iron and manganese, the result of drilling fluid impact (ERSP 2005). Arsenic was found in CdV-R-37-2 at 1,200 ft at 64 percent of the new MCL of 10 µg/L, which will be effective in 2006; the result is just above the detection limit.

At CdV-R-15-3 and CdV-R-37-2 (regional wells near Cañon de Valle), trichlorotrifluoroethane (freon 113), which may show up as a false positive when running a mass spectrometer, was found in most field trip blanks and samples, suggesting some source of sample contamination or analyte misidentification. Isopropylbenzene was detected three times in CdV-R-37-2 at 1,200 ft. This compound may be a temporary result of drilling fluids used.

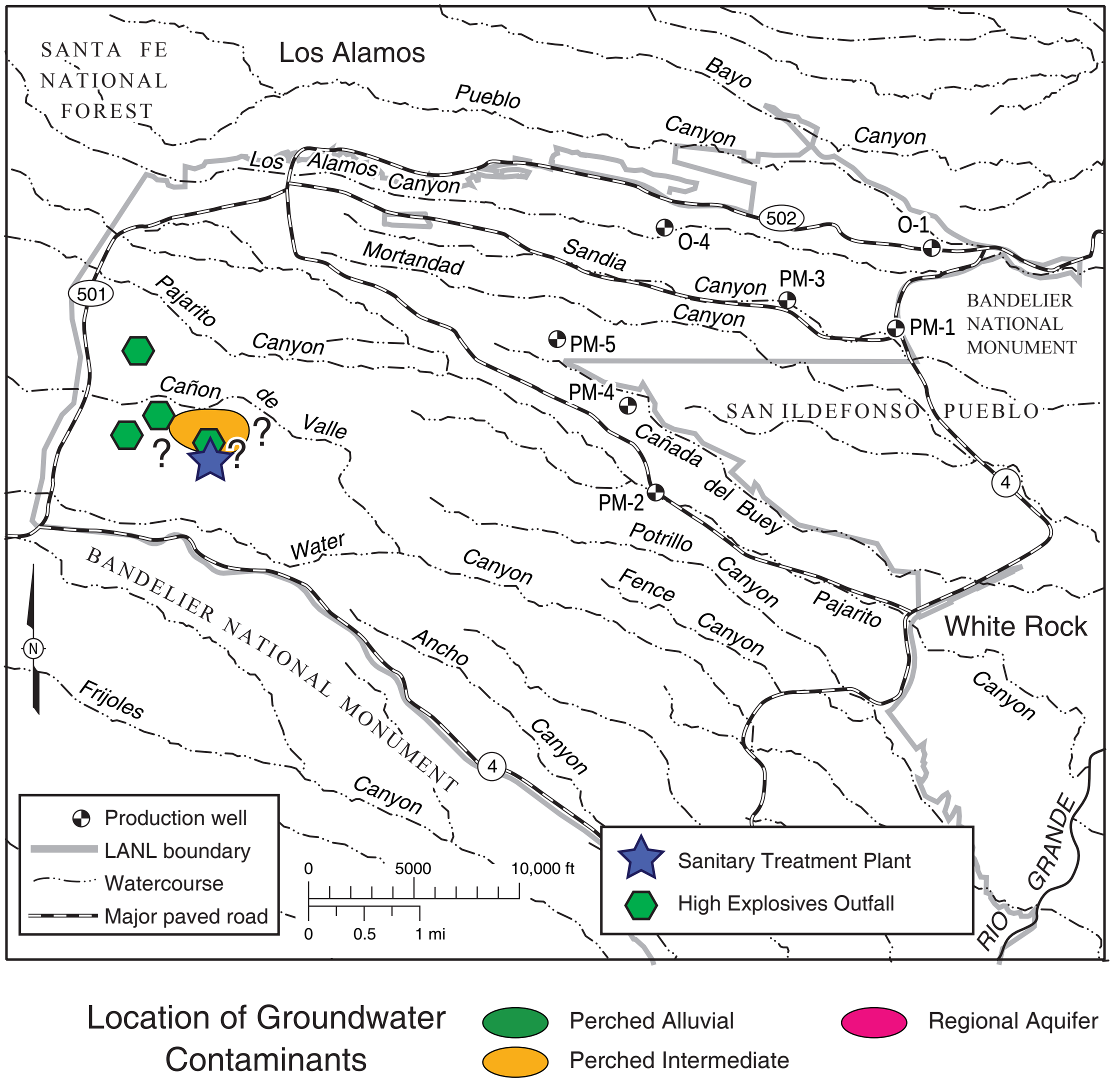

Figure 5-29. **Location of RDX above the EPA Region VI tap water screening level of 6.1 mg/L in perched intermediate groundwater. Maximum 2005 values for RDX in intermediate groundwater were up to 19 times the screening level in springs and 8.5 times that value in wells. Different colors indicate the affected groundwater zones.**

Plutonium-239,240 was found just above the MDA in one unfiltered sample from R-25 at 891 ft in an intermediate perched zone, but not in the filtered sample. Tritium was detected in three ports in R-25, two other wells, and several springs that sample intermediate perched zones. The tritium activities ranged from 7 pCi/L to 68 pCi/L for wells and 70 pCi/L to 195 pCi/L for springs, and are consistent with earlier sampling results. Perchlorate in intermediate-depth wells was either not detected or within background, with the highest value of 0.58 μg/L. For springs flowing from intermediate perched zones, perchlorate values ranged up to 0.74 μg/L, slightly above background.

High metals results (that is, near or above standards) in intermediate-depth wells and springs were found for aluminum, iron, and manganese. These results are related to sample turbidity for springs and to drilling fluids for wells. High unfiltered lead was found in June samples from CdV-16-1(i), but lead concentrations were lower on two subsequent sample dates, which suggests a temporary effect of well installation. Boron was found in Martin Spring and other nearby springs at concentrations up to 175 percent of the NM groundwater standard, a reflection of past effluents. Barium was found in Peter and Martin Springs at 50 percent to 80 percent of the NM groundwater standard.

Chromium (unfiltered) and nickel (filtered and unfiltered) were high in samples from two intermediate ports in R-25. The unfiltered concentrations for both metals, and filtered for nickel, show substantial increases over time in both ports (Figures 5-30 and 5-31). If chromium was in the hexavalent form, the filtered and unfiltered concentrations would be similar, which is not the case. The presence of both metals, and lower filtered chromium, suggests that the metals come from drilling or perhaps corrosion of well casing materials rather than groundwater. At 758 ft, unfiltered chromium has ranged from 17 µg/L to 45 µg/L with the latest value of 153 µg/L, while filtered values (not shown) have been between 0.8 µg/L and 6.2 µg/L. However, the NM groundwater standard for chromium, 50 µg/L, applies to dissolved (filtered) concentrations and the filtered sample results are much below the standard. Chromium values in the 892 ft port show a similar pattern: unfiltered chromium has ranged from 6.7 µg/L to 35 µg/L with the latest value of 70 µg/L, while filtered values (not shown) have been between 0.7 µg/L and 1.9 µg/L. For nickel the EPA MCL is 100 µg/L; recent filtered values at 758 ft and 892 ft were 720 µg/L and 520 µg/L, respectively.

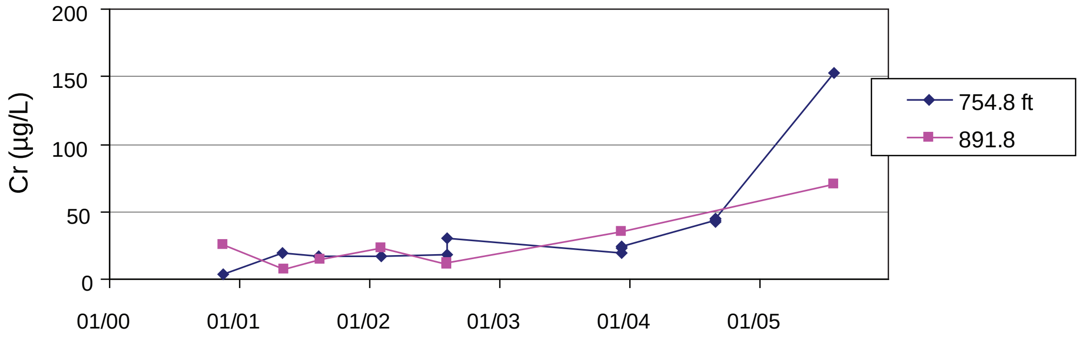

Figure 5-30. **Chromium concentration histories in the shallowest two R-25 ports.**

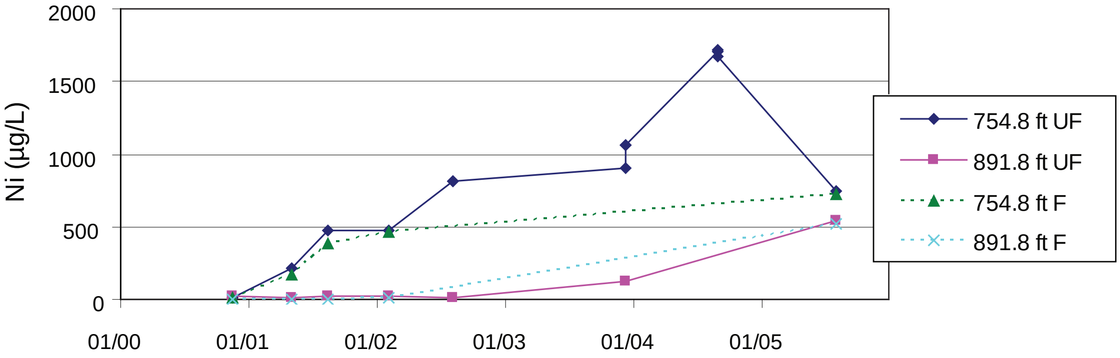

Figure 5-31. **Nickel concentration histories in the shallowest two R-25 ports.**

Intermediate perched zone well and spring samples contained several HE compounds. Of these compounds, RDX (Figure 5-29) was above the 6.1 µg/L EPA tap water screening level in springs and in wells. The chlorinated solvents tetrachloroethene (also known as tetrachloroethylene, perchloroethylene, or PERC) and trichloroethene (or trichloroethylene or TCE) continue to be found in SWSC, Burning Ground, and Martin Springs. The highest values were in Burning Ground Spring at 37 percent and 40 percent, respectively, of the EPA MCL which is 5 µg/L for both compounds. These compounds were also found in two wells, with the highest values in the shallowest port of R-25 at about 30 percent of the MCL.

Cañon de Valle alluvial well CDV-16-02657 had uranium at up to 55 percent of the 30 µg/L NM Groundwater Standard, as previously seen in that well. Tritium was found in many alluvial wells in Cañon de Valle and Martin Spring Canyon at activities ranging from 70 pCi/L to 190 pCi/L. In previous years, CDV-16-02655 has shown nitrate (as nitrogen) up to 90 percent of the NM Groundwater Standard; in 2005 one value was 67 percent of that standard. That well also showed the highest perchlorate value for this area, just above background at 0.9 μg/L. A large number of other perchlorate results for alluvial wells were nondetections.

In addition to aluminum, iron, and manganese related to sample turbidity, many other metals were above standards in alluvial groundwater samples in Cañon de Valle. Among these metals were arsenic, barium, beryllium, cadmium, nickel, lead, and vanadium. High values for these metals frequently correlate with high sample turbidity as well. Selenium also was above the NMWQCC Wildlife Habitat Standard in CDV-16-02655 and CDV-16-02657 (values were by SW-846:6010B but not estimated). (The surface water standard would apply if the ground water flowed to the surface.) Most of the high metal values occurred in two wells: CDV-16-02655, located in a swampy area on the mesa top west of building 260; and CDV-16-02657, located just below the 260 outfall. Barium, present due to past high explosives wastewater discharges, was above the NM groundwater standard in numerous wells, often by a factor of 10 or more (Figure 5-28).

Alluvial well samples contained several HE compounds. As with intermediate perched groundwater, RDX (Figure 5-28) was present at concentrations comparable to risk levels: up to two to six (and in one case, 43) times the 6.1 μg/L EPA 10^{-5} excess cancer risk level. Numerous PAH compounds, including benzo(a)pyrene were found in one well sample and one field blank from a different well. PAH compounds are subject to carryover between analytical laboratory samples and are readily transferred as field contamination from sources such as used motor oil, diesel fuel, and combustion products. In the first example, benzo(a)pyrene was found in Canon de Valle alluvial well CDV-2655 above the EPA MCL in January 2005 but not in five other sample rounds since 1997. The results for every detected semivolatile compound from that sample (including the PAH compounds) were rejected in secondary validation, as the validator identified quality deficiencies in the reported data. Tetrachloroethene was found in CDV-2655 at 10 percent of the EPA MCL; the compound is commonly found in groundwater in Cañon de Valle.

7. Ancho Canyon

Area AB at TA-49 was the site of underground nuclear weapons component testing from 1959 to 1961 (Purtymun and Stoker 1987; ESP 1988). The tests involved HEs and fissionable material insufficient to produce a nuclear reaction. In 1960, the US Geological Survey drilled three deep wells (named DT-5A, DT-9, and DT-10) to monitor regional aquifer water quality. Another well, R-31, lies downstream from firing sites at TA-39. In 2005, strontium-90 was detected slightly above the detection limit in one field blank and one sample from 670 ft in regional well R-31. The detection was in an unfiltered sample and the filtered sample was nondetect for strontium-90. Perchlorate values were either in the range for background or nondetections. Aluminum, iron, and manganese (related to aging well casings or to turbidity) were above or standards in the three DT wells. Iron and manganese are high in R-31 due to persistent effects of drilling fluids.

8. White Rock Canyon Springs

The springs that issue along the Rio Grande in White Rock Canyon represent the principal discharge of regional aquifer groundwater that flows underneath the Laboratory (Purtymun et al., 1980). A few springs such as Spring 2B appear to represent discharge of perched groundwater; that spring is supplied by municipal sanitary effluent discharge near White Rock. The springs serve as boundary monitoring points for evaluating the Laboratory's impact on the regional aquifer and the Rio Grande.

Other than tritium, the only radionuclide detection in White Rock Canyon springs was uranium in La Mesita Spring. Naturally occurring uranium is commonly detected in this and a few other springs. Few low-detection-limit tritium samples were collected from springs in 2005; results for the remaining springs are summarized in prior reports in this series. For the majority of White Rock Springs, tritium activities lie within a range for regional aquifer background; for a few springs, the tritium activity might reflect recent infiltration of precipitation or possibly LANL influence. Except where impacted by effluent discharge, activities of tritium in the regional aquifer in other parts of the Laboratory range from nondetection to between 1 and 3 pCi/L. Tritium concentrations in northern New Mexico surface water and precipitation range from 30 to 50 pCi/L; tritium activity in precipitation is higher near LANL (Adams et al. 1995). Most of the springs had tritium values ranging between nondetection (less than about 1 pCi/L) and 2 pCi/L, in the background range.

Three springs (4, 4B, and 4C) issue within a few hundred feet of each other near the Rio Grande. Springs 4 and 4C have tritium activities of about 10 pCi/L; Spring 4B has an activity of 45 pCi/L; these values are in the range of results for precipitation. These three springs issue along the river just below an extensive flat area, which is the top of an ancient landslide block. The topography creates a likely location for infiltration of local precipitation. The springs (particularly Spring 4B, which has the highest activity) show considerable seasonal variation in flow related to rainfall and snowmelt.

Results for perchlorate from spring samples were similar to prior results. Most were within the range determined by NMED to represent background (unpublished results). A few springs have higher values: one spring, La Mesita Spring, east of the river, had the highest value of 0.89 µg/L. Springs 4 and 4C have values slightly above 0.6 µg/L. In addition, the perchlorate values found in the springs appear to relate to the geologic setting where they discharge. Most of the springs discharge from one of two geologic units: the Tesuque Formation and the Totavi Lentil (the lower part of the Puye Formation) (Purtymun et al., 1980). The northern group of springs that discharge from the Totavi Lentil has slightly higher average perchlorate concentrations than the southern group that discharges from the Tesuque Formation. For example, in 2004, perchlorate concentrations for the Totavi Lentil springs (Sandia Spring, Spring 3 series, 4 series, Spring 5) averaged 0.47 µg/L. For the Tesuque Formation springs (Springs 5A, 6, 6A, 8A, 9, 9A, Doe Spring), perchlorate concentrations averaged 0.27 µg/L. Perchlorate results for 2005 fit this pattern.

Spring 2 contained arsenic at new 2006 EPA MCL of 10 µg/L. The arsenic occurs naturally in springs and wells in the area and has been at even higher concentrations in Spring 2 in prior years. Several springs had high selenium values compared with the New Mexico wildlife habitat surface water standard; most results were near detection limits, and in some cases were not detected in analyses of the sample using other analytical methods with lower detection limits.

A detection of the PCB Aroclor-1262 occurred in the Spring 1 sample. This only the second time in many years that an Aroclor has been found in a spring sample.

9. Pueblo de San Ildefonso

The groundwater data for Pueblo de San Ildefonso indicate the widespread presence of naturally occurring uranium at levels approaching the EPA MCL of 30 µg/L. These measurements are consistent with previous samples. Naturally occurring uranium concentrations near or exceeding the EPA MCL are prevalent in well water throughout the Pojoaque area and San Ildefonso Pueblo. The high gross alpha readings for these wells are related to uranium occurrence.

The U-234 value in Westside Artesian well was below half the 4-mrem DOE DCG for drinking water. The gross alpha values in these wells (except Westside Artesian well, at 18 pCi/L) were below the EPA primary drinking water standard of 15 pCi/L.

Low-detection-limit tritium measurements were nondetect in LA-5, Westside Artesian, Eastside Artesian, and Pajarito Well (Pump 1) suggesting older-age water with little contribution from recent recharge. Tritium values for J. Martinez House and Black Mesa wells were in the range of 2 pCi/L to 4 pCi/L, suggesting they are a mixture of some young water with older water.

Several of the Pueblo de San Ildefonso wells have levels of sodium, chloride, fluoride, and total dissolved solids near or above New Mexico groundwater standards or EPA health advisory levels. Perchlorate concentrations in these wells ranged from nondetect to 0.5 µg/L.

The boron value in the Westside Artesian well was 220 percent of the groundwater standard of 750 µg/L, similar to the values of past years. Boron in Pajarito Well Pump 1 was 150 percent of the NM standard. The J. Martinez House well and Pajarito Well Pump 1 had arsenic above the new 2006 EPA MCL of 10 µg/L. Organic samples from Westside Artesian and Black Mesa wells contained benzene, toluene, and xylene, suggesting contamination by gasoline, perhaps during sampling. Other than sample issues mentioned in the introduction, no further organic compounds were found in Pueblo de San Ildefonso well samples.

10. Buckman Well Field

In 2005, we sampled three wells in the City of Santa Fe's Buckman Field. As in past samples, these wells, particularly Buckman well No. 2, contain high uranium relative to drinking water standards. The gross alpha levels in these wells are attributable to the presence of uranium and were near or above the EPA primary drinking-water standard of 15 pCi/L. The EPA MCL for gross alpha, however, does not include the contribution to gross alpha by radon or uranium. The U-234 value in Buckman well No. 2 was about 134 percent of the 4-mrem drinking water DCG; for Buckman wells No. 1 and 8 this value was about 28 percent of the DCG.

Generally, no tritium is detected in these wells at a detection limit of about 1 pCi/L, and this was the case with 2005 samples. Perchlorate concentrations in the Buckman wells ranged from 0.30 µg/L to 0.36 µg/L, within the apparent range of naturally occurring values. One organic sample produced a result of 643 µg/L for dioxane[1,4-]; however, on reanalysis the sample was a nondetect and we attribute the first result to analytical error or perhaps analytical laboratory cross-contamination. Other than sample issues mentioned in the introduction, no additional organic compounds were found in the Buckman well samples. No HE compounds were detected in these well samples.

G. QUALITY ASSURANCE OF GROUNDWATER, SURFACE WATER, AND SEDIMENT SAMPLE ANALYSES

1. Introduction

Environmental sampling personnel conducted quality assurance (QA) activities in 2005 in accordance with DOE Order 414.1A, which prescribes a risk-based, graded approach to QA. This process promotes the selective application of QA and management controls based on the risk associated with each activity to maximize effective resource use.

The water quality database (http://www.lanl.gov/community/environment/h2o/) contains all the surface water, groundwater, and sediment analytical data received from our analytical laboratories. None of the data are censored or removed. If analytical results are inconsistent with prior data, we investigate the laboratory records, and the sample may be reanalyzed or the location resampled. Both the initial sample and the follow-up sample analyses are kept in the database and are available to the public. In some cases, comments are appended to the records to indicate existence of recognized analytical issues. The primary documentation of analytical issues for data from a given year is provided in this report.

All sampling was conducted using standard operating procedures. Completed chain-of-custody forms serve as an analytical request form and include the requester or owner, sample number, program code, date and time of sample collection, total number of bottles, the list of analytes to be measured, and the bottle sizes and preservatives for each analysis required.

See Supplemental Tables S5-14, S5-15, S5-16 for the analytes, analytical methods, and detection limits used for analysis of surface water, sediment, and groundwater samples during 2005.

2. Quality Assurance Program Development

During 2005, we revised one quality plan that affects collection and use of water quality compliance data. We also issued one new implementing procedure and revised approximately 21 procedures to reflect the constant improvements in the processes. Together, these plans and procedures describe or prescribe all the planned and systematic activities believed necessary to provide adequate confidence that processes perform satisfactorily.

The Laboratory is responsible for acquiring analytical services that support monitoring activities. The Statement of Work (SOW) for analytical services follows the National Nuclear Security Administration Service Center's Analytical Management Program's Model Statement of Work (Model SOW). The SOW provides contract analytical laboratories the general QA guidelines specified in the Model SOW and also includes specific requirements and guidelines for analyzing surface water, groundwater, and sediment samples.

3. QA of Field Sampling Activities

We submit quality control samples along with environmental samples so that we can detect possible field or analytical laboratory contamination and track analytical laboratory performance. Differences in analytical results between field duplicate samples, for example, may indicate that the samples were not uniform or that there was significant variation in analyses. Detection of analytes in deionized water field blanks could indicate contamination of our deionized water source or sample bottles or contamination from the analytical laboratory. We evaluate the results from QC samples along with the environmental sample results in order to understand whether the results truly represent environmental measurements.

The required analytical laboratory batch QC is defined by the analytical method, the analytical SOW, and generally accepted laboratory practices. The laboratory batch QC is used in the data-validation process to evaluate the quality of individual analytical results, to evaluate the appropriateness of the analytical methodologies, and to measure the routine performance of the analytical laboratory.

In addition to batch QC performed by laboratories, we submitted field QC samples to test the overall sampling and analytical laboratory process and to spot-check for analytical problems. These samples included equipment blanks, field blanks (deionized water), performance evaluation blanks (deionized water), and field trip blanks. Duplicate analyses of select samples were also conducted at the laboratory.

a. Equipment and Field Blanks

Equipment and field blanks were submitted for metals, organic, general inorganic, and radiochemistry analyses to monitor for contamination during sampling and decontamination of equipment.

b. Performance Evaluation Blanks

Performance evaluation blanks are deionized water (DI) blanks submitted as regular samples, without any indication that they are QC samples. They go through the same analytical process as the regular field samples. The DI blanks are measured with the same background contributions from reagents and biases as the regular samples and give an estimate of background and systematic analytical errors, and aid in the determination of false detections in associated environmental samples.

c. Field Trip Blanks

Trip blanks are a special case of performance evaluation blanks applicable to volatile organic compound measurements. They are kept with the samples from collection to analysis. Field Trip Blanks are used to help identify volatile organic compound cross contamination that may occur during sample handling, shipping, and storage, or at the analytical laboratory.

d. Field Duplicates

Field duplicates are split samples that provide information about field variation of sample results as well as analytical laboratory variation. Field duplicates can indicate sampling techniques with poor reproducibility.

The nitrate results for 10 samples at 9 groundwater and surface water locations (MCA-5, DP Spring, MCO-3, field duplicate at MCO-3, PC Spring, Bulldog Spring, Keiling Spring, Starmers above Pajarito, Pajarito 1.0 mile above Twomile, and La Delfe above Pajarito) sampled between May 6, 2005 and June 22, 2005 were reported at levels over 500 mg/L. Review of these samples found that the nitrate values were not supported by the total dissolved solids determination or the historical data for the sites, where these data were available. Additional testing at the laboratory indicated that the high levels of nitrate were not found in unpreserved samples, for those affected samples with containers still available for additional testing. The high nitrate values in these samples is likely from the incorrect use of nitric acid preservative in the field in place of the method-specified sulfuric acid preservative.

In some cases, sample results for filtered and unfiltered sample results are compared to see if the results for each are consistent with historical results, as well as with each other. There were several instances where the filtered and unfiltered results indicated that there might have been a problem with how the sample containers were labeled in the field. In these cases, results for inorganic analytes were higher in the filtered sample when compared to the unfiltered sample collected at the same time from the same location. In each case, the samples were examined at the laboratory to determine if it was possible to tell if the samples were filtered or unfiltered. In those cases where it appeared that an error was made, the data were rejected during data validation due to the possibility of a field sampling error.

There was also a continuing issue with bottle breakage during shipping. In many cases the sample loss was due to the sample container lid coming off during shipping. After investigation, it was decided to discontinue the use of the containers with large lids that were causing the problem. Once the container issue was addressed, the loss of samples was reduced significantly. Since the samples were lost, there are no data reported for the sample containers that were broken. For most locations affected by this issue, the missing analyses were covered by samples collected during subsequent sampling events.

On the whole, the equipment and field blanks and field duplicates were satisfactory, indicating no significant handling issues from sampling and analyses.

4. QA of Analytical Laboratory Results

We verify that analytical data used to support monitoring activities are defensible and of known quality. Analytical data packages undergo a rigorous review and validation process following the guidelines set in the DOE-AL Model standard operating procedure for data validation, which includes review of the data quality and the documentation's correctness and completeness. Tables S5-5, S5-6, and S5-7 in the Data Supplement list qualifier and validation flag codes that accompany 2004 sediment and water data.

Analytical Quality Associates, Inc. (AQA) validated all of the 2005 data packages. Individual validation memos were issued for each analytical fraction for each data report. The average report had five data validation memos. AQA issued a number of nonconformance reports (NCRs) for Data Validation Memos that had to be reissued. Most of the NCRs were written in response to problems concerning minor documentation and typographical errors on individual memos. These reports were corrected and reissued. Associated sample results were generally not affected.

When documentation or contract-compliance problems are identified during data validation, the analytical services laboratory is contacted and attempts are made to resolve or clarify the problem. In 2005, this process required the largest analytical services provider, General Engineering Laboratories (GEL), to issue package-specific NCRs. Most of the NCRs written in response to these problems concerned requests for clarification on data results and missing pages in data packages. GEL reissued corrected documents for all of the reports containing missing documentation or erroneous data. All NCRs were successfully closed.

In addition to routine review of data packages, analytical laboratory oversight includes audits, site visits, and conference calls to review general laboratory quality practices. Problems identified during these processes normally require the laboratory to take a formal corrective action. All requested corrective actions for 2005 were completed.

a. Radiological Data

Negative values are sometimes reported in radiological measurements. Negative numbers occur because radiochemistry counting instrument backgrounds are subtracted from sample readings to obtain net counts. Because of slight background fluctuations, individual values for samples containing little or no activity can be positive or negative numbers. Although negative values do not represent a physical reality, we report them as they are received from the analytical laboratory as required by the "Environmental Regulation Guide for Radiological Effluent Monitoring and Environmental Surveillance" (DOE 1991). Also see Appendix B.

The precision of radiological analytical results is reported as one standard deviation (one sigma) of the total propagated uncertainty. For most radionuclide measurements, we report a detection as an analytical result that does not include an analytical laboratory (or in some cases, secondary validation) qualifier code of X or U (indicating nondetect). University of Miami tritium data do not have laboratory qualifiers; in that case, a detected result is reported when analytical results are greater than three times the reported (one sigma) uncertainty.

b. Nonradiological Data

For organic compounds and some general inorganic chemistry (that is, major anions, cations, and nutrients) parameters, the nondetections are reported at the Practical Quantitation Limit (PQL). For the metals and the rest of the general inorganic chemicals, nondetections are reported at the MDL. In some cases, nonradiological results are reported at levels down to the laboratory-derived MDL. Data between the MDL and PQL are qualified as estimated by the analytical laboratory. The analytical laboratory reports results below the MDL as nondetections.

c. Detection-Limit Issues

The SOW requires that analytical laboratories verify their calculated MDLs empirically. Federal regulations prescribe a process for determining analytical laboratory detection limits which uses standards based on deionized water. For analysis of environmental samples, these detection limits may not be achievable. The additional constituents present in natural water samples may lead to matrix interference in the analytical process, which decreases the method sensitivity. Comparison of results from these analyses to a detection limit based on deionized water will lead to additional false positive results for environmental samples. Empirical determination of detection limits using natural sample matrices produces a detection limit that is achievable for these samples.

5. Field Data Results

The water sampling group developed a procedure to address the requirements for measurement of field parameters. This procedure was implemented on July 29, 2005.

6. Analytical Laboratory Assessment

A data package assessment was conducted at GEL on November 14 through 17, 2005. The assessment included data package completeness, documentation of the analytical work, instrument calibration and calibration checks, method quality control, secondary reviews and QA oversight, sample receiving and custody, holding times, use of appropriate methods, calculation review, and sample preparation. Ancillary records reviewed in support of the assessment include analyst proficiency training, standards preparation and traceability, calibrations not included in the data package, holding blanks, electronic files, laboratory performance evaluation samples, and any non-conformances and corrective actions associated with the report. Additionally, contractual compliance with the DOE-AL Model, LANL, Sandia National Laboratory, and Pantex site SOWs was reviewed.

This data package assessment included data packages for organic, radiochemical, and general inorganic analyses. All the files were retrieved quickly and contained all the required documentation except as noted in this report. There were nine items submitted for corrective action. GEL responded with corrective actions for all nine items on January 11, 2006.

a. Participation in Laboratory Intercomparison Studies

GEL is required by the SOW to participate in independent national performance evaluation programs. GEL participated in the EPA water supply and water pollution proficiency testing programs while those programs were in effect. GEL does continue to participate in the DOE Mixed Analyte Performance Evaluation Program (MAPEP) for radiochemistry, organic, and inorganic analyses. For 2005, GEL participated in 13 different performance evaluation studies that addressed a total of 2,110 parameters.

Results for the MAPEP are categorized as: (1) acceptable (result within the 2-sigma acceptance range), (2) acceptable with warning (result within the 3-sigma acceptance range), and (3) not acceptable (result outside the 3-sigma acceptance range). Participating analytical laboratories are required to initiate internal corrective actions when evaluation results are categorized as “not acceptable,” and those corrective actions are spot-checked during various analytical laboratory oversight activities. A summary of performance evaluation program deficiencies is shown in Table 5-2 for the six parameters (three parameters in each of two evaluations) that were found deficient in the performance evaluation studies relevant to water and sediment analyses. All other water and sediment analytes not shown in the table were acceptable.

Table 5-2
Summary of Performance Evaluation Program Deficiencies for General Engineering Laboratories, LLC

	MAPEP-05-MaS13 (Soil Sample)	MAPEP-05-MaS14 (Soil Sample)
Antimony	Result not acceptable	Result not acceptable
Selenium	Result not acceptable	
Chromium	Acceptable with warning	Result not acceptable
Nickel-63		Acceptable with warning

MAPEP-05-MaS13: The evaluation report determined that GEL incorrectly detected selenium at 1.35 mg/kg. possibly due to enriched Kr in the sample. GEL received a letter of concern for the repeated failure of antimony in soil performance evaluation samples. The reported value was 8.68 mg/kg and reference value was 30.9 mg/kg. GEL is working to resolve the consistent low recoveries of antimony in soils.

MAPEP-05-MaS14: The report indicated that GEL has a high bias for chromium results. Reference value for chromium was 34.1 mg/kg and the reported value was 46.0 mg/kg. There was a low bias for antimony. Reference value for antimony was 51 mg/kg and the reported value was 16.4. Since GEL failed to meet both chromium and antimony acceptance criteria, they have digested the sample following 3050 section 7.5 and had acceptable results for chromium and antimony.

7. Program Audits and Assessments

The environmental division retained Time Solutions Corporation to perform an independent assessment of the Environmental Characterization and Remediation Group and the Water Quality and Hydrology Group that formerly managed environmental restoration and groundwater monitoring. The assessment was conducted in August and September of 2005. Time Solutions observed that pre-sampling (planning) activities were inconsistently implemented within the water group. The sampling planning process was formalized and will be documented in project requirement documents.

H. REFERENCES

Adams et al. 1995: A. I. Adams, F. Goff, and D. Counce, “Chemical and isotopic variations of precipitation in the Los Alamos region of New Mexico,” Los Alamos National Laboratory report LA-12895-MS (February 1995).

Allen et al. 2000: S. P. Allen and R. J. Koch, “Groundwater Level Status Report for 2005, Los Alamos National Laboratory,” Los Alamos National Laboratory report LA-14292-PR (May 2006).

Bao et al. 2004: Bao, H. M. and B. H. Gu, “Natural perchlorate has a unique oxygen isotope signature,” Environ. Sci. Technol. 38, 5073-5077 (2004).

Bitner 2004: K. Bitner, D. Broxton, P. Longmire, S. Pearson, and D. Vaniman, “Response to concerns about selected regional aquifer wells at Los Alamos National Laboratory,” Los Alamos National Laboratory document LA-UR- 04-6777 (September 2004).

Blake et al. 1995: W. D. Blake, F. Goff, A. I. Adams, and D. Counce, “Environmental geochemistry for surface and subsurface waters in the Pajarito Plateau and outlying areas, New Mexico,” Los Alamos National Laboratory report LA-12912-MS (May 1995).

DOE 1991: “Environmental regulatory guide for radiological effluent monitoring and environmental surveillance,” DOE/EH-0173 (January 1991).

Emelity 1996: L. A. Emelity, “A history of radioactive liquid waste management at Los Alamos,” Los Alamos National Laboratory document LA-UR-96-1283 (1996).

ERSP 2005: Environmental Remediation and Surveillance Program, “Well screen analysis report,” Los Alamos National Laboratory report LA-UR-05-8615 (November 2005).

ERSP 2006: Environmental Remediation and Surveillance Program, “Interim measures work plan for chromium contamination in groundwater,” Los Alamos National Laboratory report LA-UR-06-1961 (March 2006).

ESP 1973: Environmental Surveillance Program, “Environmental monitoring in the vicinity of the Los Alamos Scientific Laboratory, calendar year 1972,” Los Alamos National Laboratory report LA-5184 (March 1973).

ESP 1981: Environmental Surveillance Program, “Radiological survey of the site of a former radioactive liquid waste treatment plant (TA-45) and the effluent receiving areas of Acid, Pueblo, and Los Alamos Canyons, Los Alamos, New Mexico, final report,” Los Alamos National Laboratory report LA-8890-ENV/US Department of Energy report DOE/EV-0005/30 (May 1981).

Fetter 1993: C. W. Fetter, Contaminant Hydrology (Macmillan Publishing Co., New York, 1993), p. 334.

Glatzmaier 1993: T. G. Glatzmaier, “RFI work plan for operable unit 1157, environmental restoration program,” Los Alamos National Laboratory document LA-UR-93-1230 (July 1993).

Jackson et al. 2005: Jackson, W. A., S. Anandam, T. A. Anderson, T. Lehman, K. A. Rainwater, S. Rajagopalan, M. Ridley, and W. R. Tock, “Perchlorate occurrence in the Texas southern high plains aquifer system,” Groundwater Monitoring and Remediation. 25(1), 137-149 (2005).

Koch and Rogers 2003: R. J. Koch and D. B. Rogers, “Water supply at Los Alamos, 1998–2001,” Los Alamos National Laboratory report LA-13985-SR (March 2003).

LANL 1996: Water Quality and Hydrology Group, “Groundwater protection management program plan, Rev. 0.0,” Los Alamos National Laboratory document LA-UR-02-1667 (January 1996).

LANL 1998: Water Quality and Hydrology Group, “Hydrogeologic workplan,” final version, Los Alamos National Laboratory (May 1998).

Longmire 2002: P. Longmire, “Characterization well R-12 geochemistry report,” Los Alamos National Laboratory report LA-13952-MS (June 2002).

Longmire and Goff 2002: P. Longmire and F. Goff, “Characterization well R-7 geochemistry report,” Los Alamos National Laboratory report LA-14004-MS (December 2002).

Martin 1993: B. Martin, “RFI work plan for operable unit 1082, environmental restoration program,” Los Alamos National Laboratory document LA-UR-93-1196 (July 1993).

Michelski et al. 2004: Michalski, G., J. K. Bohlke, and M. Thiemens, “Long term atmospheric deposition as the source of nitrate and other salts in the Atacama Desert, Chile: New evidence from mass-independent oxygen isotopic compositions,” Geochemica et Cosmochemica Acta. 68(20), 4023-4028 (2004).

NMWQCC 2000: New Mexico Water Quality Control Commission, “State of New Mexico standards for interstate and intrastate surface waters,” (effective February 23, 2000).

NMWQCC 2002: New Mexico Water Quality Control Commission, “Ground and surface water protection,” (September 15, 2002).

Nylander et al. 2003: C. L. Nylander, K. A. Bitner, G. L. Cole, E. H. Keating, S. Kinkead, P. Longmire, B. Robinson, D. B. Rogers, and D. Vaniman, “Groundwater annual status report for fiscal year 2002,” Los Alamos National Laboratory document LA-UR-03-0244 (March 2003).

Plummer et al., 2006: Plummer, L. N., J. K. Bohlke, and M. W. Doughten, Perchlorate in Pleistocene and Holocene Groundwater in North-Central New Mexico, Environ. Sci. Technol., 40, 1757-1763, 2006.

Purtymun 1995: W. D. Purtymun, “Geologic and hydrologic records of observation wells, test holes, test wells, supply wells, springs, and surface water stations in the Los Alamos Area,” Los Alamos National Laboratory report LA-12883-MS (January 1995).

Purtymun and Stoker 1987: W. D. Purtymun and A. K. Stoker, “Environmental status of Technical Area 49, Los Alamos, New Mexico,” Los Alamos National Laboratory report LA-11135-MS (November 1987).

Purtymun et al. 1980: W. D. Purtymun, R. J. Peters, and J. W. Owens, “Geohydrology of White Rock Canyon from Otowi to Frijoles Canyon,” Los Alamos Scientific Laboratory report LA-8635-MS (December 1980).

Rogers 2001: D. B. Rogers, “Impact of Sr-90 on surface water and groundwater at Los Alamos National Laboratory through 2000,” Los Alamos National Laboratory report LA-13855-MS (December 2001).

Rogers 2006: D. B. Rogers, “Control of groundwater contamination sources,” presentation to National Academy of Sciences Panel, Los Alamos National Laboratory report LA-UR-06-2146 (March 2006).